SELECTION OF EFFICIENT VA MYCORRHIZA FOR INOCULATING CARDAMOM NURSERIES

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SELECTION OF EFFICIENT VA MYCORRHIZA FOR INOCULATING CARDAMOM NURSERIES

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Affectionately Dedicated to

My Beloved Parents

DEPARTMENT OF AGRICULTURAL MICROBIOLOGY

UNIVERSITY OF AGRICULTURAL SCIENCES

BANGALORE

CERTIFICATE

This is to certify that the thesis entitled "SELECTION OF EFFICIENT VA MYCORRHIZA FOR INOCULATING CARDAMOM NURSERIES" submitted by Mr. K.R. SREE RAMULU, in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY in AGRICULTURAL MICROBIOLOGY to the university of Agricultural sciences, Bangalore is a record of the research work carried out by him, during the period of his study in this university under my guidance and supervision and that no part of the thesis has been submitted for the award of any degree, diploma, associateship, fellowship or other similar titles.

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INTRODUCTION

Introduction

Cardamom [Elettaria Cardamomum (L) Maton] popularly known as the "Queen of spices" is an important export oriented spice crop of India earning over one hundred million rupees per annum as foreign exchange (Appendix A). Cardamom belongs to the family Zingiberaceae of the natural order Scitaminae under monocotyledons which is psiophytic in habit. It is a shallow rooted, perennial, herbacious plant having an underground real stem, the rhizome (subterranian habit) with aerial shoot. The true cardamom comprises of the cultivars like Mysore, Malabar and Vazukka which are grown in different tracts of South India and are identified mainly on the nature of panicles, size of the plant and on other morphological characters.

In India cardamom is cultivated on a plantation scale in about eighty one thousand one hundred hectares of forest hill tract of western ghats extending from South Tirunelveli to North Sirsi spread over the states of Kerala (54%), Karnataka (38%) and Tamilnadu (8%)(Appendix B & C). The total national production is between 3,100 MT to 6,600 MT depending on the weather conditions every year (Appendix D).

Cardamom is used for flavouring various preparations of food, confectionary, beverages and liquors. It is also used for medicinal purposes both in allopathy and

ayurvedic systems. In the middle east countries cardamom is mainly used for the preparation of 'Ghawa' an arabic coffee (cardamom flavoured coffee).

Cardamom industry is now warranted for high productivity and a superior quality of the produce to meet the demands and standards of the international market. This can be achieved through the use of improved plant material, application of adequate nutrients, timely plant protection measures, adoption of water management techniques, shade regulation as well as suitable processing and storage measures.

Cardamom demands more of phosphatic fertilisers for better crop establishment, growth and yield. Vesicular arbuscular (VA) mycorrhizal fungi are beneficial symbiotic fungi known to help in the uptake of P nutrition in most of the crop plants besides supplying important micronutrients and growth promoting substances. Inoculation with VA mycorrhizal fungi can alleviate plant stress from nutrient deficiency, drought, root borne diseases and also help the plants to establish in degraded habitats. Few research studies have shown the occurrence of VA mycorrhizal fungi in the rhizosphere of cardamom which help in the control of root knot nematodes (Manjunath and Bagyaraj, 1982, Thomas et al, 1988). Recent studies have brought out the

host preference in VA mycorrhizal fungi (Mosse, 1975, Reena and Bagyaraj, 1990, Balakrishna reddy, 1991).

Hence screening and selecting efficient VA mycorrhizal fungi for a particular crop plant is highly essential. Since such study has not been done in cardamom there is a dire necessity to screen for an efficient strain of VA mycorrhiza suitable to different agroclimatic zones of cardamom cultivation for better crop growth, quality and yield of capsules. Cardamom being a transplanted crop an efficient VA mycorrhizal fungus may be used routinely in cardamom nurseries for obtaining healthy and vigourous cardamom seedlings besides saving p fertilizer application to certain extent in the main field.

The main objectives of the present study are as follows :

1. Survey and isolation of VA mycorrhizal fungi from cardamom plantations of different agroclimatic zones of South India, classified mainly on rainfall and altitude.
2. Purification and Identification of VA mycorrhizal fungi isolated from the rhizosphere of cardamom obtained from different cardamom plantations and its maintenance in pot cultures.
3. Primary screening to test the response of cardamom to different VA mycorrhizal fungi maintained at the

Germplasm bank of the University of Agricultural Sciences, GKVK, Bangalore.

4. Secondary screening with promising isolates from primary screening along with the native strains in the respective agro climatic zones of cardamom cultivation.
5. Selection and recommendation of the most efficient VA mycorrhizal fungus for cardamom cultivation. This will serve as a low cost input agriculture technology for the cardamom planters for routine inoculation in cardmom nurseries to get healthy and vigorously growing seedlings for better establishment and crop growth when planted in the main field.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

IMPORTANCE OF VA MYCORRHIZA IN CROP PRODUCTION

Vesicular arbuscular mycorrhizal fungi are known to play an important role in improving plant growth and nutrition, and in controlling root-borne diseases besides saving fertilisers and energy inputs (Menge, 1983). The efficiency of mycorrhizal symbiosis was found to vary with the soil type, the host plant and the environment.

Though the occurrence of VA mycorrizal fungus in the roots of plants was first reported by Link in 1809 its subsequent description and recognition of symbiotic relationship and the coinage of word "Mycorrhiza" (Fungus root) was done by Frank in 1885. The exact role it played in association with the plant was known only in the middle of 20th century.

Skujins and Allen (1986) reported that utilisation of VA mycorrhiza markedly increased the success of rehabilitation of disturbed and degraded lands either in mesic or in moisture deficient zones.

Jeffries (1987) reported that mycorrhiza help in making efficient use of cheaper natural fertilizers such as rock phosphate there by the mycorrhiza can be regarded as an important alternative strategy for a more rational and sustainable agriculture.

Now it is well known that VA mycorrhizal fungi play an important role in the growth and development of many crop plants of economic importance.

Linderman (1988) found that the response of plants to VA mycorrhizal fungi is highly variable being influenced by host physiology, genotype, edaphic factors, environmental conditions and root excretions.

Bagyaraj (1991) reported that mycorrhizal plants have several advantages over non mycorrhizal plants in terms of improved plant growth mainly through P nutrition, uptake of various mineral nutrients, hormone production, greater ability to withstand water stress, control of root pathogens and enhanced biological nitrogen fixation.

VA mycorrhizal fungi belong to the order Glomales of class Zygomycetes. These fungi are known to infect the roots of a wide variety of crop plants. The fungal hyphae spreads inside the cortex region of the roots by dichotomus branching. It ramifies intra or intercellularly and sometimes ends in vesicular structure. Hyphae inside the cells end in fine branches called arbuscules which are the preferential sites for exchange of nutrients between the fungus and plant roots, where as vesicles act as nutrient storage and reproductive organs (Cox and Sanders 1974, Scannerini and Bonfante - Faslo 1983).

OCCURRENCE AND DISTRIBUTION OF VA MYCORRHIZA

The vesicular arbuscular mycorrhizal symbiosis occur on the roots of most of the crop plants and cause significant physiological changes that affect plant growth and survival. The presence of VA mycorrhiza is critical for the regeneration of natural ecosystems in arid lands. The introduction of efficient strain of mycorrhiza and its appropriate management in the soil ecosystems has a positive effect on plant growth.

Surveying for the occurrence of VA mycorrhizal fungi in various types of soil, their symbiotic effect with different crop plants and testing the comparative efficiency of the native strains with the introduced strains of VA mycorrhizal fungi is important to decide an efficient strain of VA mycorrhizal fungus for a particular crop in a particular region.

Lilly (1975) observed the VA mycorrhizal association in the roots of Cassia tora, Melothria sp, Phyllanthus neuri, Solanum nigrum, Leucas aspera, Mullugo sp, Physalis minima etc., the common weeds growing in coconut garden. Venkataraman and Satyanarayana (1979) observed the endo- mycorrhizal association with tea plants. Nadarajah (1980) observed the soils around oil palm and cacao roots for VA mycorrhizal associations and found that most of the spores recovered were of the Glomus type, two were Sclerocystis and one each of Acaulospora and Gigaspora.

Allen and St.John (1982) reported that endomycorrhizae are wide spread in both native and agriculture ecosystems and can alter productivity and stress tolerance of many plant species. Rhizosphere and root inhabiting organisms in non sterile systems may produce growth regulators and alter nutrient status which will influence mycorrhizal infection.

Jayaratne (1982) reported the VA mycorrhizal association in rubber plantations. Different VA mycorrhizal spore types were isolated from the rhizosphere of rubber. Manjunath and Bagyaraj (1982) reported the occurrence of VA mycorrhizal association in cardamom, betelvine and pepper. These three plantation crops differed in the extent by which they were colonized by VA mycorrhizal fungi. Cardamom plants recorded higher percentage of colonization (75%) compared to betelvine (42.2%) and pepper (34.6%). Root zone soils of all the three plant species contained higher number of mycorrhizal spores compared to soil away from the influence of roots. Cardamom rhizosphere showed 208 spores/50 ml soil where as betelvine and pepper rhizosphere showed 150 and 130 spores/50 ml respectively. Non rootzone soil showed only 98 spores/50 ml soil.

Taber and Trappe (1982) observed the VA mycorrhizal association in rhizomes, scale like leaves, roots and xylem of ginger (Zingiber officinale). They

proposed the term `mycophyllon' for the leaf association and `mycorhizome' for the rhizomatal association.

Lopes et al. (1983) collected the root zone soil and root samples from 27 coffee plantations (50 to 70 year old) during summer from the central region of Sao paulo state, Brazil with the objective of determining the species of VA mycorrhizal fungi associated. A total of 22 species of VA mycorrhizal fungi were identified and 20 other possibly undescribed species were observed. The genus Acaulospora including a non described species with small golden yellow spores having laminated walls was found in all the sample sites. Glomus spp. occured in 81 percent of the sites. Gigaspora and Sclerocystis sp. were found in 60 percent and 40 percent of the sample sites respectively. Root colonization varied from 4 to 46 percent. It was found that the growth response of coffee to mycorrhizal fungi varied with the species of the endophyte.

Ikram and Mahmud (1984) examined the rhizosphere soils of rubber for the spores of VA mycorrhizae. Seven spore types were recognised but total numbers were very few (< 200 per 100 g moist soil). Species of Glomus and Acaulospora were most common together with Sclerocystis and Gigaspora. All the four endogonacious genera capable of forming VA mycorrhiza occured in soils under rubber. Rubber feeder roots showed mycorrhizal colonization ranging from 0 percent to 50 percent.

Girija and Nair (1985) made a preliminary survey at the college of Agriculture, Vellayani, Trivandrum and found the natural association of VA mycorrhiza with economically important crop plants like coconut, arecanut, cashew, rubber, cacao, pepper, nutmeg, clove, betelvine and many other plantation crops. The natural incidence of VA mycorrhiza was seen in all the 46 crops including 11 cultivars of Banana and cassava.

Iqbal and Nasim (1986 b) observed the presence of VA mycorrhiza in the roots and under ground parts of Zingiber officinale. The roots, scale like leaves and epidermal tissues of the underground rhizomatous portions of ginger (Zingiber officinale) were found heavily mycorrhizal. Vesicular infections occured in all the plant portions. Vesicles were seen in the xylem vessels, however arbuscules were not detected. Different types of endogonaceous spores were found in the scale like leaves.

Iqbal and Nasim (1986 c) examined the Banana plant (Musa paradisiaca) for the presence of VA mycorrhizal endophytes in its underground portions including roots and rhizomatous portions. Root and non root portions such as scale like leaves and epidermis of the rhizomatous portions were found to be colonized by VA mycorrhizal fungi.

Iyer et al. (1988) observed the root and root zone soil of Banana plants and found the presence of two VA mycorrhizal fungi Glomus macrocarpum and Glomus fuegianum in the sole crop system. In high density multi species cropping system they noticed the presence of three VA mycorrhizal fungi Gigaspora heterogama. Gigaspora decipens and Glomus macrocarpum. Intensity of root colonization ranged from 61 to 68 percent and the average spore count ranged from 3.3 to 4.3 per gram.

Mohan kumar et al. (1988) from their survey found that most of the plants growing along the Madras sea coast harboured VA mycorrhizal fungi. The VA mycorrhizal fungal species identified were Entrophosphora schenckii. Glomus cladrideum, Glomus clarum, Glomus intraradices, Glomus microcarpum. Glomus monosporum. Glomus occulatum. Glomus pubescens and Glomus pustulatum.

Berliner (1990) found that mycorrhiza play an important role in soil and help in plant establishment in natural ecosystems. Fitter (1990) reported that VA mycorrhiza are abundant and wide spread in many vegetation types and the levels of infection vary widely between the species and sites. McGonigle and Fitter (1990) made a field survey of endomycorrhiza in a hay meadow and found that Holcus lanatus was predominently infected by Glomus tenue. while the roots of three other herbacious species were colonized by other mycorrhizal endophytes.

Abbott and Robson (1991) reported that soils commonly contain more than one VA mycorrhizal fungus and the development of VA mycorrhiza varies with the soil type, soil depth, season and vegetation. Cuenca et al. (1991) examined the VA mycorrhizal fungi of several cacao plantations. The number of spores found was similar to other ecosystems or agro ecosystems. However VA mycorrhizal species diversity in cacao fields seem to be lower than in the natural eco systems. Glomus etunicatum is the VA mycorrhizal species which seems to be preferentially associated with cacao plants. In old established plantation the application of fertilizer diminished the percentage of VA mycorrhizal infection both in the cacao plants and in the trees used to shade cacao.

Fieldmann and Lieberei (1992) investigated the occurrence of VA mycorrhiza in rubber plantations of Amazones in Brazil. The mycorrhizal population was less in plantations where fungicides were used while fertilizer application and mechanisation had no effect. The presence of a ground flora increased mycorrhizal incidence and the greatest rubber root colonization was observed in plantations with secondary natural vegetation.

Johnson et al. (1992) made a field survey in four year old monoculture of 5 successional grass species and found that soil factors and plant species may be of equal

importance in regulating the species composition of VA mycorrhizal fungal communities. Veeraswamy et al. (1992) conducted a survey in the millet fields of black and red laterite soils in the semi arid zone of Andhra pradesh. They found that the predominent VA mycorrhizal species was Glomus. In general red soils harboured more number of isolates than black soils. The identified species of Glomus included are Glomus aggregatum, Glomus deserticola, Glomus geosporum, Glomus intraradices, Glomus invermaium, Glomus leptotichum and Glomus tortuosum.

FACTORS INFLUENCING VA MYCORRHIZAL GROWTH

Effect of Moisture

Levy et al. (1983) studied the effects of root stock, irrigation regime and water salinity on the vertical distribution of VA mycorrhiza in citrus roots under field conditions. Root stocks differed in the vertical distribution of VA mycorrhiza, notably rough lemon exhibited a uniform vertical distribution and sour orange a non uniform distribution with decreased VA mycorrhizal infection at depth. Decreasing the interval between irrigation reduced VA mycorrhizal infection of sour orange especially in the upper layers of soil. Increased salinity of irrigation water reduced VA mycorrhiza in deep layers of soil.

Ponders (1983) studied the influence of soil moisture on endomycorrhizal infection in black walnut maintained as potted seedlings, watered at different time intervals. seedlings watered every day or every second day had much longer lateral roots but fewer infected root segments than seedlings watered every third or fourth day. These results suggest that controlling the soil moisture level may alter the conditions that affect competition for colonization.

Puppi and Bras (1990) evaluated the growth of uninoculated and Glomus fasciculatum inoculated white clover under three water regimes (approximately 30%, 60% and 90% field capacity, respectively) combined with four nutritional treatments. At the lowest water regime growth was restricted. Infection, however, improved both survival and shoot dry weight. Mycorrhizal status greatly improved the ratio of dry matter produced per water unit given at all nutrient treatments.

Light and temperature

Hayman and Mosse (1972a) reported that light and temperature greatly influence the development of VA mycorrhiza and growth of onions in a phosphate deficient soil. Larger arbuscules and host growth was stimulated with 25,000 LUX than with 13,000 LUX at 23°C.

Sheik and Sanders (1988) reported that the relative growth rate of infected root was reduced more than that of the total root length by lowering the temperature. Soil temperature and moisture status of the soil influenced the infection of VA mycorrhizal fungi in plants.

Haugen and Smith (1992) studied the effect of high temperature and fallow period on infection of mung bean and cashew root by the VA mycorrhizal fungus Glomus intraradices and concluded that it can retain its infectivity in moist soil even at high temperature and their response depends on host factors such as root growth.

Effect of oxygen

Saif (1983) reported that oxygen concentration in the soil atmosphere influenced the growth and mineral uptake in Eupatorium odoratum, Sorghum bicolor and Guizotia abyosinica inoculated with Glomus macrocarpus, Glomus mosseae and white reticulate VAM fungi. Shoot and root dry weights of mycorrhizal plants increased with oxygen concentration up to 16 percent.

Effect of pH

Lopes et al. (1983) studied the relative incidence of four endogonaceous fungi in rhizosphere of coffee in relation to soil pH and found that the incidence of Acaulospora and Sclerocystis was not affected by soil pH in the range of 4.7 to 6.9. Gigaspora was not recovered from

soils with pH higher than 6.5 and Glomus was less commonly found in locations with pH lower than 5.0.

Effect of manures and fertilizers

Cuenca et al. (1983) attributed the role of VA mycorrhizal fungi in root growth and litter decomposition in a coffee plantation under shade trees. The anatomical studies of root attached to decomposing litter showed that plantation is intensely infected with VA mycorrhiza.

Hepper and Warner (1983) reported that VA mycorrhizal fungi can grow saprophytically in soil and organic matter plays an important factor in the process.

Sylvia and Schenck (1983) studied the sporulation of Gigaspora margarita, Glomus clarum, Glomus mosseae and Gigaspora heterogama. Sporulation increased significantly after establishment in pot cultures of Bahia grass drenched with super phosphate. However sporulation of Glomus etunicatum, Glomus macrocarpum and Gigaspora gigantea were reduced by superphosphate drench. Generally improved sporulation after application of super phosphate was associated with P tolerance of the mycorrhizal fungi.

Davis et al. (1984) reported that endomycorrhizal fungi can tolerate high levels of available P. He observed endomycorrhizal fungi in soil samples obtained from long established liberally fertilized hops (Humulus lupulus L) and peppermint (Mentha piperita L) fields. VA mycorrhizal

fungi were found to colonize most roots despite the very high fertility of several sites.

Warner (1984) found that Glomus mosseae and Glomus caledonicum survived as hyphae within the peat fragments.

Brechelt (1990) reported that mycorrhizal effect was better in unsterile manures.

PLANT GROWTH RESPONSE TO VA MYCORRHIZA

Mosse et al. (1969) observed that mycorrhizal onion seedlings grew better in both sterilized and unsterilized soils compared to non mycorrhizal control plants.

Hirrel and Gerdemann (1980) found that onion and bell pepper plants inoculated with Glomus fasciculatum grew larger than those inoculated with Gigaspora margarita. The effect of salinity in lowering the percentage fresh weight was greatest in the non mycorrhizal controls.

Sanni (1981) studied the effect of VA mycorrhizal fungus Gigaspora gigantea on the growth of oil palm seedlings in some nigerian soils. The pot experiment data revealed that oil palm seedlings responded well to mycorrhizal inoculation especially in the presence of added phosphate.

Palipane and Bandara (1985) reported that vigorously growing unfertilised 10 year old coffee and cacao

plants responded well to Glomus sp. inoculation. Seedlings of both crops inoculated by mixing mycorrhizal root fragments in the soil had a higher growth rate than uninoculated seedlings. The VA mycorrhizal fungi seemed to compete effectively with the indigenous soil mycoflora. The symbiotic association of VA mycorrhiza in coffee seedlings was found to be beneficial in plant establishment, growth and uptake of nutrients.

Chulan and Ragu (1986) studied the effects of VA mycorrhiza on growth and phosphorus uptake of cacao seedlings (Theobroma cacao) grown for 100 days in polythene bags at five levels of P fertilisation, in both steamed and unsterile bunger series soil (a fine clay kaolinite isohyper thermic type paleuduit). The cacao seedlings responded well to phosphorus fertilisation and mycorrhizal treatments. Plants inoculated with VA mycorrhizal fungi (Gigaspora sp) gave the most vigorous growth and higher phosphorus in the leaf tissue in unsterile soil compared to plants grown in steamed soil.

Jayaratne et al. (1986) reported that VA mycorrhizal inoculation enhances the growth of rubber seedlings.

Firdaus E Bareen et al. (1988) found a significant growth increase in Allium sativum plants treated with mycorrhiza compared to non mycorrhizal plants.

Bopaiah and Khader (1989) studied the combined effect of Azotobacter, Azospirillum and Glomus mosseae (VA mycorrhiza) by treating the root cuttings of black pepper (Piper nigrum). The root cuttings were dipped in peat based culture slurry consisting of the above three icrobial cultures and then planted in 5 kg garden soil aken in polythene bags. It was noticed that plant height, shoot and root weight were greatest with the combined treatment followed by the VA mycorrhiza alone treatment.

Cruz (1989) studied the effect of VA mycorrhizal symbiosis on coffee growth. He found that VA mycorrhizal noculation in non disinfested soil gave the greatest plant eight, dry matter and leaf area.

Morita and Konishi (1989) reported that VA mycorrhiza were involved in the uptake and utilisation of P by the tea plant in the presence of aluminium.

Waterer and Coltman (1989) studied the esponse of mycorrhizal and non mycorrhizal capsicum cv. Green Emerald Giant) plants to P concentration anging from 0.01 to 1 mg/lit as a pot study. Mycorrhizal plants inoculated with Glomus aggregatum showed increased P uptake, total dry matter production and fruit yield and reduced the time of anthesis. Extensive preplanting infection improved the subsequent growth by reducing the

time required for establishment of a functional mycorrhizal symbiosis following transplanting.

Blal and Gianinazzipearson (1990) reported that inoculation with efficient VA mycorrhiza enhanced the growth and mineral nutrition of each oil palm clone.

Cuenca et al. (1990) studied the effect of VA mycorrhizal inoculation on the growth of cacao seedlings (Theobroma cacao vari : ocumare 60) grown for 5 months in a nursery. The effect of introduced VA mycorrhizal fungi (Glomus occulatum, Acaulospora appendicula, Glomus manihotes, Acaulospora morrowae, and Scutellospora pellucida) in soils treated with copper oxychloride or methyl bromide were compared with the indigenous VA mycorrhiza and with their respective non inoculated controls. Cacao seedlings responded well to indigenous VA mycorrhizal fungi which included Scutellospora calospora as the dominant species inducing significant increase in plant height, dry weight and foliar uptake of P, Cu, and Zn in relation to the sterile control. Glomus occulatum and Acaulospora appendicula increased the height of the seedlings. Scutellospora pellucida and Acaulospora appendicula doubled the phosphorus uptake in cacao seedlings.

Reena and Bagyaraj (1990) studied the effect of 13 different VA mycorrhizal fungi obtained from different

parts of the world on two slow growing forest tree species Acacia nilotica and Calliandra calothyrsus. Inoculated plants had greater plant height, leaf number, stem girth, biomass, P and Zn content. They also had more mycorrhizal root colonization, spores and external hyphae in soil. Acacia nilotica seedlings responded best to inoculation with Glomus mosseae (ICRISAT) followed by Glomus caledonicum where as Calliandra calothyrsus responded best to Glomus velum and Glomus merredum both fungi being equally good.

Chulan and Martin (1992) assessed the effect of VA mycorrhizal inoculation on growth and nutrient uptake of vegetatively propagated cacao plants. Inoculation with mixed species of Scutellospora and Glomus resulted in high dry matter yield and stem diameter of mycorrhizal plants, obtained through budding, air layering and stem cutting. Budded mycorrhizal plants gave a significant increase in P content of the shoot. In contrast only budded mycorrhizal plants gave a significantly higher Ca concentration in tops compared to uninoculated plants.

Khasa et al. (1992) tested 19 agricultural and sylvicultural plant species under field conditions for their response to endomycorrhizal fungi. All plant species except amaranth, showed various degrees of root colonization in non fumigated and fumigated soil. Eight species Viz., African Yam Bean (Sphenostylis stenocarpa), wild mung

(Vigna vexillata), Leucaena leucocephala, onion, sweet potato, tomato and cassava were found to be highly dependent on mycorrhiza for normal growth and development. The added endomycorrhizal inoculum significantly increased the root fungal colonization in 16 of the 19 plant species cultivated.

Vasanthakrishna et al. (1994) studied the response of Casuarina equisetifolia to inoculation with Glomus fasciculatum and or Frankia in P deficient unsterile soils. Mycorrhizal colonization and sporulation was greatest in plants inoculated with Glomus fasciculatum alone compared to other treatments. Single inoculation with either Glomus fasciculatum or Frankia significantly improved the plant growth compared with uninoculated control plants. Dual inoculation with both the symbionts enhanced the growth to a larger extent than single inoculation with either organism.

Other crops of importance on which VA mycorrhiza colonize and enhance crop growth and yield are sunflower (Iqbal and Qureshi 1977), soybean (Bagyaraj et al., 1979), Groundnut (Krishna et al., 1981), mustard and niger (Joseph and Dube 1988), castor and safflower (Sulochana and Manoharachary 1989) and important pulse crops like cowpea, peas, black gram, chick pea, mung bean, soybean and other legumes (Shroeder. 1958, Gerdemann. 1968, Ross and Harper. 1970, Godse et al., 1978),

Bagyaraj and Manjunath. 1980, Islam et al., 1980, Jalali and Thareja. 1981, Rao and Parvathi. 1982, Struble and Skipper. 1988) and important cereals like maize (Gerdemann.1964, Khan. 1972, Sreeramulu et al.,1988), sorghum and barley (Hayman. 1982, Jensen. 1982), rice (Sanni. 1976), wheat (Khan. 1975, Sreenivasa and Rajashekara 1989) and ragi (Govinda rao et al., 1983).

The VA mycorrhizal fungi are known to improve the yields of vegetable crops like onion (Hayman and Mosse. 1972a, Hatting et al., 1973, Powell. 1975, Rhodes and Gerdemann. 1975); chillies (Bagyaraj and Sreeramulu.1982, Sreeramulu and Bagyaraj.1986, Sreenivasa and Gaddgimath. 1993, Sreenivasa et al., 1993); assava(Sieverding,1985);tomato (Khaliel and Elkhider.1987); cucumber, lettuce, leek and celery (Mayer et al., 1989, Rosendahl and Rosendahl. 1991); bean, broad bean (Al-Raddad and Al-Momany. 1991). Enhanced crop yield due to VA mycorrhizal inoculation was also reported in commercial crops like sugarcane (Ciferri. 1928); tobacco (Koch. 1935); cotton (Butler. 1939, Johnson. 1949, Bagyaraj nd Manjunath. 1980). VA mycorrhizal association in most of the fruit crops are known to enhance crop growth and fruit yields. Apple (Mosse. 1957); citrus (Gerdemann. 1968, Menge et al., 1978, Nemec. 1978, Krikun and Levy. 1980, Chandrababu and Shanmugam. 1983, Manjunath et al., 1983, Ferguson and Menge. 1986); strawberry and other fruit crops

(Gianinazzi *et al.*, 1983, Koomen *et al.*, 1987); banana (Lin and Chang. 1987); mango and papaya (Harinikumar and Bagyaraj. 1988, Silva and Siqueira. 1991). Research studies have also showed that the quality and yield of flowers and growth of ornamental plants will increase due to VA mycorrhizal inoculation (Kawai *et al.*, 1986, Rani *et al.*, 1987).

DUAL INOCULATION STUDIES

Interaction with beneficial soil microorganisms

Vesicular arbuscular mycorrizal fungi are known to synergistically interact with beneficial soil microorganisms like *Azospirillum*, *Azotobacter*, *Rhizobium*, P solubilizers etc.

Barea *et al.* (1975) reported that dual inoculation of VA mycorrhizal fungi and P solubilizing bacterium has enhanced the growth of maize, lavender, lucerne and tomato.

Bagyaraj and Menge (1978) observed larger populations of bacteria and actinomycetes in the rhizosphere of tomato plants inoculated with the mycorrhizal fungi *Glomus fasciculatum* and *Azotobacter chroococum* together. The fungal population remained unaffected in *Glomus* inoculated plants but reduced by inoculation with *Azotobacter*. Inoculation of tomato with *Glomus fasciculatum* increased the *Azotobacter chroococum* population in the rhizosphere at high level for longer time. On the other

hand Azotobacter enhanced infe ion and spore produced by Glomus.

Inoculation with selected efficient strains of hizobia and VAM fungi improved nodulation, N fixation, rowth and P nutrition in forage and grain legumes (Bagyaraj et al., 1979, Munns and Mosse. 1980, Redente and Reeves. 1981); pigeonpea and cowpea (Manjunath and Bagyaraj. 1984) and leucaena (Nalini et al., 1986).

Gopalakrishna (1980) reported that inoculation of finger millet with Glomus fasciculatum and with two P solubilizing fungi, Aspergillus niger and Pencillium funiculosum increased significantly the dry weight of the root and shoot of the host. Dual inoculation also increased the concentration of P, K, Zn and Mn in the shoot.

Synergistic effect on growth of tomato with the inoculation of Glomus fasciculatum, Beijerinckia mobilis nd Aspergillus niger have been reported Manjunath et al.,1981). Similar beneficial interaction of VAM fungi with P solubilizing Bacillus circulans was observed in finger millet (Raj et al., 1981).

Krishna et al. (1982) reported that when G.fasciculatum and Streptomyces cinnamomeus were dually noculated to finger millet, they stimulated plant growth ess than when inoculated individually because of antagonistic interaction.

Brown and Carr (1984) found that the dual inoculation of Azotobacter chroococcum and VA mycorrhiza to lettuce seedlings increased the growth and yield compared to individual inoculation.

Manjunath et al. (1984) reported that dual inoculation of VA mycorrhiza and Rhizobium enhanced nodulation, mycorrhizal colonization, dry weight, N and P content of leucaena plant compared to single inoculation.

Chang et al. (1986) found that dual inoculation of Rhizobium and VA mycorrhizal fungi to Acacia auriculiformis resulted in the greater number of nodules, seedling weight, uptake of nitrogen and phosphorus and acetylene reduction compared to single inoculation of either Rhizobium or VA mycorrhiza.

Mohandas (1987) reported that when Glomus asciculatum and Azotobacter Vinelandii were inoculated to tomato plants, leaf area, shoot dry weight, nitrogen content, phosphorus content and yield increased significantly compared to uninoculated control.

Azcon (1989) observed that when tomato plants were inoculated with Azotobacter vinelandii and enterobacterial strain and VA mycorrhiza in a sand vermiculite medium, they found that the bacterial inoculations increased the growth of mycorrhizal plants. Germination, hyphal growth and

vegetative spore production of Glomus mosseae were increased n the presence of Azotobacter and enterobacteria.

Pal et al. (1989) found that triple inoculation to chickpea with Rhizobium, Bacillus polymyxa and Glomus fasciculatum resulted in significant increase in dry matter production compared to single or dual inoculation.

Sreenivasa and Krishnaraj (1992) studied the synergistic interaction between VA mycorrhizal fungi and a phosphate solubilizing bacterium Pseudomonas striata on chilli. Dual inoculation increased the shoot dry mass, fruit yield, shoot P and micronutrient content of chilli. It was concluded that P solubilizing bacteria increased the amount of soluble P and mycorrhiza increased P uptake to the plant and thus a synergistic effect occured when both were present.

Baird and Kimberly (1994) reported that dual inoculation of VA mycorrhiza and Rhizobium strain 127 K_{44} in bean (Phaseolus vulgaris) resulted in formation of larger nodules in clusters compared to plants inoculated with Rhizobium alone, which produced single or linear groups of nodules. They observed that after 5 weeks of inoculation, hyphal infection of the nodule cortex was abundant. Vesicles were observed in root and nodule tissue.

MYCORRHIZAL DEPENDENCY

Certain plant species require mycorrhiza to a much greater extent than do others, and this is usually referred to as mycorrhizal dependency, which is "the degree to which plant is dependent on mycorrhiza to produce its maxium growth or yield, at a given level of soil fertility" (Gerdemann, 1975). Menge et al. (1978) defined this parameter numerically as the ratio of dry weight of a mycorrhizal plant to dry weight of non mycorrhizal plant of the same species expressed as percentage. Mycorrhizal dependency is affected by plant species, soil type, soil phosphorus etc. A wide range of mycorrhizal dependencies have been observed in plants and were significantly influenced by fungal species.

Mehraveran (1977) studied soil and plant factors involved in mycorrhizal dependency of various citrus cultivars. He reported that dependency of cultivars is inversely related to efficiency of cultivars in phosphate uptake and translocation to the leaves. Cultivars with lower degree of dependency on mycorrhiza produced more thinner roots and generally had higher root/shoot or root/leaf ratios.

Ojala et al. (1983) predicted mycorrhizal dependency of citrus using different P extraction techniques in response to the mycorrhizal fungus Glomus fasciculatum by

regression models. Of the five methods, saturation extract -P (pse), an ion exchange resin P and 1:10 soil to water extract were acceptable for predicting mycorrhizal response. Bicarbonate extractable P (PBIC) and ammonium fluoride P (PAF) were less acceptable.

Menge et al. (1978) observed that citrus root stock exhibited the greatest mycorrhizal dependency at medium fertilizer regime.

Peterson et al. (1984) reported that most of the crop plants and trees are dependent on mycorrhiza for their growth. Approximately 90 percent of all vesicular plants including most of the important agricultural species have mycorrhizal infection.

Graham and Syvertsen (1985) examined the mycorrhizal dependancy in the seedlings of five citrus root stocks grown in a low P sandy soil using Glomus intraradices as VA mycorrhizal inoculum. The order of mycorrhizal dependency (MD) of the five root stocks was sour orange = cleopatra mandrin > swingle citrumeto > carrizo citrange > Trifoliate orange.

A great variation in dependency on mycorrhiza was observed among forage legume species. Total uptake of all elements by non mycorrhizal legumes and uptake of phosphorus, nitrogen and potassium by non mycorrhizal

grasses correlated inversely with mycorrhizal dependency (Saif, 1987).

Hetrick et al. (1989) studied the impact of mycorrhizal symbiosis on the growth of Andropogon gerardii (Big blue stem) and Koeleria pyranidata (June grass). Andropogon gerardii was 98 percent dependent on symbiosis where as Koeleria pyranidata displayed less than 0.02 percent dependence. Fifty times larger growth and increased dry weight was seen in Andropogon gerardii at low P levels.

Sieverding (1990) reported that the known edaphic and climatic stress situations in the tropics imply that agronomic crops depend for trition and growth on VA mycorrhiza.

Khalil et al. (1994) reported that plants in nutrient deficient soils often benefit when colonized by VA mycorrhizal fungi. In their study they found that soybean had higher mycorrhizal dependency than corn. Considerable variation in responsiveness or mycorrhizal dependency was noticed among the cultivars. Total uptake of N, P, K, Ca, Mg and Zn were significantly greater in mycorrhizal plants.

EFFECT OF VA MYCORRHIZA ON UPTAKE OF NUTRIENTS

VA mycorrhiza occur in almost all tropical crop plants and are known to enhance plant growth by augmenting the nutrient uptake especially phosphorus.

Gray and Gerdemann (1969) compared the uptake and accumulation of phosphorus by mycorrhizal and non mycorrhizal onion plants. The results of the experiment indicated that mycorrhizal onion plants accumulated significantly more phosphorus in the roots and tops than non mycorrhizal plants. VA mycorrhizae are sites of increased phosphorus accumulation compared to non mycorrhizal roots.

Sanders and Tinker (1971) conducted an experiment to know the effects of Endogone on plant growth responses and increased uptake of ph sphate from the soils and possible mechanisms to account for the increased uptake. Their results indicated that Endogone infection can improve phosphate nutrition in crops through increased surface area of absorption.

Hayman and Mosse (1972b) reported that plants with VA mycorrhiza frequently absorb more phosphate from soil. In a range of soils containing unknown sources of phosphate plants respond to mycorrhiza when there is much Fe and Al, but little available P. It was concluded from these studies and from experiments in 32p labelled soils that mycorrhizal roots obtained their extra P from the soluble fraction and that the major role of VA mycorrhiza in increasing the uptake of soil P by roots is a physical one namely the provision of extra absorbing surface.

Bowen and Rovira (1976) made a detailed study on phosphate physiology of VA mycorrhiza. The auto radiographic studies indicated that in mycorrhiza much of the increase in P uptake is due to uptake and translocation by the fungal hyphae external to the root rather than to a fungal stimulation of ion uptake by uninfected cells. Increase in phosphate absorbing power from solution and phosphate uptake from soil were affected primarily by the extent of external hyphal growth which vary widely depending on soil conditions and the fungus host combination.

Lambert et al. (1979) reported that mycorrhiza increases the uptake of Zn and Cu in many plants but mycorrhizal activity was suppressed by P fertilization. They determined the shoot dry weights and total uptake of P, Zn, Cu, Fe, Mn, K , Ca and Mg of mycorrhizal (Gigaspora gigantea) and non mycorrhizal plants given 0,25,75 or 200 ppm P. Phosphorus fertilization significantly reduced Zn and Cu concentrations in mycorrhizal plants of corn and soybeans but concentrations in non mycorrhizal treatments were not affected.

Gildon and Tinker (1981) reported that VA mycorrhizal fungi increase the uptake of zinc by their host plant and mycorrhizal hyphae are able to translocate the metal.

Gildon and Tinker (1983) found th increased concentrations of Cu in leeks inoculated with Glomus mosseae in Y irradiated soils. It is suggested that copper is absorbed and translocated by my rrhizal hyphae in a manner analogus to that which occurs for P.

Bolan et al. (1984) in their trial with Trifolium subterraneum inoculated with Glomus fasciculatum and Acaulospora laevis found that increased P supply to plants has enhanced the infection of both indigenous and introduced VA mycorrhizal fungi.

Baon (1986) reported that uptake of macro and micro nutrients especially P was better in the mycorrhizal cacao plants than the non mycorrhizal plants.

Watteau and Berthelin (1990) reported that mycorrhizal fungi produce siderophores and help in the plant growth.

Champawat (1991) found that Cuminum cyminum plants inoculated with four different VA mycorrhizal fungi (Gigaspora calospora, Glomus fasciculatum, Glomus mosseae, and Acaulospora laevis) alone or in association enhanced the nutrient uptake in P deficient sandy loam soil.

Davis and Linderman (1991) reported that Capsicum annum cultivar "Early bountiful" responded well to VA mycorrhizal inoculation in terms of increased fruit number,

leaf area, shoot, root and fruit dry weight. Increased P fertility decreased tissue Cu and Zn and increased the tissue P levels. Mycorrhizal colonization (% root length) and spores recovered per unit of soil were greater with plants fertilized with 11 and 44 $\mu g\ ml^{-1}$ P level.

Silva and Siqueira (1991) studied the effect of six VA mycorrhizal fungi singly or in combination on initial growth and nutrients in avocado, mango and papaya seedlings under green house conditions in a soil-vermiculite mix amended or unamended with super phosphate. It was found that root colonization and plant growth effects differed among the inoculated fungi. Growth responses were related to the contents of P, Zn and S. It was concluded that combined use of superphosphate and inoculation with selected VA mycorrhizal fungi is advantageous to early growth of these plants.

Sreenivasa and Krishnaraj (1992) in their synergistic interaction study between two VA mycorrhizal fungi Glomus fasciculatum and Glomus macrocarpum with a phosphate solubilizing bacterium Pseudomonas striata on chilli found that dual inoculation improved plant growth, biomass and uptake of nutrients like P, Zn, Cu, Fe and Mn.

Treeby (1992) reported that mycorrhizal inoculation increased the iron concentration in rough lemon

(Citrus jambhiri) and Trifoliate orange (Poncirus trifoliata) which were grown in acidic potting mix or in an alkaline calcarious potting mix. He found that inoculation of mycorrhizal fungi in the alkaline calcarious potting mix had no effect on shoot Fe concentration.

PRODUCTION OF GROWTH PROMOTING SUBSTANCES

Strzelczyk et al. (1984) observed the production of auxins and gibberlin like substances by the mycorrhizal fungi, bacteria and actinomycetes isolated from the soil and mycorrhizosphere of scots pine. Chromatography and bioassays revealed that most of these organisms required tryptophan for auxin production. It was stated that auxin production is much more common among the root zone organs of pine than the production of gibberlin like substances.

Edriss et al. (1984) found that in sour orange (Citrus aurantium) cytokinin production by mycorrhizal plants were more than twice those of non mycorrhizal plants.

Becard and Piche (1989) used the transformed roots of carrot to determine the effects of root metabolites on hyphal development from the spores of the VA mycorrhizal fungus Gigaspora margarita. Hyphal growth of this obligately biotrophic symbiont was greatly stimulated by a synergistic interaction between volatile and exudated factors produced by roots. Root volatiles alone provided little stimulation and root exudates alone had no effect.

For the first time Co_2 was demonstrated to be a critical root volatile in the enhancement of hyphal growth.

Gogala (1990) studied the root exudates of Pinus sylvestris and concluded that the growth of mycelium was dependent on the specific combination of all growth regulators present in the root or root exudate.

Nair and Safir (1991) isolated two isoflavonoids from clover roots grown under phosphate stress and were characterised as Formononetin (7-hydroxy 4'- methoxy isoflavone) and biochanin A (5,7-dihydroxy 4'- methoxy isoflavone). At 5 ppm these compounds stimulated hyphal growth in vitro and root colonization of an undescribed Glomus sp. These findings suggest that the isoflavonoids studied may act as signal molecules in VA mycorrhizal symbiosis.

MYCORRHIZAL ROOT COLONIZATION AND SPORULATION

Biermann and Linderman (1981) assessed the mycorrhizal colonization in the root samples of Easter lily (Lilium longiflorum) and pepper mint (Mentha piperita). Roots were found to be highly colonized by clear fungal structures.

Lin and Chang (1987) reported that the roots of micropropagated banana plantlets were colonized by all the three Glomus sp. tested (Glomus mosseae, Glomus

fasciculatum, Glomus etunicatum). Four months after inoculation more than 80 percent of roots were colonized.

Louis and Lim (1987) studied the spore density and mycorrhizal colonization at different months in four plant species. Highest spore numbers were recorded from August to October, while most mycorrhizal colonization occured from December to March.

Thomas and Ghai (1987) assessed the VA mycorrhizal colonization in one year old coconut seedlings of 17 cultivars and 4 hybrids growing in a sandy loam soil. The proportion of root segments with VAM ranged from 56.8 to 95.2 per cent. In general more root segments of tall cultivars were infected more (68.8 - 95.2%) than those of dwarf cultivars (62.4 - 75.2%) and Hybrids (56.8 - 86.4%). The extent of VAM colonization within infected root segments of the same cultivars also varied. The VAM fungi associated with coconut seedlings were Gigaspora decipens, Gigaspora coralloidea, Gigaspora auriqloba, Gigaspora rosea, Glomus multicaule and Glomus fasciculatum. The difference in VAM colonization within the same cultivar was attributed to genetic factors, host/fungus compatability, physiological and biochemical characters of the root system.

Arines et al. (1988) studied the root colonization abilities among different VA mycorrhizal fungi in red clover plants grown in acid soils. He found the

competetive ability of root colonization by fine and coarse endophytes. The competetive ability against Glomus tenue followed the order Glomus fasciculatum > Glomus mosseae > Glomus epigaeum > Glomus macrocarpum.

Land et al. (1990) evaluated the VA mycorrhizal spore density, frequency of spore types and mycorrhizal colonization in winter barley grown on three different agricultural soils (three locations). In all the three locations the VA mycorrhizal root colonization was high (20-55% of all roots) and spore density was up to 6000/kg soil. However it was found that the main endophytes were different in each soil.

Shanker et al. (1991) examined some members of the family Amaranthaceae for VA mycorrhizal association in arid and semiarid zone. Ten species belonging to 5 genera Achyranthes, Aerva, Alternanthera, Amaranthus and Celosia were examined using 1.0 cm long root standards. Intracellular hyphae, vesicles and arbuscules were observed in the root cortex. The VA mycorrhizal spores isolated from these rhizosphere represented 9 species belonging to 4 genera Glomus, Gigaspora, Sclerocystis and Scutellospora.

BIOLOGICAL CONTROL OF ROOT PATHOGENS BY VA MYCORRHIZA

VA mycorrhizal inoculation is also known to help the plants to overcome various root borne diseases and pathogens.

Perrin (1985) reported that mycorrhiza act as biological deterrents to diseases of plants. The mycorrhizal association can act either as a source of improvement or aggregation of sanitory state of the plants. The protective ability was only demonstrated for certain soil borne diseases. The expression of this natural potential was related to several factors like nature of the host plant, mycorrhizal symbiont, plant pathogen and conditions of the telluric environment.

Suresh et al. (1985) studied the effect of mycorrhizal colonization by Glomus fasciculatum on survival, penetration and development of the root knot nematode Meloidogyne incognita in tomato. The number of giant cells formed in mycorrhizal plants was significantly low. Mycorrhizal roots did not prevent the penetration by the nematode larvae. Root extract from the mycorrhizal plants brought about 50 percent mortality of the nematode larvae in four days time.

Cooper and Grandison (1986) reported that mycorrhizal inoculation increased the plant resistance to root knot nematode (Meloidogyne hapla). This was probably due to some alteration in the physiology of the root system but not entirely a result of better host nutrition and improved P uptake by mycorrhizal plants.

Iqbal and Nasim (1986a) found that pre-inoculated VA mycorrhizal seedlings of turmeric showed greater resistance to pathogenic invasion at soil moisture contents favourable for the VA mycorrhizal infection.

Smith and Kaplan (1988) reported that burrowing nematode population densities were lower in roots of mycorrhiza infected rough lemon seedlings than non mycorrhizal plants.

Thomas et al. (1988) studied the effect of inoculation of six different species of VA mycorrhizal fungi individually and in different combination with root knot nematode Meloidogyne incognita on cardamom. The effect was studied at 6 and 12 months after inoculation. Results revealed that VA mycorrhizal inoculation significantly improved the growth of cardamom plants. The nematode inoculation alone reduced plant growth. However the growth response induced by VA mycorrhizal fungi was similar when inoculation was made simultaneously and after nematode inoculation. VA mycorrhizal fungi significantly reduced the nematode population in roots.

Fieldmann et al. (1990) reported that VA mycorrhiza colonized rubber trees have an increased resistance against a foliar disease (South american leaf blight) caused by the Ascomycete Mirocylus ulei. The lesion

size and the production of spores by the pathogen were significantly lowered due to VA mycorrhizal inoculation.

Huzhengjia and Guixiangdong (1991) raised the cotton seedlings in sterilized soil in plastic bags and inoculated separately with Glomus intraradices or Glomus mosseae. After 4 weeks of growth the seedlings were transplanted into pots containing 6 kg unsterilized soil. Some plants were infested with Fusarium vasinfectum at the time of transplanting. Plants were harvested 60 days after transplanting. The final dry matter yields of plants inoculated with VA mycorrhizal fungi were significantly higher than uninoculated plants. Fusarium infection had no significant effect on Glomus infection.

Mishra and Shukla (1995) studied the influence of Glomus fasciculatum inoculation with nine pesticides for effective and long lasting management of root knot nematode of tomato. They found that simultaneous inoculation (500 nematodes + 200 chlamydospores of Glomus) resulted in maximum reduction in number and size of the galls. Application of Glomus fasciculatum 15 days earlier to the nematode, significantly increased the plant growth and reduced the number of root galls and nematode population in soil.

MATERIAL AND METHODS

MATERIAL AND METHODS

The present study was taken up to select the most efficient VA mycorrhizal fungi that can be used for inoculating cardamom in the nursery.

Survey, Collection and Isolation of native VA mycorrhiza from cardamom plantations

An intensive survey was made to collect soil samples from the cardamom rhizosphere of different cardamom plantations from Karnataka and Kerala. These soil collections were made in different agroclimatic zones of cardamom cultivation classified mainly on rainfall and altitude. From the collected samples native VA mycorrhizal status was assessed and the predominant native VA mycorrhizal fungi were isolated.

Isolation, Purification and Maintenance

The different VA mycorrhizal spore types in the rhizosphere soil were observed under a binocular stereo microscope. The dominant native strains based on spore morphology were isolated. They were surface sterilized using Chloramine T (2%), Streptomycin sulphate (0.02%) and two drops of tween 80 for 20 minutes and brought into pot cultures using funnel technique (Nicolson, 1967).

Multiplication of Native strains

Pots holding 2 kg sand : soil (1:1) mixture were sterilized in an autoclave at 1.1 kg cm^2 pressure(at 121° C)

for one hour. The sorghum seedlings along with the substrate in the funnel used for isolating and bringing VA mycorrhizal spores to pot culture were transferred to the sterile sand: soil mixture and sown with Chloris gayana (Rhodes grass).

Each isolate was multiplied separately and most probable number of each isolate was determined before utilising for plant response studies.

Identification of native VA mycorrhiza

The native VA mycorrhizal strains which were collected during the survey and maintained as pure cultures were identified as per the synoptic key to genera and species of Endogonaceae developed by Schenck and Perez (1987).

I PRIMARY SCREENING TRIAL

A primary screening trial was conducted under mat house conditions in the department of Agril. Microbiology, UAS, GKVK campus, Bangalore to test the response of cardamom to thirteen different strains of VA mycorrhiza which were maintained at the culture collection bank of the university.

Soil Characteristics

Forest top soil of sandy clay loam was used in the primary screening trial. The physical and chemical properties of the soil is given in Appendix E.

Potting mixture

Cardamom plants were maintained in polybags (Size 20 cm x 28 cm of 100 gauze thickness) filled with 2 kg potting mixture comprising of forest top soil:sand: FYM (2:1:1). The polybags were punched with four holes at the bottom before filling potting mixture to provide sufficient drainage.

Plant material

Cardamom seedlings [*Elettaria cardamomum* (L) Maton] cultivar Malabar raised on sterilized soil were used. Healthy and three leaf staged uniform sized seedlings were selected and used for planting. One cardamom seedling per polybag was maintained.

VA mycorrhizal cultures used in the primary screening

Thirteen different VA mycorrhizal cultures maintained at the culture collection bank of the university of Agricultural Sciences, GKVK, Bangalore were used. These cultures were maintained separately on Rhodes grass in sterile sand : soil mixture (1:1 proportion). The extramatrical chlamydospores, infected root bits and hyphae served as VA mycorrhizal inoculum. Based on the MPN values the infective propagules (IP) per gram was calculated. VA mycorrhizal cultures were added at the rate of 12,500 IP per plant.

The VA mycorrhizal fungi which were used in the primary screening trial, their source and MPN values are as follows :

VA mycorrhizal fungi used in primary screening at UAS, GKVK, Bangalore

Sl NO	VA mycorrhizal fungi	Source	INOCULUM DENSITY	
			IPxX10^4/g	Amount of inoculum used to get 12,500 IP per Plant in gms
1.	Gigaspora margarita	ICRISAT, India	0.093	13.44
2.	Glomus monosporum	Univ. of Western Australia, Nedlands	0.95	1.32
3.	Glomus fasciculatum	University of California, Riverside, USA	0.08	15.63
4.	Glomus mosseae	ICRISAT, India	0.27	4.63
5.	Glomus intraradices	Native Plant Inst. Salt lake city, USA	0.062	20.16
6.	Acaulospora laevis	Invermay Research Station, New Zealand	0.20	6.25
7.	Glomus deserticola	Native Plant Inst. Salt lake city, USA	0.16	7.81
8.	Glomus macrocarpum	Univ. of Agril. Sciences, GKVK, Bangalore	0.14	8.93
9.	Glomus leptotichum	Univ. of Agril. Sciences, GKVK, Bangalore	0.093	13.44
10.	Glomus versiformae	Univ. of Agril. Sciences, GKVK, Bangalore	1.70	0.74
11.	Glomus etunicatum	Native Plant Inst. Salt lake city, USA	0.12	10.42
12.	Gigaspora calospora	ICRISAT,India	0.13	9.62
13.	Glomus caledonicum	Univ. of Western Australia, Nedlands	1.80	0.69

Application of the inoculum

After 20 days of plant establishment in polybags mycorrhizal inoculum at the rate of 12,500 IP/g was added on either side of the plant close to the root by making holes in the soil which was subsequently closed.

Fertilizer levels

Cardamom plants of primary screening were supplemented with full recommended dose of nitrogen (N) and potash (K) and half the recommended dose of phosphorus (P). The recommended fertilizer dose for an optimum yield as per package of practice, UAS, Bangalore is 37.5 - 37.5 - 75kgs NPK/ha. The quantity of fertilizers required for 2 kg potting mixture was calculated and added. Fertilizers were mixed thoroughly in the soil before filling into polybags and then the seedlings were planted.

Design of the experiment

Primary screening trial was laid out in a completely randomized block design having 14 treatments and 20 replications.

II SECONDARY SCREENING TRIALS

The secondary screening trials were conducted in the predominant cardamom growing regions of Karnataka and Kerala. At Karnataka it was conducted at the Regional Research Station of Spices Board at Sakleshpur, Hassan District, and at Kerala it was conducted at the Main Research Station of Spices Board at Myladampara, Idukki

District. Both the trials were conducted under mat house conditions.

SAKLESHPUR SECONDARY SCREENING TRIAL

Soil Characteristics

Forest top soil of sandy loam was used in the experiment. The physical and chemical properties of the soil is given in Appendix E.

Potting MIxture

The preparation of potting mixture and plant maintenance were similar as stated in primary screening.

Plant material

Cardamom seedlings (cultivar Malabar) raised in sterilized soil were used. Healthy and three leaf staged uniform seedlings were selected and planted in polybags. One cardamom seedling per polybag was maintained.

VA mycorrhizal cultures used

Based on the performance of VA mycorrhizal cultures in primary screening trial, the top six promising VA mycorrhizal fungi were selected and used in the secondary screening trial along with three dominant native VA mycorrhizal fungi. Based on the MPN values of VA mycorrhizal cultures, inoculum was added at the rate of 12,500 IP per plant.

The VA mycorrhizal fungi which were used at Sakleshpur secondary screening trial, their source and MPN values are given below :

Sl No	VA mycorrhizal fungi	Source	INOCULUM DENSITY	
			IPxX10^4/g	Amount of inoculum used to get 12,500 IP per Plant in gms
1.	Glomus monosporum	Univ. of Western Australia, Nedlands	0.95	1.32
2.	Glomus mosseae	ICRISAT, India	0.27	4.63
3.	Glomus fasciculatum	University of California, Riverside, USA	0.08	15.63
4.	Gigaspora margarita	ICRISAT, India	0.093	13.44
5.	Glomus intraradices	Native plant Inst. Salt Lake city, USA	0.062	20.16
6.	Acaulospora laevis	Invermay Research Station, New Zealand	0.20	6.25
7.	Sakleshpur Native strain (S_1)	Native	0.039	32.05
8.	Sakleshpur Native strain (S_2)	Native	0.045	27.78
9.	Sakleshpur Native Strain (S_9)	Native	0.028	44.64

Application of the inoculum

The inoculum placement was similar as explained earlier in primary scre ıing.

Fertilizer levels

The recommended fertilizers and application are same as that of primary screening.

Design of the Experiment

The experiment was laid out in a completely randomized block design having 10 treatments and 20 replications.

MYLADAMPARA SECONDARY SCREENING TRIALS

Soil Characteristics

Forest top soil of sandy loam was used in the experiment. The physical and chemical properties of the soil is given in Appendix E.

Potting Mixture

Preparation of potting mixture and plant maintenance was same as done in primary screening.

Plant Material

Cardamom seedlings of cultivar Mysore and Vazukka raised in sterilized soil were used. Healthy and three leaf staged uniform seedlings were selected and planted in polythene bags. One cardamom seedling per polybag was maintained.

VA mycorrhizal cultures used

The best six promising VA mycorrhizal fungi selected out of primary screening and five predominant native VA mycorrhizal fungi obtained from an extensive survey made in different cardamom plantations of Kerala were used in this trial. Based on MPN values VA mycorrhizal cultures were added at the rate of 12,500 IP per plant. The VA mycorrhizal fungi which were used at Myladampara field trials, their source and MPN values are given below.

Sl No	VA mycorrhizal fungi	Source	INOCULUM DENSITY	
			IPxX10^4/g	Amount of inoculum used to get 12,500 IP per Plant in gms
1.	Glomus monosporum	Univ. of Western Australia, Nedlands	0.95	1.32
2.	Glomus fasciculatum	University of California, Riverside, USA	0.08	15.63
3.	Glomus mosseae	ICRISAT, India	0.27	4.63
4.	Gigaspora margarita	ICRISAT, India	0.093	13.44
5.	Glomus intraradices	Native plant Inst. Salt lake city, USA	0.062	20.16
6.	Acaulospora laevis	Invermay Research station, New Zealand	0.20	6.25
7.	Myladampara Native strain (M_1)	Native	0.052	24.04
8.	Myladampara Native- strain (M_2)	Native	0.054	23.15
9.	Myladampara Native strain (M_3)	Native	0.062	20.16
10.	Myladampara Native strain (M_6)	Native	0.047	26.60
11.	Myladampara Native strain (M_7)	Native	0.062	20.16

Application of the inoculum

The inoculum placement was similar as explained under primary screening.

Fertilizer levels

Both the cultivars of cardamom plants viz., Mysore and Vazukka were supplemented with full recommended dose of nitrogen (N) and potash (K) and half the recommended dose of phosphorus (P). The recommended fertilizer dose for cardamom cultivation in Kerala as per the ICRI recommendation is 25-25-50 kgs NPK/ha. The quantity of fertilizers required for 2 kg potting mixture was calculated and added. Fertilizers were mixed thoroughly in the soil before filling in to the polybags and then the seedlings were planted.

Design of the Experiment

The experiment was laid out separately for cultivar Mysore and Vazukka in completely randomized block design having 12 treatments and 10 replications.

NURSERY MANAGEMENT

Post planting operations

The nursery management, post planting operations and the procedure followed in recording various plant observations, chemical and microbiological analysis was common for both primary and secondary screening trials.

1. Irrigation and Mulching

After transplanting of cardamom seedlings in to the poly bags having 2 kg of potting mixture, they were

watered immediately. Seedlings were mulched with thinly sliced leaf material. In the subsequent plant growth period plants were watered regularly looking in to soil moisture conditions.

2. Plant protection measures and weeding

Since the cardamom plants were healthy throughout the study period of both primary and secondary screening trials no plant protection measures were taken. Weeds were removed as and when they appeared in the polybags.

3. Shade regulation

Shade regulation is one of the important practice in cardamom cultivation. Cardamom seedlings which were planted in polybags were maintained in coir mat house to regulate shade and to provide partial or diffused sunlight which is highly essential for cardamom plants.

Plant Biometric observations

1. Plant height

The height of the plants were measured in cm from ground level to base of the penultimate leaf. The plant height was recorded at 3 months interval i.e., 3, 6 and 9 months after transplanting.

2. Number of leaves

The number of fully opened leaves on the plant were recorded at 3, 6 and 9 months after transplanting.

3. Leaf area

In each treatment the leaf area of plant was calculated when the plants were at the age of 9 months after transplanting using the formula developed by George et al., (1984) for cardamom plant. The area (P) of any individual leaf of one year old cardamom seedlings can be estimated by a linear function P = 0.813 B + 0.657 LB where L and B are length and breadth of the leaf.

4. **Number of tillers**

The number of tillers per plant was recorded before harvest.

5. **Harvesting of plants**

Cardamom plants were harvested (shoot portion) on the day of completion of 9 months after transplanting. About 200 ml of rhizosphere soil were collected from each polybag and labelled according to treatment and replication for further analysis. The root portion of each plant was carefully removed from the polybag and washed with a jet of water, air dried and labelled according to the treatments. Few fine root bits of about 1 cm length were collected from each treatment and placed in screw cap vials containing FAA [Formalin 5 ml: Acetic acid 5ml: Alcohol 90 ml] for estimating percent mycorrhizal colonization. Care was taken during the collection of soil and root samples to avoid the chances of contamination.

6. Root length

Root length of each treatment was recorded in cm taking in to account the longest root in the root system.

7. Plant dry weight

Shoot and root of each plant was separately dried in an oven at 60°C to a constant weight and their dry weights were recorded. The total plant dry weight was also estimated.

CHEMICAL ANALYSIS OF PLANT SAMPLES

Estimation of nutrient contents

The dried shoot and root samples of each treatment were powdered separately in a grinder and used for nutrient analysis.

The finely ground sample (0.5 g) was digested in triacid mixture comprising concentrated nitric acid, perchloric acid and sulphuric acid (7:3:1 V/V). The digestion was done on a hot plate until there was no more emission of white fumes. The contents were not allowed to evaporate to dryness. The digested residues were diluted to 100 ml using distilled water in a Volumetric flask. The diluted aliquot was used for the estimation of different nutrients.

Estimation of phosphorus

Plant phosphorus content (shoot and root separately) was estimated as per the procedure given by

Jackson (1973). Ten ml of the triacid digested residual aliquot was taken in a 50 ml volumetric flask. Ten ml of vanadomolybdate reagent was added and the volume was made up to 50 ml using distilled water. The intensity of yellow colour developed due to phosphovanodomolybdate complex was read at 420 nm in spectronic 20 (Bausch and Lomb) spectrophotometer. Total P in the sample was determined by comparing with the standard and expressed as percentage P, and total P was later calculated (P in mg per plant).

Preparation of standards

Fifty µg/ml P standard was prepared from analar grade potassium dihydrogen phosphate. The chemical (0.2192g) was taken in 1000 ml volumetric flask and dissolved in distilled water. Twenty five ml of 7 N. H_2SO_4 was added and volume made up to 1000 ml to give 50 µg/ml P. Different quantities of this standard solution were taken in 50 ml volumetric flasks to give 5, 10, 20, 30, 40 and 50 µg P/ml. 10 ml vanadomolybdate reagent was added and the volume made up to 50 ml. A blank was prepared without the standard solution. The colour was read colorimetrically at 420 nm in spectronic 20 and the standard curve was drawn.

Micronutrient Analysis

Micronutrients like iron, copper and zinc present in cardamom plant was estimated using atomic absorption spectrophotometer (Issac and Kerber. 1971). Estimation were made treatment wise separately for shoot and root and the total plant concentration was determined. Iron

concentration was determined using a cathode tube specific for iron whose wavelength was adjusted to 248 nm. Ferrous ammonium sulphate (Fe $(NH_4)_2$ $(SO_4)_2.6H_2O$) was used for preparing the standard curve. The digested and diluted samples were fed to the atomic absorption Spectrophotometer and the readings were recorded. Iron concentration was computed using the standard curve.

Similar to estimation of iron concentration, plant copper and zinc concentrations were also estimated using atomic absorption spectrophotometer. Cathode tube specific for copper was used in estimating the copper concentration by adjusting the wavelength to 325 nm. Copper sulphate ($CuSo_4.5H_2O$) was used for preparing the standard curve. Similarly cathode tube specific for zinc was used and wavelength was adjusted to 215 nm when zinc concentration was estimated. Zinc chloride solution was used for preparing the standard curve.

MICROBIOLOGICAL ANALYSIS

The intensity of mycorrhizal association with the host plant was assessed in terms of VA mycorrhizal spore count in the rhizosphere soil and by estimating the percent mycorrhizal root colonization.

VA mycorrhizal spore count

Extramatrical chlamydospores of the mycorrhizal fungi in the rootzone soil was determined by wet sieving and decantation method [Gerdemann and Nicolson, 1963]. 25 ml of rhizosphere soil sample was transferred to a

500 ml beaker and sufficient quantity of water was added and stirred thoroughly. The stirred soil suspension was allowed to stand for 1 minute without any disturbance for the settlement of heavier particles at the bottom. After one minute the soil suspension was decanted through a set of sieves viz., 1000, 450, 325, 250, 105 and 45 µm pore size which were arranged one below the other in the same order. After decanting the soil suspension in to the sieves a jet of running water was passed through these arranged sieves for the clear separation of spores. The spores collected on 105 µm and 45 µm sieves were washed down on to a nylon mesh (less than 45 µm). The nylon mesh with spores on it was placed in a petri plate and the spores were counted using a hand tally counter under a binocular stereo microscope.

Percent mycorrhizal root colonization

The percent mycorrhizal root colonization was determined after staining the roots with trypan blue as per the procedure outlined by Phillips and Hayman (1970). The root bits which were collected at harvest and which were in FAA (Formalin 5ml : Acetic acid 5ml : Alcohol 90ml) for more than 5 hrs were taken out and hydrolysed with 10% KOH by autoclaving at 1.1 kg cm^2 pressure (at 121 °C) for 15 minutes. The roots were then immersed in alkaline hydrogen peroxide (H_2O_2:H_2O:NH_3 50:50:3) until all pigments were removed. Hydrogen peroxide was decanted and roots were rinsed in water. The root bits were then neutralised with 10% Hcl for 5 minutes and then washed with distilled water and stained

by simmering the roots for 10 mts in 0.05 percent trypan blue in lacto glycerol (Lactic acid 40 ml, Glycerol 50 ml, Distilled water 10 ml). The stained root bits were preserved in lacto glycerol till observation.

Microscopic observation

The stained 1 cm root bits were arranged on a clean slide and a cover slip was placed over it and pressed gently and observed under microscope for the presence of arbuscules and vesicles to confirm mycorrhizal colonization. The percentage mycorrhizal colonization was calculated using the formula :

$$\% \text{ colonization} = \frac{\text{No. of root bits having colonization}}{\text{Total number of root bits examined}} \times 100$$

Inoculum potential

Infectivity of mycorrhizal inoculum was determined using the most probable number (MPN) method adopted from Porter (1979).

Thirty grams of air dried pot culture soil (inoculum) was used for ten fold series of soil dilution upto 10^{-7}, using 270 g of sterilized sand : Soil (1:1) mix per dilution. The diluted cultures from 10^{-1} to 10^{-7} were filled to plant tubes (15x2.5 cm) at the rate of 50 g per tube. Five replica e tubes per dilution were prepared and onion seeds (Chickballapur red variety) were sown in plant tubes. Onion seedlings were grown for 6 weeks in a glass

house. Roots were washed and stained with trypan blue in lacto glycerol (Phillips and Hayman, 1970) and were examined microscopically for the presence or absence of VAM colonization. MPN values were calculated by referring to MPN table given by Alexander (1965).

EXPERIMENTAL RESULTS

EXPERIMENTAL RESULTS

The results of primary and secondary screening trials conducted to study the response of cardamom cultivars to different VA mycorrhizal fungal isolates are given below :

PRIMARY SCREENING TRIAL AT BANGALORE

Selection of efficient VA mycorrhizal fungi from germplasm bank

The symbiotic response of cardamom (cultivar: Malabar) to thirteen different isolates of VA mycorrhizal fungi obtained from the germ plasm bank of the university of Agril. Sciences, GKVK, B'lore was evaluated in terms of plant growth and nutrient uptake.

Plant biometric observations

Plant height

The effect of VA mycorrhizal inoculation on plant height of cardamom was recorded when the plants were at the age of 3,6 and 9 months after transplanting (Table 1;Fig.1). In general plants inoculated with VA mycorrhizal fungi grew taller than the uninoculated plants. Significant differences were noticed between the treatments. Among the thirteen different VA mycorrhizal fungi tested plants inoculated with Gigaspora margarita and Glomus monosporum showed maximum plant height at 9 months after transplanting both being statistically on par with each other (86.3 and 84.5 cm respectively). The lowest plant height (63.2 cm) was seen

Plate 1. General view of Cardamom nursery -

(a) Primary Screening conducted at

GKVK, Bangalore

(b) Secondary screening conducted at

KSB Spices Board, Sakleshpur.

Table - 1

Influence of VA mycorrhiza on plant height of Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore

Sl No	Inoculation treatment	Plant height (cm) - MAT*		
		3 M*	6 M*	9 M*
1.	Acaulospora laevis	23.8 ef	60.0 fg	80.2 cde
2.	Gigaspora calospora	20.7 b	51.4 bc	76.9 c
3.	Gigaspora margarita	28.8 h	66.5 i	86.3 g
4.	Glomus caledonicum	20.5 b	50.6 b	71.9 b
5.	Glomus deserticola	22.8 de	57.6 ef	79.9 cde
6.	Glomus etunicatum	21.1 bc	52.1 bc	77.1 cd
7.	Glomus fasciculatum	26.1 g	63.0 h	82.8 efg
8.	Glomus intraradices	24.7 fg	61.2 gh	80.4 cde
9.	Glomus leptotichum	21.8 bcd	55.5 de	78.7 cd
10.	Glomus macrocarpum	22.3 cd	56.3 de	79.5 cde
11.	Glomus monosporum	28.2 h	65.8 i	84.5 fg
12.	Glomus mosseae	25.4 g	62.5 gh	81.0 def
13.	Glomus versiformae	21.6 bcd	54.0 cd	77.8 cd
14.	Uninoculated	18.4 a	44.2 a	63.2 a
	SEM ±	0.51	0.96	1.43
	CD (0.05)	1.41	2.67	3.96
	CV%	9.79	7.53	8.12

Note: Values representing mean of 20 replicates

* MAT = Months after transplanting

Means with similar alphabets in each column do not differ significantly at p= 0.05.

Plate 2. Response of Cardamom Cv. Malabar to different isolates of VA mycorrhizal fungi

Notations

1. F = *Gigaspora margarita*
2. 4 = *Glomus monosporum*
3. 10 = *Glomus fasciculatum*
4. LL_3 = *Glomus mosseae*
5. 11 = *Glomus intraradices*
6. 7 = *Acaulospora laevis*
7. 13 = *Glomus deserticola*
8. H = *Glomus macrocarpum*
9. PP_4 = *Glomus leptotichum*
10. LL_4 = *Glomus versiformae*
11. 12 = *Glomus etunicatum*
12. B = *Gigaspora calospora*
13. 5 = *Glomus caledonicum*
14. C = Uninoculated control

(a) Shoot

5
B
12
LL
PP
4
F

CARDAMOM «VAN
(= MALABAR)
F
4
10
LL3
11
7
13
H
PP4
LL4
12
B
5

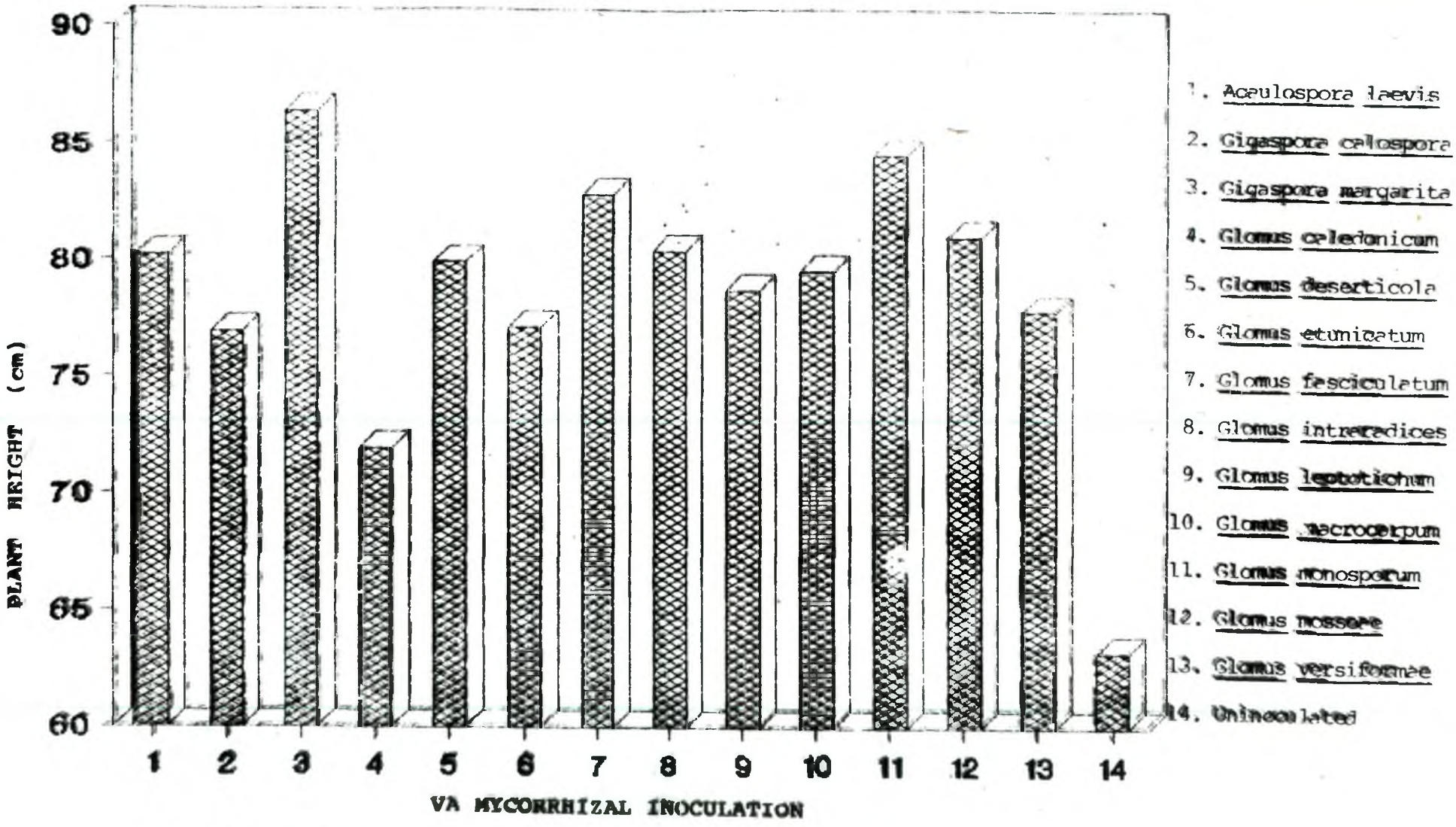


Fig. 1. Influence of VA mycorrhiza on plant height of Cv. Malabar of cardamom at 9 months after transplanting - primary screening conducted at GKVK, UAS, Bengalore.

uninoculated plants which differed significantly from all other mycorrhizal treatments.

Number of leaves

The number of leaves produced by each plant recorded at the age of 3, 6 and 9 months after transplanting is shown in table 2. In general inoculated plants had more number of leaves compared to uninoculated plants. Significant differences were noticed between the treatments at all the three stages of plant growth. Nine months after transplanting, plants inoculated with Gigaspora margarita had more number of leaves (12.6) followed by plants inoculated with Glomus monosporum (12.5). These two treatments did not differ statistically from each other but differed significantly compared to uninoculated control plants which had the lowest number of leaves (10.8).

Leaf Area

Influence of VA mycorrhizal inoculation on leaf area of cardamom was estimated at harvest (9 months after transplanting) (Table 3). In most of the mycorrhizal treatments no significant differences were observed.

Cardamom plants inoculated with Gigaspora margarita showed maximum leaf area (144.4 cm^2) followed by those treated with Glomus monosporum (141.4 cm^2). The lowest leaf area was recorded in uninoculated plants (108.5 cm^2).

Table - 2

Influence of VA my rrhiza on the number of leaves in Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore

Sl No	Inoculation treatment	No of leaves /Pl^{-1} - MAT*		
		3 M*	6 M*	9 M*
1.	Acaulospora laevis	6.3 cdef	9.6 efgh	11.9 cdefg
2.	Gigaspora calospora	5.8 abc	8.6 abc	11.2 abc
3.	Gigaspora margarita	6.6 f	10.5 i	12.6 g
4.	Glomus caledonicum	5.5 ab	8.4 ab	11.1 ab
5.	Glomus deserticola	6.2 cdef	9.4 defg	11.8 bcdef
6.	Glomus etunicatum	5.9 bcd	8.8 bcd	11.4 abcd
7.	Glomus fasciculatum	6.4 def	9.8 ghi	12.2 efg
8.	Glomus intraradices	6.3 cdef	9.7 fgh	12.0 defg
9.	Glomus leptotichum	6.1 cdef	9.0 bcdef	11.7 bcde
10.	Glomus macrocarpum	6.2 cdef	9.2 cdefg	11.8 bcdef
11.	Glomus monosporum	6.5 ef	10.3 hi	12.5 fg
12.	Glomus mosseae	6.4 def	9.8 ghi	12.0 defg
13.	Glomus versiformae	6.0 bcde	8.9 bcde	11.6 bcde
14.	Uninoculated	5.3 a	8.0 a	10.8 a
	SEM ±	0.21	0.25	0.26
	CD (0.05)	0.59	0.71	0.72
	CV%	15.53	12.28	9.93

Note:- As in table 1

No of tillers per plant

The number of tillers produced by each plant was recorded before harvesting the plants (Table 3; Fig. 2). There were more number of tillers in inoculated plants than the uninoculated control plants. Cardamom plants inoculated with Gigaspora margarita produced maximum number of tillers per plant (2.0) which differed significantly from all other treatments. Least number of tillers were observed in control plants (1.2).

Root length

Root length of plants in each treatment was measured at harvest (Table 3). Significant differences were noticed between the inoculated and the uninoculated plants. Maximum root length was found in plants inoculated with Gigaspora margarita (45.3 cm) followed by those inoculated with Glomus monosporum (43.7 cm), both being statistically on par with each other but differed significantly from all other treatments. Control plants had the lowest root length (20.6 cm).

Plant dry weight

The dry weights of shoot and root of cardamom plants were estimated separately and the total plant biomass was determined. In general, inoculated plants produced more plant biomass compared to uninoculated plants.

Shoot dry weight

Cardamom plants inoculated with Gigaspora margarita showed maximum shoot dry weight (14.5 g/plant)

Table - 3

Influence of VA mycorrhiza on leaf area, number of tillers and root length in Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore

Sl No	Inoculation treatment	Growth parameters - 9 MAT		
		Leaf area (cm^2)	No of tillers per plant	Root length (cm)
1.	*Acaulospora laevis*	133.3 bcdef	1.6 de	32.5 g
2.	*Gigaspora calospora*	124.4 bc	1.4 bc	25.0 bc
3.	*Gigaspora margarita*	144.4 f	2.0 g	45.3 j
4.	*Glomus caledonicum*	120.6 ab	1.3 ab	22.8 ab
5.	*Glomus deserticola*	132.2 bcdef	1.5 cd	31.3 fg
6.	*Glomus etunicatum*	126.4 bcd	1.4 bc	26.8 cd
7.	*Glomus fasciculatum*	138.4 def	1.7 ef	40.3 i
8.	*Glomus intraradices*	134.2 cdef	1.6 de	33.6 gh
9.	*Glomus leptotichum*	130.3 bcde	1.5 cd	28.0 de
10.	*Glomus macrocarpum*	130.8 bcde	1.5 cd	29.4 de
11.	*Glomus monosporum*	141.4 ef	1.8 f	43.7 j
12.	*Glomus mosseae*	137.0 cdef	1.7 ef	36.0 h
13.	*Glomus versiformae*	128.9 bcde	1.4 bc	27.5 cde
14.	Uninoculated	108.5 a	1.2 a	20.6 a
	SEM ±	4.74	0.06	1.06
	CD (0.05)	13.13	0.18	2.95
	CV%	16.20	18.42	15.03

Note:- As in table 1

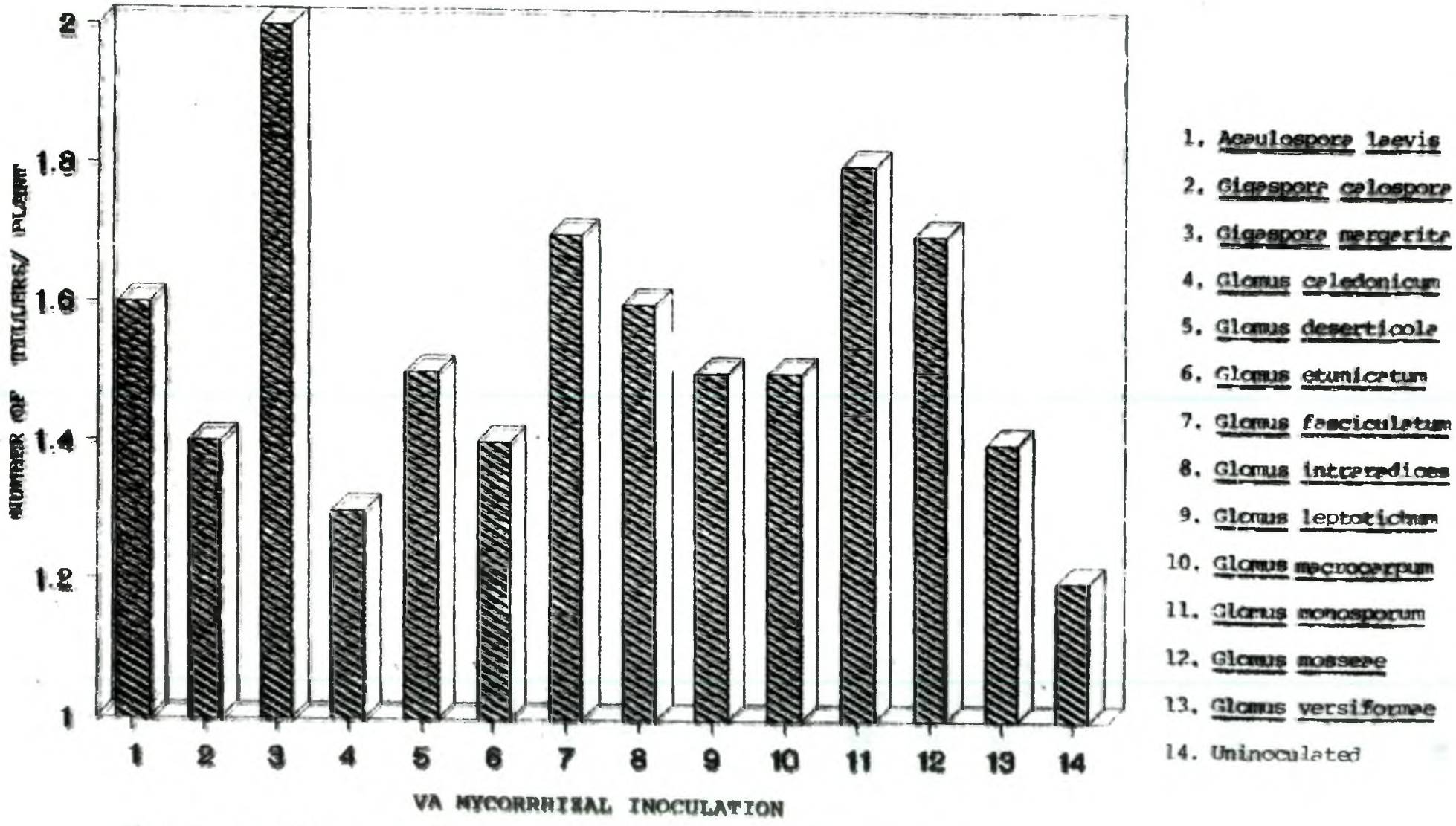


Fig. 2. Influence of VA mycorrhiza on number of tillers in Cv. Malabar of cardamom at 9 months after transplanting - primary screening conducted at GKVK, UAS, Bangalore.

followed by those inoculated with Glomus monosporum (13.8 g/plant), Glomus fasciculatum (13.5 g/plant) and Glomus mosseae (13.2 g/plant). These four treatments were statistically on par with each other but differed significantly from other treatments (Table 4; Fig. 3). Among the different VA mycorrhizal treatments lowest shoot dry weight was recorded in plants inoculated with Glomus caledonicum (10.5 g/plant). Uninoculated control plants had the least shoot biomass (8.6 g/plant).

Root dry weight

VA mycorrhizal inoculation significantly increased the root dry weight of cardamom plants compared to uninoculated plants (Table 4; Fig. 3). Root dry weight significantly differed with different VA mycorrhizal fungi used for inoculation. Plants inoculated with Gigaspora margarita showed maximum root dry weight (8.5 g/plant) followed by Glomus monosporum (7.4 g/plant) both being statistically on par with each other but differed significantly from all other treatments. Lowest root dry weight was observed in uninoculated control plants (3.1 g/plant).

Total plant dry weight

In general mycorrhizal inoculation significantly increased the total plant biomass compared to the uninoculated control (Table 4; Fig.3). Among the thirteen different VA mycorrhizal fungi tested plants inoculated with Gigaspora margarita produced the maximum total plant biomass

Table - 4

Influence of VA mycorrhiza on dry weight of Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore

Sl No	Inoculation treatment	Dry weight (g/pl^{-1})		
		Shoot	Root	Total
1.	Acaulospora laevis	12.9 defg	5.6 bcd	18.5 defg
2.	Gigaspora calospora	10.9 bc	4.5 b	15.4 bc
3.	Gigaspora margarita	14.5 h	8.5 g	23.0 i
4.	Glomus caledonicum	10.5 b	4.5 b	15.0 b
5.	Glomus deserticola	12.2 cdef	5.3 bcd	17.5 cdef
6.	Glomus etunicatum	11.4 bc	4.7 bc	16.1 bc
7.	Glomus fasciculatum	13.5 fgh	6.8 ef	20.3 gh
8.	Glomus intraradices	13.0 defg	5.7 cde	18.7 efg
9.	Glomus leptotichum	11.9 cde	5.1 bcd	17.0 bcde
10.	Glomus macrocarpum	12.0 cde	5.2 bcd	17.2 cdef
11.	Glomus monosporum	13.8 gh	7.4 fg	21.2 hi
12.	Glomus mosseae	13.2 efgh	6.0 de	19.2 fgh
13.	Glomus versiformae	11.7 bcd	4.8 bc	16.5 bcd
14.	Uninoculated	8.6 a	3.1 a	11.7 a
	SEM +	0.46	0.39	0.72
	CD (0.05)	1.34	1.13	2.10
	CV%	6.56	12.18	7.08

Note:- As in table 1

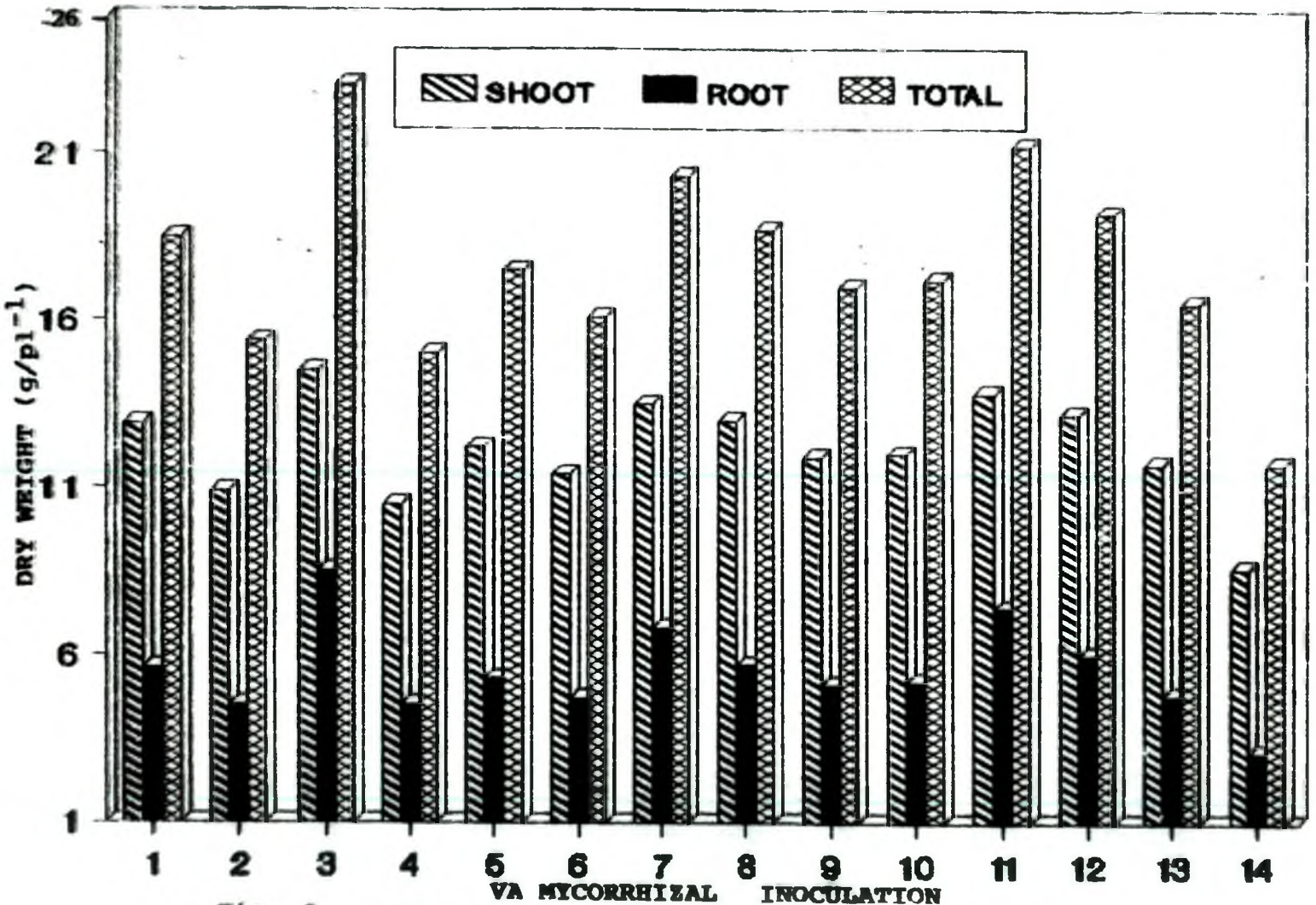


Fig. 3. Influence of VA mycorrhiza on dry weight of Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore.

1. Acaulospora laevis
2. Gigaspora caloespora
3. Gigaspora margarita
4. Glomus caledonicum
5. Glomus deserticola
6. Glomus etunicatum
7. Glomus fasciculatum
8. Glomus intraradices
9. Glomus leptoticlum
10. Glomus macrocarpum
11. Glomus monosporum
12. Glomus mosseae
13. Glomus versiforme
14. Uninoculated

(23 g/plant) followed by plants inoculated with Glomus monosporum (21.2 g/plant). Uninoculated plants had a plant dry weight of 11.7 g/plant which was the lowest among all the treatments.

Phosphorus uptake

The dried shoot and root samples of cardamom plants were analysed separately for their P content.

Shoot Phosphorus

Mycorrhizal inoculation resulted in significant increase in the shoot P content of cardamom compared to uninoculated plants. The difference between the treatments were statistically significant (Table 5; Fig. 4). Maximum shoot P content was recorded in plants inoculated with Gigaspora margarita (123.25 mg/plant) followed by plants inoculated with Glomus monosporum (113.16 mg/plant) both being statistically on par with each other. Uninoculated plants had the lowest shoot P content (37.84 mg/plant).

Root phosphorus

Similar to shoot, Gigaspora margarita inoculation resulted in maximum root P content (45.90 mg/plant)followed by Glomus monosporum (39.22 mg/plant). These two treatments were statistically on par with each other but differed significantly fr other treatments (Table 5; Fig. 4). Though differences were seen between the treatments most of them did not differ significantly from each other. Plants i culated with Gigaspora calospora (16.65 mg/plant), Glomus

Table - 5

Influence of VA mycorrhiza on phosphorus uptake in Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore

Sl No	Inoculation treatment	P uptake			
		Shoot		Root	
		% P	mg/plant	% P	mg/plant
1.	*Acaulospora laevis*	0.69 egf	89.01 gh	0.44 efg	24.64 cde
2.	*Gigaspora calospora*	0.50 ab	54.50 bc	0.37 abc	16.65 ab
3.	*Gigaspora margarita*	0.85 h	123.25 k	0.54 i	45.90 h
4.	*Glomus caledonicum*	0.45 a	47.25 ab	0.36 ab	16.20 ab
5.	*Glomus deserticola*	0.68 defg	82.96 fg	0.42 def	22.26 bcde
6.	*Glomus etunicatum*	0.54 abc	61.56 cd	0.39 bcd	18.33 bc
7.	*Glomus fasciculatum*	0.78 gh	105.30 ij	0.51 hi	34.68 fg
8.	*Glomus intraradices*	0.70 efg	91.00 gh	0.45 fg	25.65 de
9.	*Glomus leptotichum*	0.64 cde	76.16 ef	0.41 cdef	20.91 bcd
10.	*Glomus macrocarpum*	0.66 def	79.20 efg	0.41 cdef	21.32 bcde
11.	*Glomus monosporum*	0.82 h	113.16 jk	0.53 i	39.22 gh
12.	*Glomus mosseae*	0.75 fgh	99.00 hi	0.47 gh	28.20 ef
13.	*Glomus versiformae*	0.58 bcd	67.86 de	0.40 bcde	19.20 bcd
14.	Uninoculated	0.44 a	37.84 a	0.34 a	10.54 a
	SEM ±	0.04	4.21	0.02	2.42
	CD (0.05)	0.10	12.23	0.04	7.03
	CV%	9.59	9.04	6.18	17.07

Note:- As in table 1

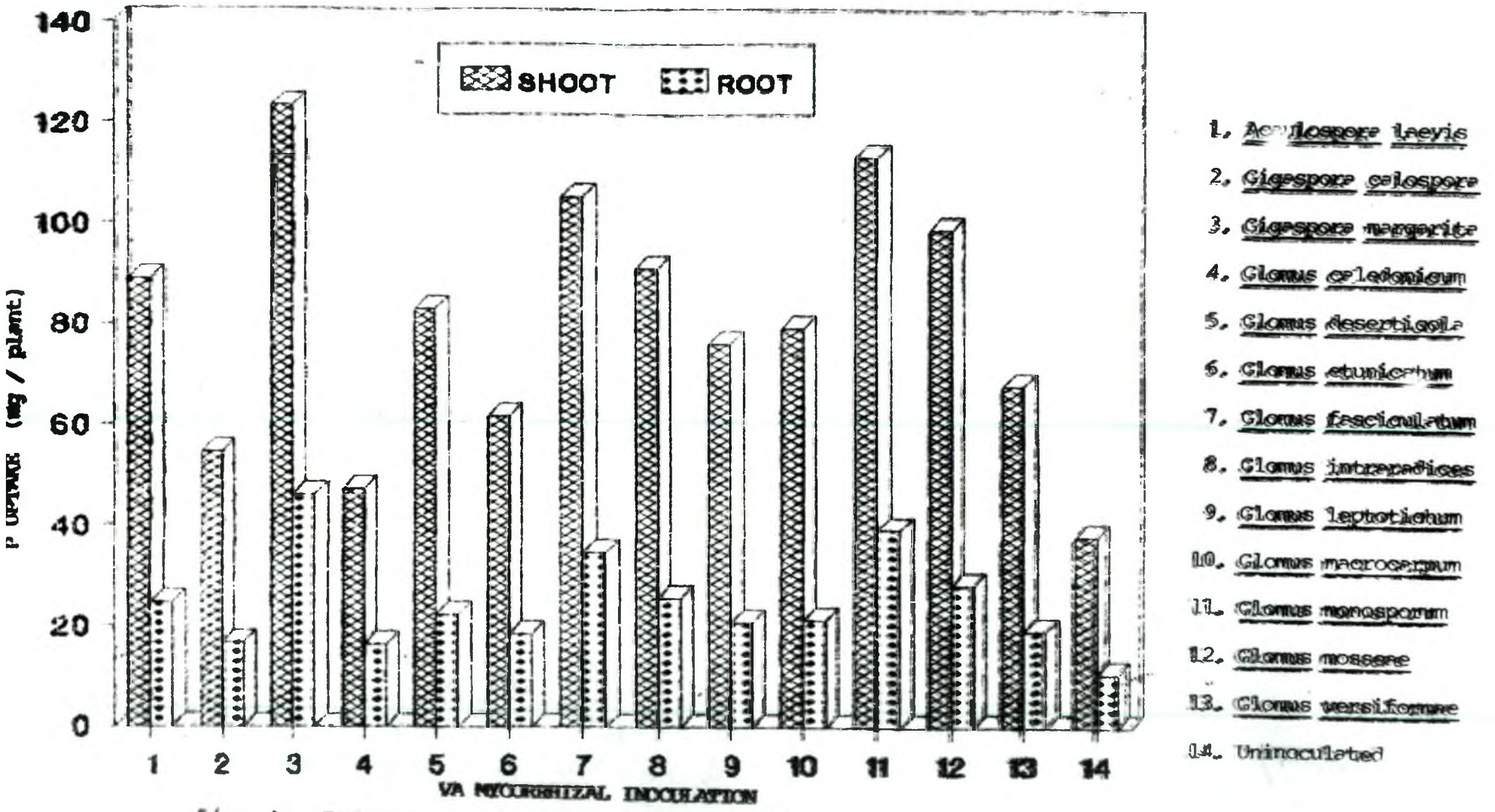


Fig. 4. Influence of VA mycorrhiza on phosphorus uptake in Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore.

caledonicum (16.20 mg/plant) and uninoculated plants (10.54 mg/plant) had the low root P content. These three treatments did not differ significantly from each other.

MICRONUTRIENT ANALYSIS

Iron content

Iron uptake in plants due to VA mycorrhizal inoculation was estimated separately for shoot and root and the total iron content of the plant was determined.

Shoot Iron content

Maximum iron content in shoot was observed in plants inoculated with Gigaspora margarita (2.842 mg/plant) followed by plants inoculated with Glomus monosporum (2.691 mg/plant), Glomus fasciculatum (2.606 mg/plant) and Glomus mosseae (2.534 mg/plant). These four treatments were statistically on par with each other but differed significantly from other treatments (Table 6). Untreated plants had the lowest iron content in shoot (1.479 mg/plant).

Root Iron content

Most of the inoculated plants had significantly higher iron content in root compared to control plants (Table 6). Plants inoculated with Gigaspora margarita had the maximum root iron content (0.612 mg/plant) which differed significantly from other treatments. The lowest root iron content was observed in uninoculated plants (0.174 mg/plant).

Table - 6

Influence of VA mycorrhiza on iron content in Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore

Sl No	Inoculation treatment	Iron content (mg/plant)		
		Shoot	Root	Total
1.	Acaulospora laevis	2.399 efgh	0.381de	2.780 efg
2.	Gigaspora calospora	1.918 bc	0.266 b	2.184 bc
3.	Gigaspora margarita	2.842 i	0.612 h	3.454 i
4.	Glomus caledonicum	1.827 b	0.261 b	2.088 b
5.	Glomus deserticola	2.257 defg	0.350 cde	2.607 def
6.	Glomus etunicatum	2.018 bcd	0.282 bc	2.300 bcd
7.	Glomus fasciculatum	2.606 hi	0.476 fg	3.082 gh
8.	Glomus intraradices	2.470 fgh	0.388 de	2.858 fg
9.	Glomus leptotichum	2.178 cdef	0.321 bcd	2.499 cde
10.	Glomus macrocarpum	2.208 cdef	0.338 bcde	2.546 def
11.	Glomus monosporum	2.691 hi	0.533 g	3.224 hi
12.	Glomus mosseae	2.534 ghi	0.414 ef	2.948 gh
13.	Glomus versiformae	2.106 bcde	0.298 bc	2.404 bcd
14.	Uninoculated	1.479 a	0.174 a	1.653 a
	SEM ±	0.112	0.026	0.116
	CD (0.05)	0.325	0.077	0.337
	CV%	8.597	12.538	7.666

Note:- As in table 1

Total Iron content

The total iron content of cardamom plants as influenced by different VA mycorrhizal fungi is given in table 6. In general, inoculated plants had significantly higher iron content than the uninoculated plants. cardamom plants inoculated with Gigaspora margarita (3.454 mg/plant) and Glomus monosporum (3.224 mg/plant) had the highest iron content compared to other VA mycorrhizal treatments. Uninoculated plants had the lowest total iron content (1.653 mg/plant).

Copper content

The copper content in shoot and root was estimated separately and then added to get total copper content of the plant.

Shoot Copper content

Gigaspora margarita, Glomus monosporum and Glomus fasciculatum inoculation resulted in increased uptake of copper in the shoot of cardamom plants though the maximum was observed in plants inoculated with Gigaspora margarita (0.203 mg/plant) (Table 7). By and large all the VA mycorrhizal fungi increased the shoot copper content significantly compared to the uninoculated control plants (0.077 mg/plant).

Root Copper content

Mycorrhizal inoculation significantly increased the copper content in root compared to control (Table 7). Gigaspora margarita inoculation was found to be the best

Table - 7

Influence of VA mycorrhiza on copper content in Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore

Sl No	Inoculation treatment	Copper content (mg/plant)		
		Shoot	Root	Total
1.	Acaulospora laevis	0.159 fgh	0.024 efg	0.183 fg
2.	Gigaspora calospora	0.109 bc	0.016 bc	0.125 bc
3.	Gigaspora margarita	0.203 j	0.039 j	0.242 j
4.	Glomus caledonicum	0.098 b	0.014 ab	0.112 b
5.	Glomus deserticola	0.146 efg	0.022 defg	0.168 ef
6.	Glomus etunicatum	0.120 cd	0.018 bcd	0.138 cd
7.	Glomus fasciculatum	0.185 ij	0.031 hi	0.216 hi
8.	Glomus intraradices	0.163 gh	0.025 fg	0.188 fg
9.	Glomus leptotichum	0.131 de	0.020 cdef	0.151 de
10.	Glomus macrocarpum	0.139 def	0.021 cdefg	0.160 de
11.	Glomus monosporum	0.193 ij	0.033 i	0.226 ij
12.	Glomus mosseae	0.177 hi	0.026 gh	0.203 gh
13.	Glomus versiformae	0.126 cde	0.019 bcde	0.145 cd
14.	Uninoculated	0.077 a	0.009 a	0.086 a
	SEM ±	0.007	0.002	0.008
	CD (0.05)	0.020	0.005	0.022
	CV%	8.225	13.376	7.868

Note:- As in table 1

resulting in maximum copper content in root (0.039 mg/plant). Uninoculated plants had the least content of copper in root (0.009 mg/plant).

Total Copper content

In general the total copper content was high in VA mycorrhizal inoculated plants compared to control (Table 7). Maximum plant copper content was found in plants inoculated with Gigaspora margarita (0.242 mg/plant) followed by Glomus monosporum (0.226 mg/plant) both being statistically on par with each other. Among the different VA mycorrhizal fungi the low plant copper content was found in plants inoculated with Gigaspora calospora (0.125 mg/plant) and Glomus caledonicum (0.112 mg/plant). The least copper content was recorded in uninoculated control plants (0.086 mg/plant).

Zinc content

Zinc content in shoot and root of cardamom plants was estimated separately and the total zinc content of the plant was computed.

Shoot Zinc content

Maximum zinc content in shoot was found in plants inoculated with Gigaspora margarita (0.580 mg/plant) followed by Glomus monosporum (0.552 mg/plant), Glomus fasciculatum (0.527 mg/plant) and Glomus mosseae (0.502 mg/plant) treated plants. These four fungi were statistically on par with each other but differed

Table - 8

Influence of VA mycorrhiza on zinc content in Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore

Sl No	Inoculation treatment	Zinc content (mg/plant)		
		Shoot	Root	Total
1.	Acaulospora laevis	0.477 efgh	0.073 def	0.550 fg
2.	Gigaspora calospora	0.349 bc	0.045 ab	0.394 bc
3.	Gigaspora margarita	0.580 i	0.136 i	0.716 j
4.	Glomus caledonicum	0.326 ab	0.045 ab	0.371 b
5.	Glomus deserticola	0.451 defg	0.064 cde	0.515 efg
6.	Glomus etunicatum	0.376 bcd	0.052 bc	0.428 bcd
7.	Glomus fasciculatum	0.527 ghi	0.102 gh	0.629 hi
8.	Glomus intraradices	0.494 efgh	0.080 ef	0.574 gh
9.	Glomus leptotichum	0.417 cde	0.061 bcd	0.478 def
10.	Glomus macrocarpum	0.432 def	0.062 bcde	0.494 def
11.	Glomus monosporum	0.552 hi	0.111 h	0.663 ij
12.	Glomus mosseae	0.502 fghi	0.084 fg	0.586 gh
13.	Glomus versiformae	0.398 bcd	0.053 bc	0.451 cde
14.	Uninoculated	0.249 a	0.028 a	0.277 a
	SEM ±	0.027	0.006	0.026
	CD (0.05)	0.078	0.018	0.074
	CV%	10.624	14.817	8.698

Note:- As in table 1

significantly from other treatments (Table 8). The least shoot zinc content was recorded in uninoculated plants (0.249 mg/plant).

Root Zinc content

Cardamom plants inoculated with Gigaspora margarita had the maximum zinc uptake in root (0.136 mg/plant), which differed significantly from other treatments (Table 8). Gigaspora calospora and Glomus caledonicum performed equally and had the lowest zinc content in root (0.045 mg/plant). Uninoculated plants had the least root zinc content (0.028 mg/plant).

Total Zinc content

In general VA mycorrhiza inoculated plants had higher zinc content compared to control. Significant differences were noticed between the treatments (Table 8). The top three fungi which enhanced the uptake of zinc in plants were Gigaspora margarita (0.716 mg/plant), Glomus monosporum (0.663 mg/plant) and Glomus fasciculatum (0.629 mg/plant). The lowest zinc content was observed in uninoculated control plants (0.277 mg/plant).

VA mycorrhizal spore count

More number of VA mycorrhizal spores were encountered in the root zone of inoculated plants compared to uninoculated plants (Table 9). Maximum number of spores occured in the root zone soil of cardamom plants inoculated with Gigaspora margarita (95/25ml) followed by

Table - 9

VA mycorrhizal spore numbers in the root zone and percent mycorrhizal root colonization in Cv. Malabar of cardamom - primary screening conducted at GKVK, UAS, Bangalore

Sl No	Inoculation treatment	Spore count (per 25 ml soil)	Percent colonization
1.	*Acaulospora laevis*	71 gh	43.3 efg
2.	*Gigaspora calospora*	47 bc	25.0 b
3.	*Gigaspora margarita*	95 i	58.3 i
4.	*Glomus caledonicum*	44 b	21.7 ab
5.	*Glomus deserticola*	64 efg	41.7 efg
6.	*Glomus etunicatum*	52 bcd	28.3 bc
7.	*Glomus fasciculatum*	80 h	50.0 ghi
8.	*Glomus intraradices*	76 h	45.0 efg
9.	*Glomus leptotichum*	59 def	36.7 cde
10.	*Glomus macrocarpum*	62 defg	40.0 ef
11.	*Glomus monosporum*	93 i	55.0 hi
12.	*Glomus mosseae*	78 h	46.7 fgh
13.	*Glomus versiformae*	54 bcde	30.0 bcd
14.	Uninoculated	24 a	13.3 a
	SEM ±	3.82	3.23
	CD (0.05)	11.10	9.38
	CV%	10.30	14.62

Note:- As in table 1

Glomus monosporum (93/25 ml). The least number of chlamydospores occured in the rootzone of uninoculated plants (24/25ml).

Percent VA mycorrhizal colonization

Similar to spore numbers maximum root colonization was observed in plants inoculated with Gigaspora margarita (58.3%) followed by Glomus monosporum (55.0%) and Glomus fasciculatum (50.0%) (Table 9). These three treatments were statistically on par with each other but differed significantly from other treatments. In general inoculated plants had significantly higher percentage of mycorrhizal colonization compared to uninoculated control plants (13.3%). Among the different VA mycorrhizal treatments, the lowest root colonization occured in plants inoculated with Glomus caledonicum (21.7%).

SECONDARY SCREENING TRIALS

In order to select an efficient VA mycorrhizal fungus for inoculating cardamom in the nursery, six promising VA mycorrhizal fungi obtained from primary screening trial and the predominant native VAM fungi isolated from the root zone of cardamom grown in different regions of South India were tested in the secondary screening trials. These trials were conducted in cardamom growing areas of South India having varied agroclimatic conditions. The results of these trials are presented below :

Secondary screening trial at Sakleshpur

This trial was conducted at Regional research station, spices Board, Sakleshpur, Karnataka. In this trial the response of Malabar Cultivar of cardamom to nine different strains of VA mycorrhizal fungi was tested. The results obtained are as follows :

Plant biometric observations

Plant height

Inoculation with different VA mycorrhizal fungi influenced the plant height significantly at all the three stages of plant growth viz., 3, 6 and 9 months after transplanting (Table 10; Fig.5). All the inoculated plants grew taller than the uninoculated plants. Nine months after transplanting, plants inoculated with Glomus monosporum showed maximum plant height (87.0 cm) which differed significantly from all other treatments. Next to Glomus monosporum plants inoculated with Glomus mosseae (83.0 cm) and Glomus fasciculatum (81.0 cm) proved best in improving the plant height both being statistically on par with each other. Among the native strains Glomus fasciculatum (S_2) (76.0 cm) was found to be the best in improving the plant height. The lowest plant height was seen in uninoculated plants (65.0 cm).

Number of leaves

The number of leaves produced differed significantly with VA mycorrhizal treatments (Table 11). Nine months after transplanting, plants inoculated with

Table - 10

Influence of VA mycorrhiza on plant height of Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka

Sl No	Inoculation treatment	Plant height (cm) - MAT*		
		3M *	6 M *	9 M *
1.	Acaulospora laevis	24.0 cd	54.0 bcd	73.0 cd
2.	Gigaspora margarita	26.0 ef	57.5 def	80.4 fg
3.	Glomus fasciculatum	26.5 f	58.3 ef	81.0 g
4.	Glomus intraradices	25.6 def	56.4 cde	77.0 ef
5.	Glomus monosporum	28.5 g	61.0 f	87.0 h
6.	Glomus mosseae	27.2 fg	59.0 ef	83.0 g
7.	Glomus fasciculatum (S_2)	24.7 cde	55.5 cde	76.0 de
8.	Glomus sp. (S_1)	23.4 bc	53.2 bc	70.0 bc
9.	Glomus sp. (S_9)	22.3 b	51.0 ab	68.0 ab
10.	Uninoculated	17.8 a	48.5 a	65.0 a
	SEM ±	0.58	1.45	1.32
	CD (0.05)	1.61	4.03	3.67
	CV%	10.57	11.73	7.78

Note:- As in table 1

Plate 3. Response of Cardamom Cv. Malabar to inoculation with *Glomus mosporum* - Secondary screening conducted at Sakleshpur, Karnataka

Notations:-

4 = *Glomus monosporum*

C = Uninoculated control

(a) Shoot

(b) Root


CARDAMOM x VAM
(Cv. MALABAR)
4
C


CARDAMOM x VAM
(Cv. MALABAR)
4
C

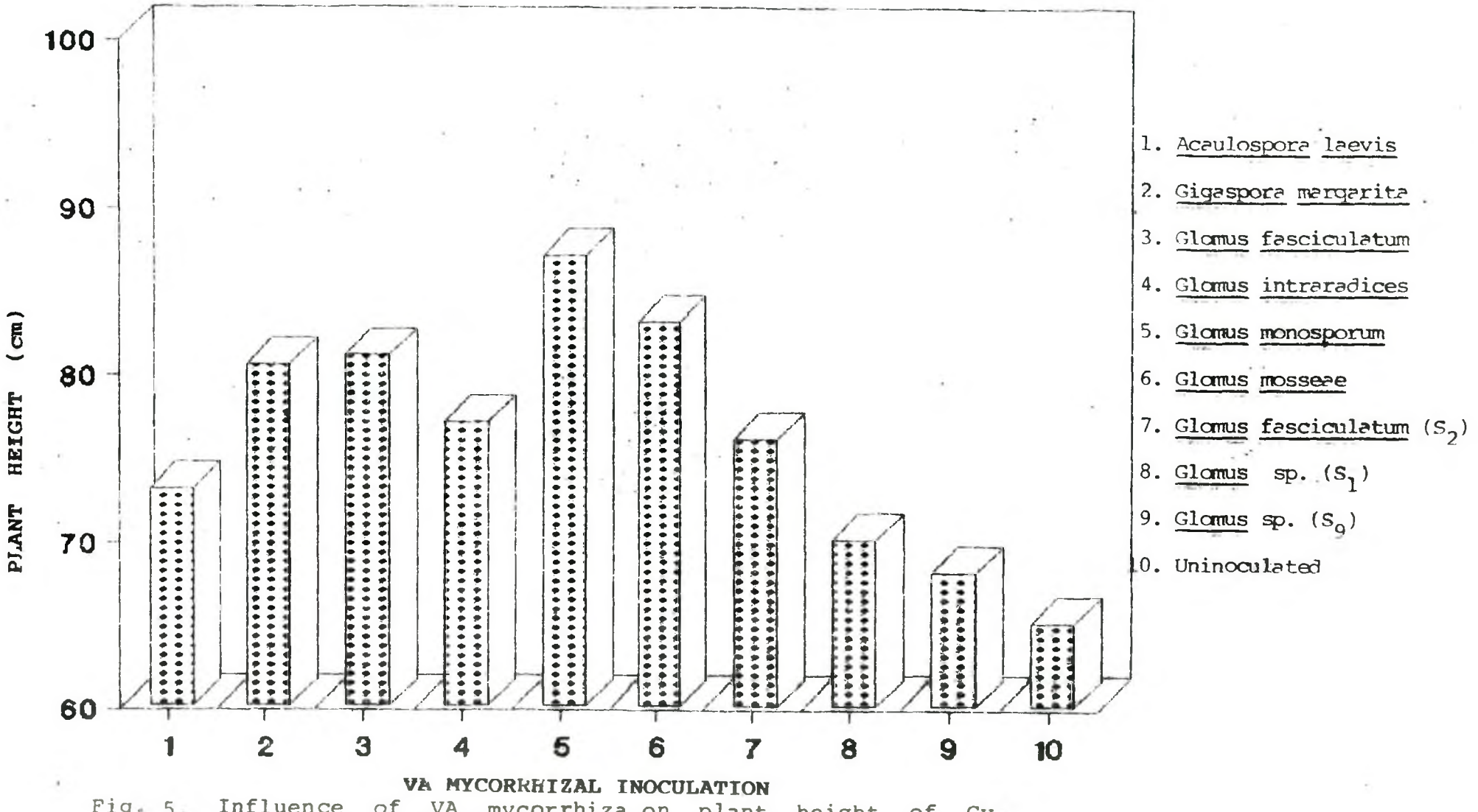


Fig. 5. Influence of VA mycorrhiza on plant height of Cv. Malabar of cardamom at 9 months after transplanting - secondary screening conducted at Sakleshpur, Karnataka.

Table - 11

Influence of VA mycorrhiza on the number of leaves in Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka

Sl No	Inoculation treatment	Number of leaves/Pl^{-1} - MAT*		
		3 M*	6 M*	9 M*
1.	Acaulospora laevis	5.6 bc	9.0 abc	10.8 b
2.	Gigaspora margarita	6.0 de	9.4 cde	11.5 de
3.	Glomus fasciculatum	6.2 ef	9.5 cde	11.6 de
4.	Glomus intraradices	6.0 de	9.2 bcd	11.3 cd
5.	Glomus monosporum	6.4 f	9.8 e	12.1 f
6.	Glomus mosseae	6.3 f	9.6 de	11.8 ef
7.	Glomus fasciculatum (S_2)	5.8 cd	9.1 bcd	10.9 bc
8.	Glomus sp. (S_1)	5.5 b	8.8 ab	10.7 b
9.	Glomus sp. (S_9)	5.4 b	8.7 ab	10.0 a
10.	Uninoculated	5.1 a	8.5 a	9.6 a
	SEM ±	0.08	0.19	0.17
	CD (0.05)	0.23	0.52	0.48
	CV%	6.28	9.13	7.02

Note:- As in table 1

Glomus monosporum (12.1) and Glomus mosseae (11.8) had the maximum number of leaves compared to other treatments. Among the promising isolates from primary screening, plants inoculated with Acaulospora laevis produced the lowest number of leaves per plant (10.8). Uninoculated plants had the least number of leaves (9.6).

Leaf area

The leaf area was determined on the day of harvest i.e., 9 months after transplanting (Table 12). Maximum leaf area was observed in plants inoculated with Glomus monosporum (148.6 cm^2), Glomus mosseae (136.9 cm^2), Glomus fasciculatum (135.7 cm^2) and Gigaspora margarita (135.6 cm^2). These four values did not differ significantly from each other. The least leaf area was recorded in uninoculated plants (105.7 cm^2).

Number of tillers per plant

Maximum number of tillers were observed in plants inoculated with Glomus monosporum (2.0) followed by Glomus mosseae (1.9) both being statistically on par with each other (Table 12; Fig.6). Significant difference in tiller production was observed between the treatments. Uninoculated plants produced the lowest number of tillers per plant (1.0).

Root length

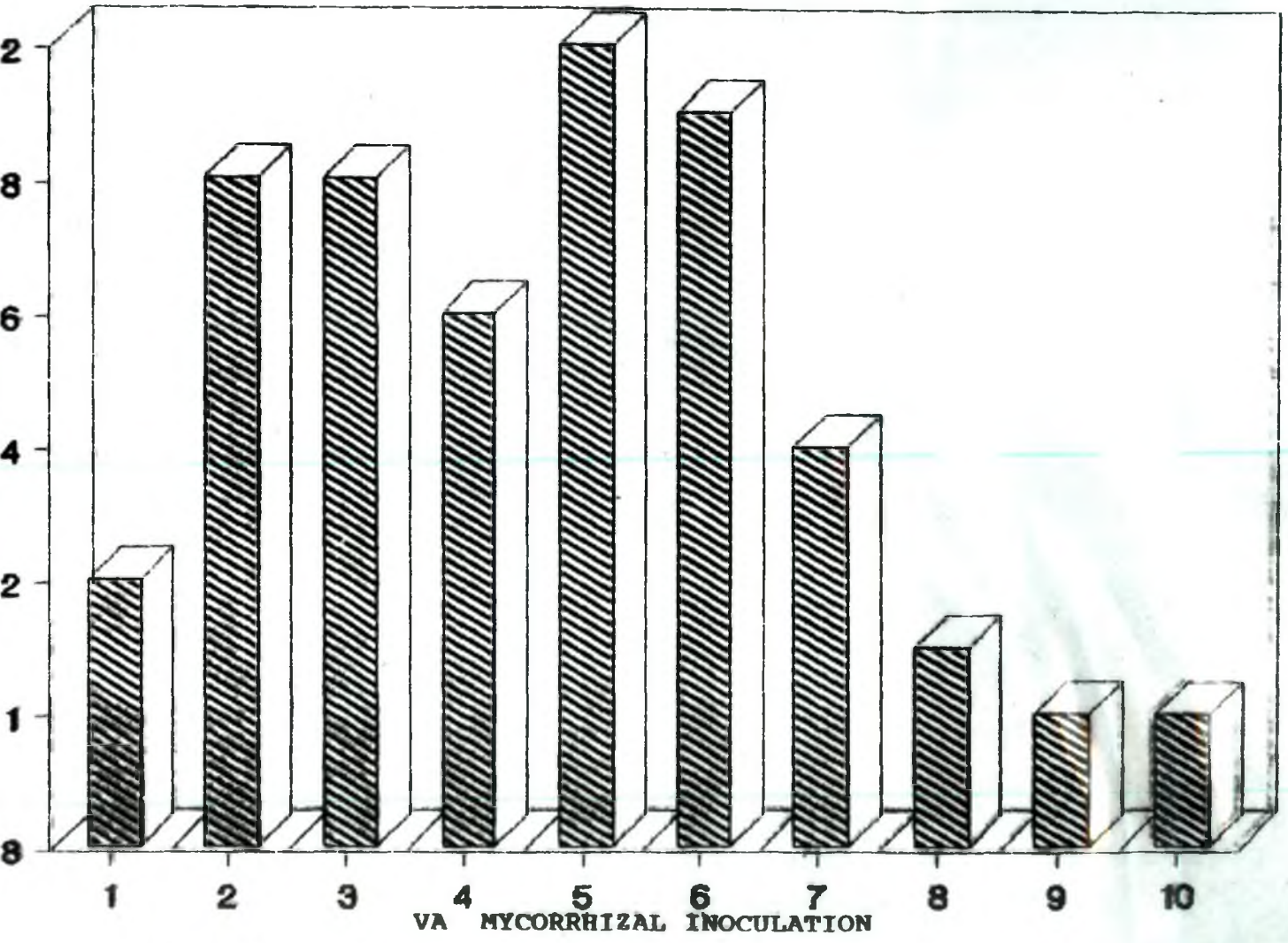
Root length was maximum in plants inoculated with Glomus monosporum (42.6 cm) followed by plants inoculated

Table - 12

Influence of VA mycorrhiza on leaf area, number of tillers and root length in Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka

Sl No	Inoculation treatment	Growth parameters - 9 MAT		
		Leafarea (cm^2)	No of tillers per plant	Root length (cm)
1.	*Acaulospora laevis*	125.9 bc	1.2 b	26.1 cd
2.	*Gigaspora margarita*	135.6 cd	1.8 e	30.0 e
3.	*Glomus fasciculatum*	135.7 cd	1.8 e	34.3 f
4.	*Glomus intraradices*	130.2 bc	1.6 d	28.6 de
5.	*Glomus monosporum*	148.6 d	2.0 f	42.6 h
6.	*Glomus mosseae*	136.9 cd	1.9 ef	38.1 g
7.	*Glomus fasciculatum* (S_2)	128.1 bc	1.4 c	27.4 de
8.	*Glomus* sp. (S_1)	124.6 bc	1.1 ab	24.5 bc
9.	*Glomus* sp. (S_9)	120.3 ab	1.0 a	23.3 b
10.	Uninoculated	105.7 a	1.0 a	20.0 a
	SEM ±	5.46	0.06	0.96
	CD (0.05)	15.13	0.17	2.66
	CV%	18.89	18.25	14.55

Note:- As in table 1



1. Acaulospora laevis
2. Gigaspora margarita
3. Glomus fasciculatum
4. Glomus intraradices
5. Glomus monosporum
6. Glomus mossee
7. Glomus fasciculatum (S_2)
8. Glomus sp. (S_1)
9. Glomus sp. (S_9)
10. Uninoculated

Fig. 6. Influence of VA mycorrhiza on number of tillers in Cv. Malabar of cardamom at 9 months after transplanting - secondary screening conducted at Sakleshpur, Karnataka.

with Glomus mosseae (38.1 cm) and Glomus fasciculatum (34.3 cm) (Table 12). All the above three treatments differed significantly from each other and from other treatments. In general inoculated plants had more root length and differed significantly from the uninoculated plants which had the shortest root length (20.0 cm).

Plant dry weight

The shoot and root dry weight of cardamom plants were estimated separately after drying to a constant weight and then both were added to get total plant dry weight.

Shoot dry weight

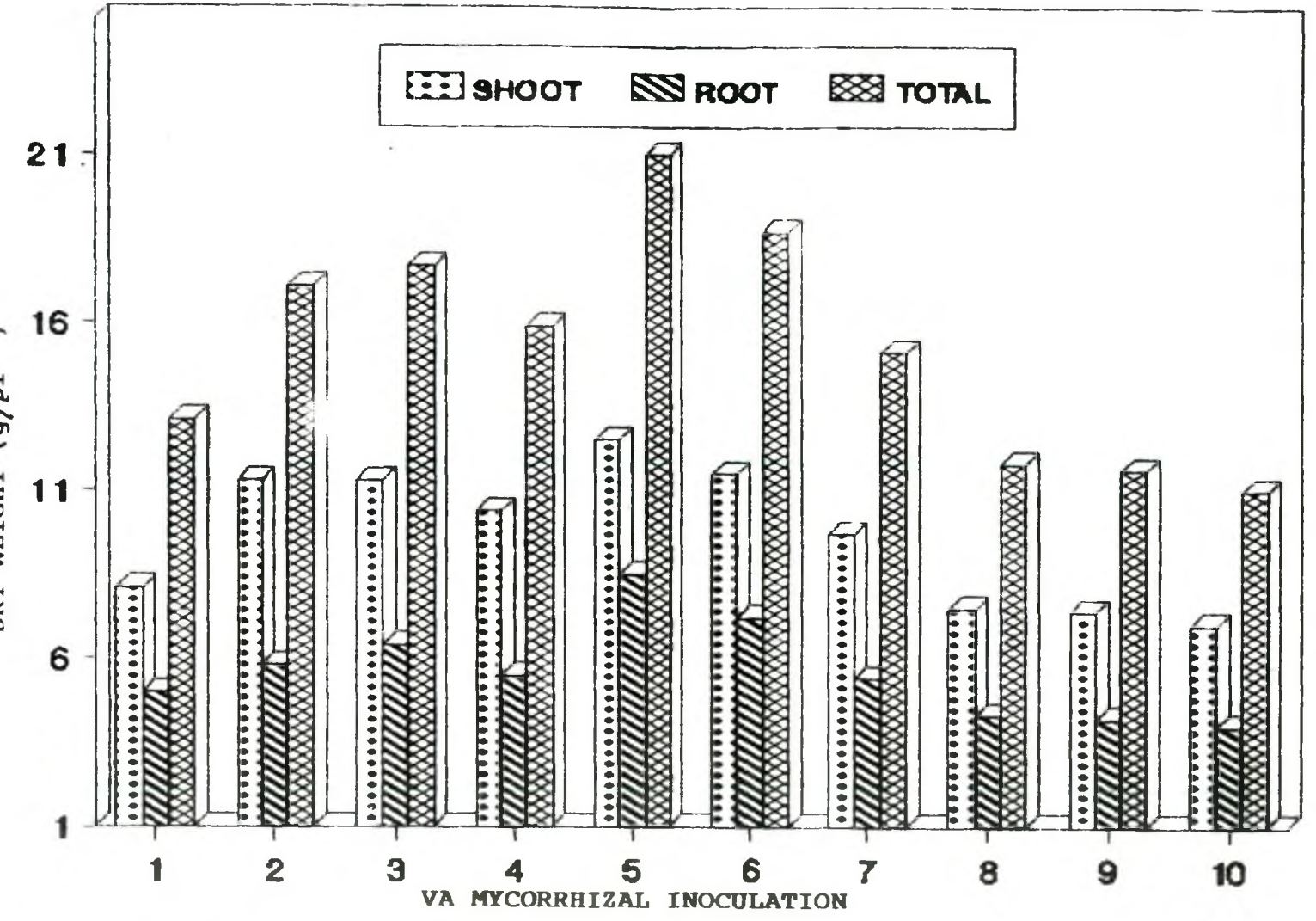
Maximum shoot biomass was recorded in plants inoculated with Glomus monosporum (12.5 g/plant) followed by plants inoculated with Glomus mosseae (11.5 g/plant). Next to these two treatments, Glomus fasciculatum and Gigaspora margarita inoculated plants performed equally in improving the plant shoot dry weight (11.3 g/plant) (Table 13; Fig.7). These four treatments were statistically on par with each other but differed significantly from uninoculated control plants. Lowest shoot dry weight was recorded in plants inoculated with Acaulospora laevis (8.1 g/plant), native VA mycorrhizal isolates Glomus sp S_1 and S_9 (7.5 and 7.4 g/plant respectively) and in uninoculated plants (7.0 g/plant). These four treatments did not differ significantly from each other.

Table - 13

Influence of VA mycorrhiza on dry weight of Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka

Sl No	Inoculation treatment	Dry Weight (g/pl^{-1})		
		Shoot	Root	Total
1.	*Acaulospora laevis*	8.1 a	5.0 bc	13.1 b
2.	*Gigaspora margarita*	11.3 cd	5.8 cd	17.1 de
3.	*Glomus fasciculatum*	11.3 cd	6.4 de	17.7 e
4.	*Glomus intraradices*	10.4 bc	5.5 cd	15.9 cd
5.	*Glomus monosporum*	12.5 d	8.5 f	21.0 f
6.	*Glomus mosseae*	11.5 cd	7.2 e	18.7 e
7.	*Glomus fasciculatum* (S_2)	9.7 b	5.4 c	15.1 c
8.	*Glomus* sp. (S_1)	7.5 a	4.3 ab	11.8 ab
9.	*Glomus* sp. (S_9)	7.4 a	4.2 ab	11.6 ab
10.	Uninoculated	7.0 a	4.0 a	11.0 a
	SEM ±	0.51	0.31	0.57
	CD (0.05)	1.50	0.93	1.69
	CV %	9.06	9.67	6.44

Note:- As in table 1



1. Acaulospora laevis
2. Gigaspora margarita
3. Glomus fasciculatum
4. Glomus intraradices
5. Glomus monosporum
6. Glomus mosseae
7. Glomus fasciculatum (S_2)
8. Glomus sp. (S_1)
9. Glomus sp. (S_9)
10. Uninoculated

Fig. 7. Influence of VA mycorrhiza on dry weight of Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka.

Root dry weight

Maximum root dry weight was observed in plants inoculated with Glomus monosporum (8.5 g/plant). The next best VA mycorrhizal fungi which improved the root dry weight were Glomus mosseae (7.2 g/plant) and Glomus fasciculatum (6.4 g/plant) (Table 13; Fig.7). These three treatments differed significantly from each other and from other treatments. Plants inoculated with native VA mycorrhizal fungi Glomus sp S_1 and S_9 had lower root dry weights (4.3 and 4.2 g/plant respectively).The least root dry weight was observed in uninoculated control plants (4.0 g/plant).

Total plant dry weight

Plants inoculated with different VA mycorrhizal fungi varied significantly with respect to total plant biomass (Table 13; Fig.7). Glomus monosporum inoculation resulted in obtaining plant biomass to the maximum extent (21.0 g/plant) which was significantly superior over all other treatments. Inoculation of plants with Glomus mosseae (18.7g/plant) and Glomus fasciculatum (17.7 g/plant) were the next best treatments in improving the total plant biomass. Among the native strains Glomus fasciculatum (S_2) (15.1 g/plant) was found to be the best. The lowest plant biomass was recorded in uninoculated plants (11.0 g/plant).

Phosphorus uptake

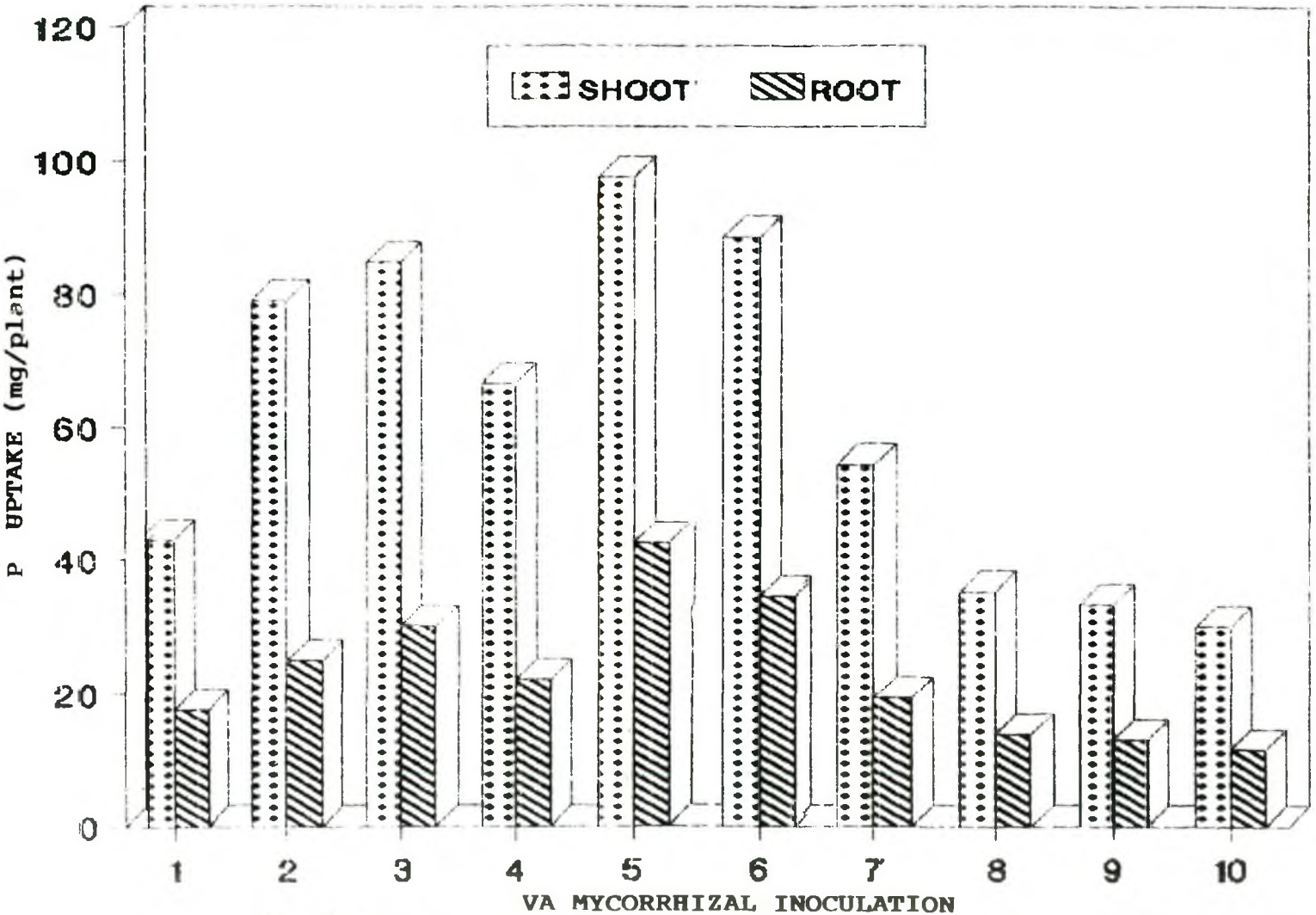
The phosphorus content of the shoot and root was determined separately.

Table - 14

Influence of VA mycorrhiza on phosphorus uptake and content in Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka

Sl No	Inoculation treatment	P uptake			
		Shoot		Root	
		% P	mg/plant	% P	mg/plant
1.	Acaulospora laevis	0.53 bc	42.93 ab	0.35 abc	17.50 bc
2.	Gigaspora margarita	0.70 ef	79.10 d	0.43 de	24.94 de
3.	Glomus fasciculatum	0.75 f	84.75 de	0.47 ef	30.08 ef
4.	Glomus intraradices	0.64 de	66.56 c	0.40 cd	22.00 cd
5.	Glomus monosporum	0.78 f	97.50 e	0.50 f	42.50 g
6.	Glomus mosseae	0.77 f	88.55 de	0.48 ef	34.56 f
7.	Glomus fasciculatum (S_2)	0.56 cd	54.32 bc	0.36 bc	19.44 cd
8.	Glomus sp. (S_1)	0.47 ab	35.25 a	0.32 ab	13.76 ab
9.	Glomus sp. (S_9)	0.45 ab	33.30 a	0.31 ab	13.02 ab
10.	Uninoculated	0.43 a	30.10 a	0.29 a	11.60 a
	SEM ±	0.03	4.35	0.02	1.90
	CD (0.05)	0.08	12.94	0.06	5.64
	CV%	7.21	12.31	8.77	14.32

Note:- As in table 1



. Acaulospora laevis
2. Gigaspora margarita
3. Glomus fasciculatum
4. Glomus intraradices
5. Glomus monosporum
6. Glomus [illegible] seae
7. Glomus fasciculatum (S_2)
8. Glomus sp. (S_1)
9. Glomus sp. (S_9)
10. Uninoculated

Fig. 8. Influence of VA mycorrhiza on phosphorus uptake in Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka.

Shoot phosphorus

In general, inoculated plants had higher shoot P content than uninoculated plants (Table 14; Fig.8). Maximum shoot P was recorded in plants inoculated with Glomus monosporum (97.50 mg/plant). Next best VA mycorrhizal fungi for improving shoot P content were Glomus mosseae (88.55 mg/plant) and Glomus fasciculatum (84.75 mg/plant). These three treatments were statistically on par with each other but differed significantly from other treatments. The lowest shoot P was recorded in uninoculated plants (30.10 mg/plant).

Root phosphorus

Phosphorus content in root was highest in plants inoculated with Glomus monosporum (42.50 mg/plant) which significantly differed from all other treatments (Table 14; Fig. 8). Plants inoculated with Glomus mosseae (34.56 mg/plant) and Glomus fasciculatum (30.08 mg/plant) were the next best treatments and were statistically on par with each other. Uninoculated plants had the lowest root phosphorus content (11.60 mg/plant).

MICRONUTRIENT ANALYSIS

Similar to primary screening, iron, copper and zinc content in shoot and root were estimated separately and the content of each micronutrient present in shoot and root was added to get the total content of a particular micronutrient in a plant.

Shoot Iron content

Mycorrhizal inoculation in plants resulted in higher iron content in shoot compared to uninoculated control. All the promising isolates of primary screening except Acaulospora laevis resulted in significantly more iron content in shoot compared to plants inoculated with native isolates (Table 15). Maximum iron content in shoot was recorded in plants inoculated with Glomus monosporum (2.413 mg/plant). The lowest iron content in shoot was observed in uninoculated plants (1.176 mg/plant) which was statistically on par with the shoot iron content of plants inoculated with native VA mycorrhizal fungi Glomus sp S_1. Glomus sp S_9 and Acaulospora laevis.

Root Iron content

Similar to shoot the uptake of iron in root was high in all the inoculated plants compared to the control plants (Table 15). Except Acaulospora laevis all the exotic strains (promising isolates) performed better in improving the root iron content compared to the native strains. Maximum root iron content was recorded in plants inoculated with Glomus monosporum (0.604 mg/plant) which differed significantly from all other treatments. Uninoculated plants had the least iron content in root (0.228 mg/plant).

Total Iron content

In general, inoculated plants had higher iron content than the uninoculated plants (Table 15). Maximum iron content was recorded in plants inoculated with Glomus

Table - 15

Influence of VA mycorrhiza on iron content in Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka

Sl No	Inoculation treatment	Iron content (mg/plant)		
		Shoot	Root	Total
1.	*Acaulospora laevis*	1.434 ab	0.315 bc	1.749 bc
2.	*Gigaspora margarita*	2.102 de	0.394 de	2.496 ef
3.	*Glomus fasciculatum*	2.124 de	0.448 e	2.572 ef
4.	*Glomus intraradices*	1.893 cd	0.363 cd	2.256 de
5.	*Glomus monosporum*	2.413 e	0.604 g	3.017 g
6.	*Glomus mosseae*	2.208 de	0.511 f	2.719 fg
7.	*Glomus fasciculatum* (S_2)	1.727 bc	0.351 cd	2.078 cd
8.	*Glomus* sp. (S_1)	1.298 a	0.258 ab	1.556 ab
9.	*Glomus* sp. (S_9)	1.265 a	0.248 a	1.513 ab
10.	Uninoculated	1.176 a	0.228 a	1.404 a
	SEM ±	0.112	0.020	0.112
	CD (0.05)	0.332	0.060	0.332
	CV %	10.981	9.475	9.069

Note:- As in table 1

monosporum (3.017 mg /plant) followed by Glomus mosseae (2.719 mg/plant) both being statistically on par with each other, but differed significantly from other treatments. Uninoculated plants had the lowest plant iron content (1.404 mg/plant).

Shoot Copper content

Plants inoculated with different VA mycorrhizal fungi varied significantly with respect to copper content in the shoot (Table 16). Shoot copper content was maximum in plants inoculated with Glomus monosporum (0.173 mg/plant) followed by Glomus mosseae (0.152 mg/plant). These two treatments were statistically on par with each other but differed significantly from other treatments. Among all the treatments the lowest copper content in shoot was observed in uninoculated plants (0.063 mg/plant).

Root Copper content

Glomus monosporum inoculation resulted in maximum uptake of copper in root (0.038 mg/plant) which differed significantly from all other treatments (Table 16). The lowest root copper content was recorded in uninoculated plants (0.012 mg/plant).

Total Copper content

Promising isolates from primary screening were found to be more efficient in improving the total plant copper content than the native fungi (Table 16). Plants inoculated with Glomus monosporum resulted in maximum uptake of copper in plants (0.211 mg/plant) which differed

Table - 16

Influence of VA mycorrhiza on copper content in Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka

Sl No	Inoculation treatment	Copper content (mg/plant)		
		Shoot	Root	Total
1.	*Acaulospora laevis*	0.085 ab	0.019 bc	0.104 b
2.	*Gigaspora margarita*	0.141 de	0.023 cd	0.164 de
3.	*Glomus fasciculatum*	0.145 de	0.026 d	0.171 e
4.	*Glomus intraradices*	0.125 cd	0.021 c	0.146 cd
5.	*Glomus monosporum*	0.173 f	0.038 f	0.211 f
6.	*Glomus mosseae*	0.152 ef	0.032 e	0.184 e
7.	*Glomus fasciculatum* (S_2)	0.107 bc	0.021 c	0.128 c
8.	*Glomus* sp. (S_1)	0.071 a	0.015 ab	0.086 ab
9.	*Glomus* sp. (S_9)	0.070 a	0.013 a	0.083 ab
10.	Uninoculated	0.063 a	0.012 a	0.075 a
	SEM ±	0.008	0.001	0.007
	CD (0.05)	0.023	0.004	0.022
	CV %	11.622	10.094	9.450

Note:- As in table 1

significantly from other treatments. The next best treatments were plants inoculated with Glomus mosseae (0.184 mg/plant), Glomus fasciculatum (0.171 mg/plant) and Gigaspora margarita (0.164 mg/plant). These three treatments were statistically on par with each other but differed significantly from other treatments. The lowest plant copper content was observed in uninoculated plants(0.075 mg/plant).

Shoot Zinc content

All the promising isolates from primary screening, except Acaulospora laevis, performed better in improving the zinc content in shoot compared to native VA mycorrhizal fungi (Table 17). Maximum shoot zinc content was recorded in plants inoculated with Glomus monosporum (0.500 mg/plant) and the lowest in uninoculated control plants (0.210 mg/plant).

Root Zinc content

Similar to shoot, inoculated plants had more zinc content in root compared to uninoculated plants (Table 17). Zinc content in root was maximum in plants inoculated with Glomus monosporum (0.128 mg/plant) which differed significantly from all other treatments. The next best fungi in improving root zinc content were Glomus mosseae (0.101 mg/plant) and Glomus fasciculatum (0.083 mg/plant). The lowest zinc content in root was observed in uninoculated plants (0.040 mg/plant).

Table - 17

Influence of VA mycorrhiza on zinc content in Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka

Sl No	Inoculation treatment	Zinc content (mg/plant)		
		Shoot	Root	Total
1.	*Acaulospora laevis*	0.284 ab	0.060 bcd	0.344 bc
2.	*Gigaspora margarita*	0.429 de	0.075 ef	0.504 ef
3.	*Glomus fasciculatum*	0.441 de	0.083 f	0.524 ef
4.	*Glomus intraradices*	0.385 cd	0.072 def	0.457 de
5.	*Glomus monosporum*	0.500 e	0.128 h	0.628 g
6.	*Glomus mosseae*	0.449 de	0.101 g	0.550 fg
7.	*Glomus fasciculatum* (S_2)	0.349 bc	0.065 cde	0.414 cd
8.	*Glomus* sp. (S_1)	0.255 a	0.052 abc	0.307 ab
9.	*Glomus* sp. (S_9)	0.244 a	0.046 ab	0.290 ab
10.	Uninoculated	0.210 a	0.040 a	0.250 a
	SEM ±	0.026	0.005	0.027
	CD (0.05)	0.076	0.014	0.081
	CV %	12.523	11.485	11.035

Note:- As in table 1

Total Zinc content

Most of the promising VA mycorrhizal fungi selected from primary screening significantly improved the plant zinc uptake compared to native VA mycorrhizal fungi (Table 17). The fungi which resulted in maximum uptake of zinc were Glomus monosporum (0.628 mg/plant) and Glomus mosseae (0.550 mg/plant) both being statistically on par with each other. Uninoculated plants had the lowest plant zinc content (0.250 mg/plant).

VA mycorrhizal spore count

The mycorrhizal spore count in the cardamom root zone soil as influenced by inoculation with different VA mycorrhizal fungi is shown in table 18. Maximum spore count was recorded in the root zone of plants inoculated with Glomus monosporum (84/25 ml) followed by Glomus mosseae (79/25 ml) and Glomus fasciculatum (76/25 ml), all the three being statistically on par with each other but differed significantly from other treatments. The lowest spore count was recorded in the rhizosphere of uninoculated plants (26/25 ml).

Percent VA mycorrhizal colonization

Inoculated plants had higher percentage mycorrhizal root colonization compared to the uninoculated plants (Table 18). Root colonization was maximum in plants inoculated with Glomus monosporum (53.3%) followed by Glomus mosseae (46.7%) inoculated plants both being statistically on par

Table - 18

VA mycorrhizal spore numbers in the root zone and percent mycorrhizal root colonization in Cv. Malabar of cardamom - secondary screening conducted at Sakleshpur, Karnataka

Sl No	Inoculation treatment	Spore count (per 25 ml soil)		Percent colonization	
1.	*Acaulospora laevis*	52	bc	25.0	bc
2.	*Gigaspora margarita*	68	de	36.7	de
3.	*Glomus fasciculatum*	76	ef	40.0	ef
4.	*Glomus intraradices*	63	d	31.7	cd
5.	*Glomus monosporum*	84	f	53.3	g
6.	*Glomus mosseae*	79	f	46.7	fg
7.	*Glomus fasciculatum* (S_2)	60	cd	28.3	bc
8.	*Glomus* sp. (S_1)	50	bc	23.3	b
9.	*Glomus* sp. (S_9)	43	b	21.7	ab
10.	Uninoculated	26	a	15.0	a
	SEM ±	3.41		2.53	
	CD (0.05)	10.14		7.51	
	CV %	9.84		13.60	

Note:- As in table 1

with each other but differed significantly from other treatments. The lowest root colonization was observed in uninoculated control plants (15.0%).

Secondary screening trial at Myladampara

This trial was conducted at Main Research Station, Spices Board, Myladampara, Idukki Dist, Kerala with two cultivars of cardamom viz., Mysore and Vazukka. In this trial the efficiency of six promising VA mycorrhizal isolates obtained from primary screening trial and five predominant native VA mycorrhizal fungi collected from different cardamom plantations of Kerala were tested. The location and soil used for the study was common to both the cultivars. The results obtained are presented below :

Screening trial with cultivar Mysore

Plant height

Mycorrhizal inoculation resulted in significant increase in plant height at all the three stages of plant growth viz., 3, 6 and 9 months after transplanting (Table 19 Fig.9). Throughout the growth period maximum plant height was recorded in plants inoculated with Glomus monosporum. Nine months after transplanting, maximum plant height was recorded in plants inoculated with Glomus monosporum (88.3 cm) followed by Glomus fasciculatum (84.8 cm) and native VA mycorrhizal isolate Glomus caledonicum (M_7) (82.9 cm), all the three being statistically on par with each other.The lowest plant height was recorded in uninoculated control plants (68.0 cm).

Table - 19

Influence of VA mycorrhiza on plant height of Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Plant height (cm) - MAT*		
		3 M *	6 M *	9 M *
1.	Acaulospora laevis	22.7 bcd	57.4 abcd	74.1 bc
2.	Gigaspora margarita	25.5 efg	60.2 cd	80.8 defg
3.	Glomus fasciculatum	27.5 g	62.1 d	84.8 gh
4.	Glomus intraradices	24.7 def	58.8 bcd	77.9 cdef
5.	Glomus monosporum	30.2 h	69.5 e	88.3 h
6.	Glomus mosseae	25.8 efg	60.9 d	82.2 fg
7.	Glomus caledonicum (M_7)	26.4 fg	62.1 d	82.9 fgh
8.	Glomus sp. (M_1)	22.1 bc	55.9 abc	72.3 abc
9.	Glomus sp. (M_2)	23.3 bcde	57.6 abcd	74.5 bc
10.	Glomus sp. (M_3)	24.4 cdef	58.4 bcd	75.0 cde
11.	Glomus sp. (M_6)	21.7 b	54.0 ab	68.7 ab
12.	Uninoculated	19.0 a	52.8 a	68.0 a
	SEM ±	0.94	1.78	2.12
	CD (0.05)	2.59	4.92	5.87
	CV%	12.10	9.49	8.64

Note:- 1. Values represent mean of 10 replicates.

MAT* Months after transplanting

Means with similar alphabets in each column do not differ significantly at p = 0.05.

Plate 4. Response of Cardamom Cv. Mysore to inoculation with *Glomus monosporum* - Secondary screening conducted at MRS, Spices board, Myladampara, Kerala

Notations:-

4 = *Glomus monosporum*

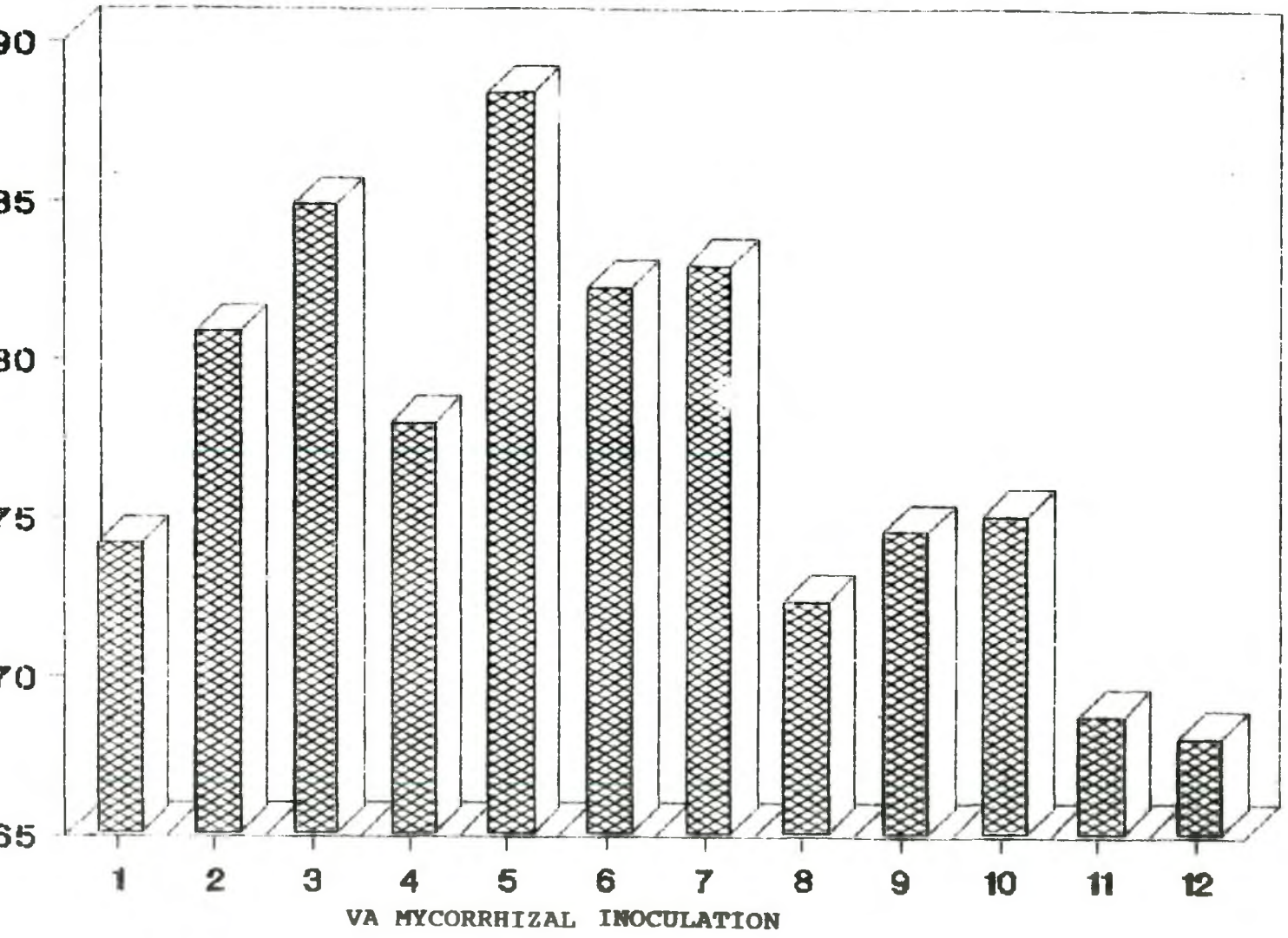
C = Uninoculated control

(a) Shoot

(b) Root


CARDAMOM
(cv. MYSORE) x VAM
4
C


CARDAMOM
(cv. MYSORE) x VAM
4
C



1. Acaulospora laevis
2. Gigaspora margarita
3. Glomus fasciculatum
4. Glomus intraradices
5. Glomus monosporum
6. Glomus mosseae
7. Glomus caledonicum (M_7)
8. Glomus sp. (M_1)
9. Glomus sp. (M_2)
10. Glomus sp. (M_3)
11. Glomus sp. (M_6)
12. Uninoculated

Fig. 9. Influence of VA mycorrhiza on plant height of Cv. Mysore of cardamom at 9 months after transplanting - secondary screening conducted at Myladampara, Kerala.

Number of leaves

Inoculated plants had more number of leaves compared to control at all the three stages of plant growth (Table 20). Nine months after transplanting maximum number of leaves were recorded on plants inoculated with Glomus monosporum (12.6) followed by Glomus fasciculatum (12.4) and native VA mycorrhizal fungus Glomus caledonicum (M_7) (12.0). No significant difference was found between these three treatments. Plants inoculated with Glomus intraradices. Acaulospora laevis and native VA mycorrhizal fungi M_3, M_2, M_1 and M_6 recorded the least number of leaves per plant and all of them were statistically on par with each other and with uninoculated plants (10.6).

Leaf area

Most of the mycorrhizal treatments did not differ significantly from each other with respect to leaf area (Table 21). Fungi selected from the primary screening improved the leaf area better compared to native fungi, all of which were statistically on par with each other. Maximum leaf area was recorded in plants inoculated with Glomus monosporum (147.1 cm^2) followed by Glomus fasciculatum (144.5 cm^2). The lowest leaf area was observed in uninoculated plants (115.2 cm^2).

Number of tillers per plant

Significant difference in the tiller number was observed between the treatments. Fungi selected from

Table - 20

Influence of VA mycorrhiza on the number of leaves in Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Number of leaves/pl-1 -MAT*		
		3M *	6 M *	9 M *
1.	*Acaulospora laevis*	5.8 abc	9.3 abc	10.8 a
2.	*Gigaspora margarita*	6.1 abcde	9.6 abc	11.6 bc
3.	*Glomus fasciculatum*	6.4 de	10.0 cd	12.4 de
4.	*Glomus intraradices*	6.1 abcde	9.5 abc	11.1 ab
5.	*Glomus monosporum*	6.6 e	10.6 d	12.6 e
6.	*Glomus mosseae*	6.2 bcde	9.6 abc	11.8 cd
7.	*Glomus caledonicum* (M_7)	6.3 cde	9.8 bc	12.0 cde
8.	*Glomus* sp. (M_1)	5.7 ab	9.2 ab	10.7 a
9.	*Glomus* sp. (M_2)	5.9 abcd	9.4 abc	10.8 a
10.	*Glomus* sp. (M_3)	6.0 abcd	9.5 abc	10.9 a
11.	*Glomus* sp. (M_6)	5.7 ab	9.1 ab	10.6 a
12.	Uninoculated	5.6 a	9.0 a	10.6 a
	SEM ±	0.19	0.26	0.23
	CD (0.05)	0.52	0.71	0.64
	CV%	9.77	8.48	6.42

Note:- As in table 19

Table - 21

Influence of VA mycorrhiza on leaf area, number of tillers and root length in Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Growth parameters - 9 MAT		
		Leaf area (cm^2)	No of tillers per plant	Root length (cm)
1.	*Acaulospora laevis*	126.7 ab	1.2 ab	26.5 bcd
2.	*Gigaspora margarita*	133.1 bcd	1.8 ef	31.6 ef
3.	*Glomus fasciculatum*	144.5 cd	2.2 h	38.6 gh
4.	*Glomus intraradices*	130.4 abcd	1.6 de	31.0 def
5.	*Glomus monosporum*	147.1 d	2.3 h	41.6 h
6.	*Glomus mosseae*	135.1 bcd	1.9 fg	33.7 fg
7.	*Glomus caledonicum* (M_7)	138.5 bcd	2.1 gh	34.1 fg
8.	*Glomus* sp. (M_1)	124.0 ab	1.2 ab	25.9 abc
9.	*Glomus* sp. (M_2)	128.9 abc	1.3 bc	28.2 bcde
10.	*Glomus* sp. (M_3)	129.3 abc	1.5 cd	30.2 cde
11.	*Glomus* sp. (M_6)	122.0 ab	1.1 ab	24.2 ab
12.	Uninoculated	115.2 a	1.0 a	21.5 a
	SEM ±	6.08	0.09	1.80
	CD (0.05)	16.86	0.26	4.99
	CV%	14.65	18.74	18.61

Note:- As in table 19

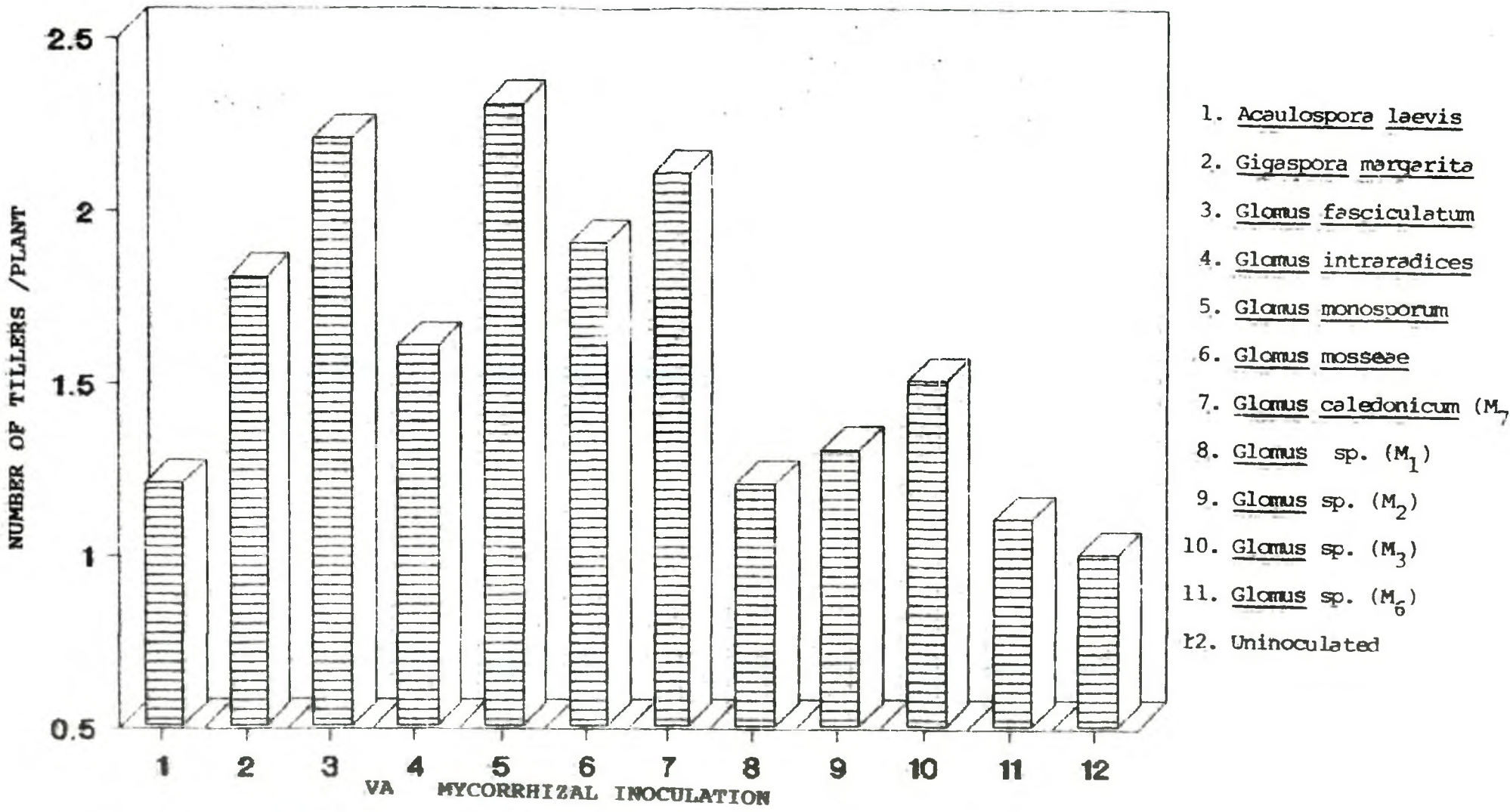


Fig. 10. Influence of VA mycorrhiza on number of tillers in Cv. Mysore of cardamom at 9 months after transplanting- secondary screening conducted at Myladampara, Kerala.

primary screening were better and produced more number of tillers than the native isolates (Table 21; Fig.10). Glomus monosporum inoculation resulted in maximum number of tillers per plant (2.3) followed by inoculation with Glomus fasciculatum (2.2). Among the native VA mycorrhizal strains Glomus caledonicum (M_7) was found to be the best in improving the tiller number per plant (2.1). All these three treatments were statistically on par with each other but differed significantly from uninoculated plants and with other mycorrhizal treatments. The lowest number of tillers was observed in control plants (1.0).

Root length

Inoculation with Glomus monosporum (41.6 cm) resulted in maximum root length which differed significantly from all other treatments except Glomus fasciculatum inoculation which was the next best fungus in improving the root length (38.6 cm) (Table 21). Plants inoculated with native VA mycorrhiza Glomus caledonicum (M_7) (34.1 cm) and other promising isolates from primary screening Glomus mosseae (33.7 cm), Gigaspora margarita (31.6 cm) and Glomus intraradices (31.0 cm) also resulted in increased root length compared to plants inoculated with other native isolates and uninoculated plants. The lowest root length was recorded in control plants (21.5 cm).

Shoot dry weight

Maximum shoot dry weight was recorded in plants inoculated with Glomus monosporum (14.3 g/plant) followed by

Glomus fasciculatum (13.4 g/plant) both being statistically on par with each other (Table 22; Fig. 11). Native VA mycorrhizal fungus Glomus caledonicum (M_7) (12.6 g/plant) was found to be the next best treatment. Isolates selected from the primary screening trial were better in improving shoot dry weight compared to native VA mycorrhizal strains. Lowest shoot biomass was recorded in control plants (8.1 g/plant).

Root dry weight

The trend in the root dry weight was similar to that of shoot dry weight, being the highest in plants inoculated with Glomus monosporum (9.0 g/plant) and the lowest in uninoculated plants (4.2 g/plant) (Table 22; Fig.11).

Total plant dry weight

Mycorrhizal inoculation resulted in more plant dry weight compared to uninoculated plants. Maximum plant dry weight was recorded in plants inoculated with Glomus monosporum (23.3 g/plant) followed by Glomus fasciculatum (21.9 g/plant) both being statistically on par with each other but differed significantly from other treatments (Table 22; Fig.11). Among the native VA mycorrhizal strains Glomus caledonicum (M_7) recorded maximum plant dry weight (20.3 g/plant) which also differed significantly from other treatments. The lowest plant dry weight was recorded in uninoculated plants (12.3 g/plant).

Table - 22

Influence of VA mycorrhiza on dry weight of Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Dry weight (g/pl^{-1})		
		Shoot	Root	Total
1.	*Acaulospora laevis*	9.8 bcd	5.0 abc	14.8 bc
2.	*Gigaspora margarita*	11.6 fg	6.2 de	17.8 ef
3.	*Glomus fasciculatum*	13.4 hi	8.5 fg	21.9 h
4.	*Glomus intraradices*	11.0 ef	5.8 cde	16.8 def
5.	*Glomus monosporum*	14.3 i	9.0 g	23.3 h
6.	*Glomus mosseae*	11.8 fg	6.5 e	18.3 f
7.	*Glomus caledonicum* (M_7)	12.6 gh	7.7 f	20.3 g
8.	*Glomus* sp. (M_1)	9.3 bc	4.7 abc	14.0 b
9.	*Glomus* sp. (M_2)	10.4 cde	5.3 abcd	15.7 cd
10.	*Glomus* sp. (M_3)	10.7 def	5.6 bcde	16.3 cde
11.	*Glomus* sp. (M_6)	8.8 ab	4.5 ab	13.3 ab
12.	Uninoculated	8.1 a	4.2 a	12.3 a
	SEM ±	0.37	0.39	0.52
	CD (0.05)	1.10	1.14	1.52
	CV%	5.90	11.04	5.24

Note:- As in table 19

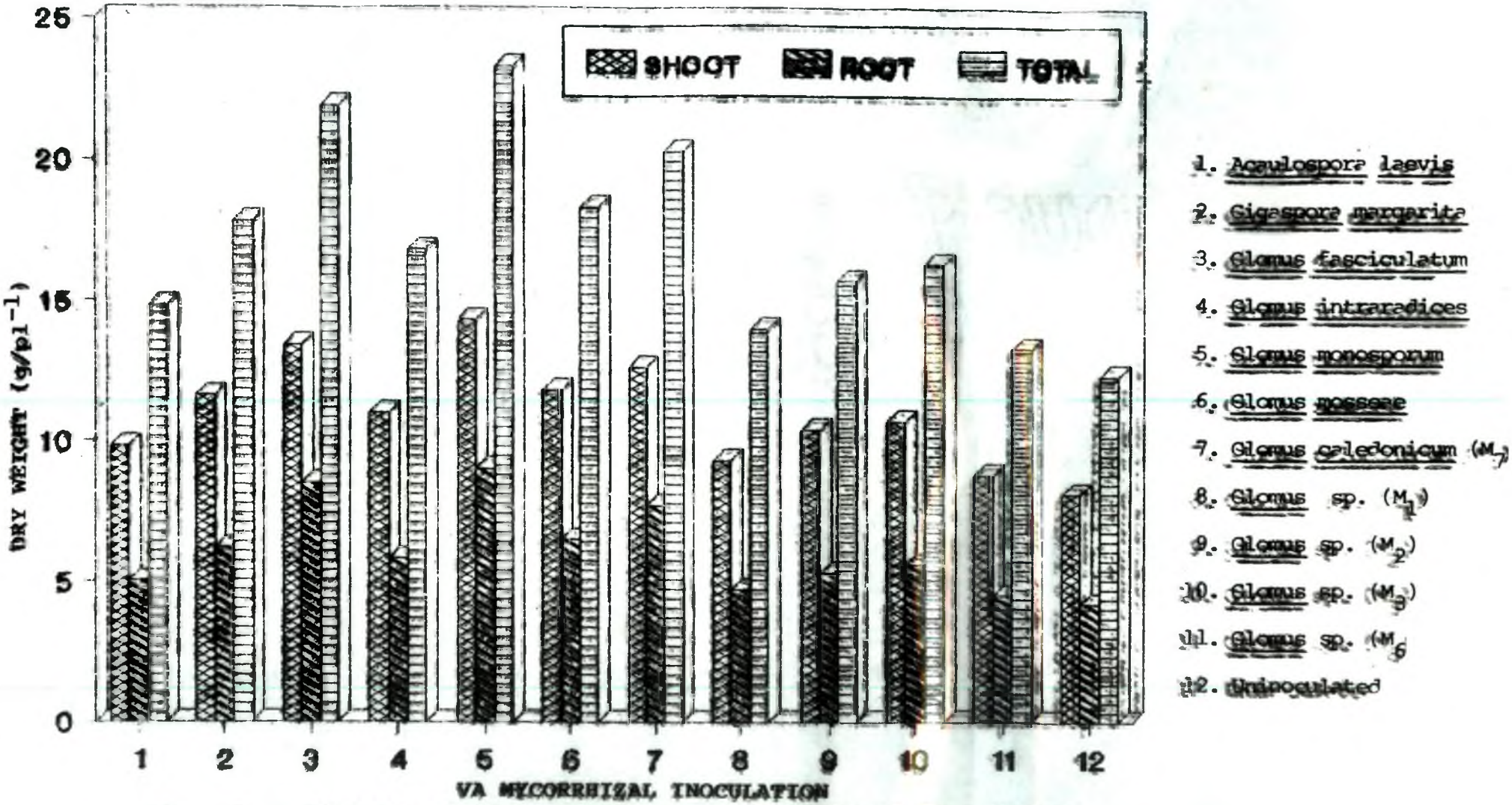


Fig. 11, Influence of VA mycorrhiza on dry weight of Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala.

Shoot Phosphorus

Phosphorus content in shoot was maximum in plants inoculated with Glomus monosporum (118.69 mg/plant) which differed significantly from all other treatments (Table 23; Fig.12). Among the native VA mycorrhizal strains plants inoculated with Glomus caledonicum (M_7) had the highest P content in shoot (94.50 mg/plant). Uninoculated plants had the lowest shoot P content (38.88 mg/plant).

Root Phosphorus

Inoculation with Glomus monosporum resulted in maximum uptake of P in root (47.70 mg/plant) followed by Glomus fasciculatum (43.35 mg/plant) both being statistically on par with each other but differed significantly from other treatments (Table 23; Fig. 12). Isolates selected from primary screening proved more efficient in improving the root phosphorus than most of the native fungi. Uninoculated plants had the least phosphorus content in root (13.02 mg/plant).

MICRONUTRIENT ANALYSIS

Shoot Iron content

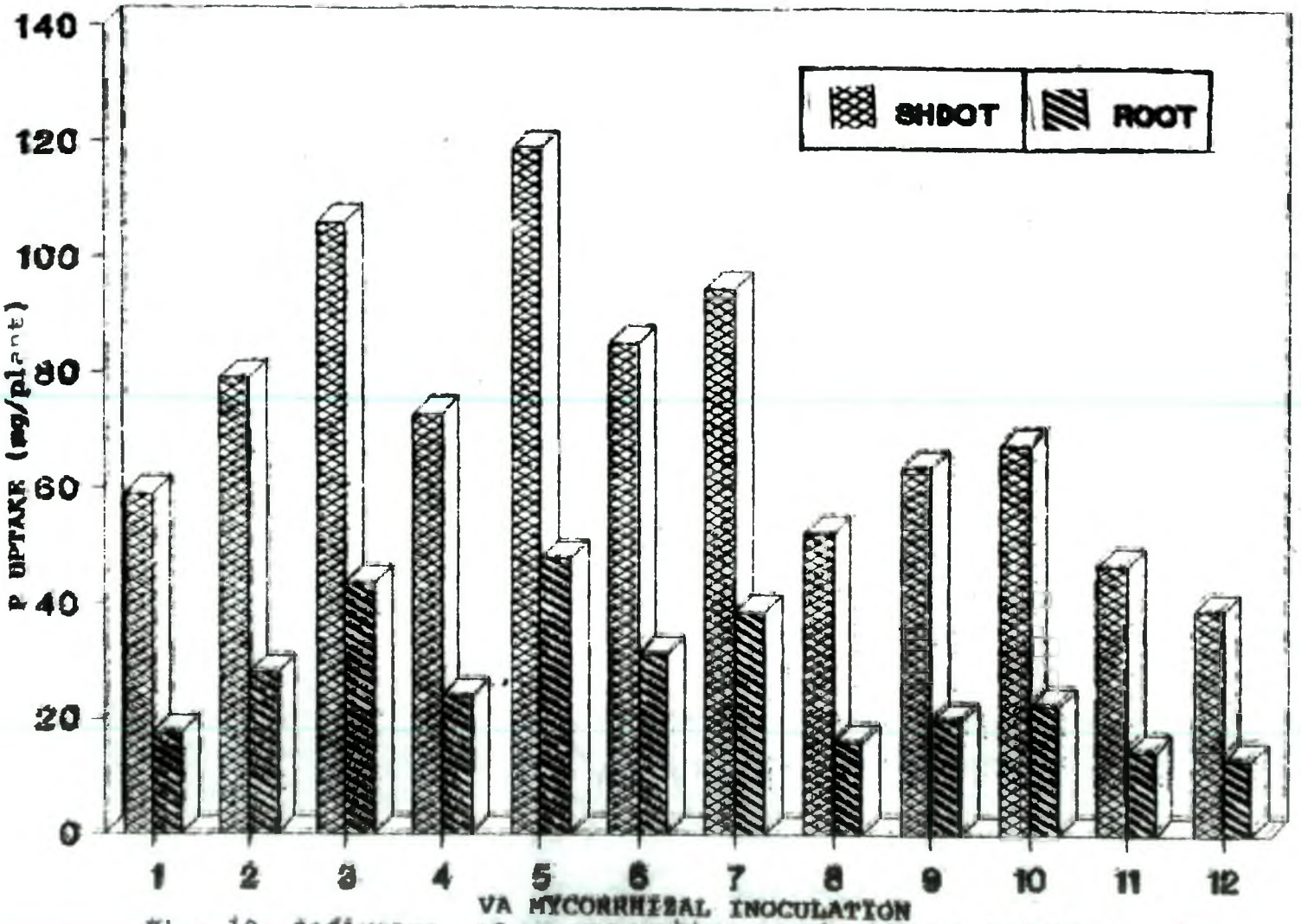
Iron content in shoot varied differently with mycorrhizal treatments. Maximum iron content in shoot was observed in plants inoculated with Glomus monosporum (2.789 mg/plant) and the lowest in uninoculated plants (1.369 mg/plant) (Table 24).

Table - 23

Influence of VA mycorrhiza on phosphorus uptake and content in Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	P uptake			
		Shoot		Root	
		% P	mg/plant	% P	mg/plant
1.	Acaulospora laevis	0.60 cd	58.80 cd	0.35 abc	17.50 abc
2.	Gigaspora margarita	0.68 fg	78.88 fg	0.45 ef	27.90 de
3.	Glomus fasciculatum	0.79 ij	105.86 i	0.51 g	43.35 gh
4.	Glomus intraradices	0.66 ef	72.60 ef	0.41 de	23.78 cde
5.	Glomus monosporum	0.83 j	118.69 j	0.53 g	47.70 h
6.	Glomus mosseae	0.72 gh	84.96 gh	0.48 fg	31.20 ef
7.	Glomus caledonicum (M_7)	0.75 hi	94.50 h	0.50 fg	38.50 fg
8.	Glomus sp. (M_1)	0.56 bc	52.08 bc	0.34 ab	15.98 ab
9.	Glomus sp. (M_2)	0.61 cde	63.44 de	0.37 bcd	19.61 abc
10.	Glomus sp. (M_3)	0.63 def	67.41 de	0.40 cde	22.40 bcd
11.	Glomus sp. (M_6)	0.53 ab	46.64 ab	0.32 ab	14.40 a
12.	Uninoculated	0.48 a	38.88 a	0.31 a	13.02 a
	SEM ±	0.02	3.28	0.02	2.53
	CD (0.05)	0.05	9.62	0.05	7.42
	CV %	4.72	7.72	6.95	16.68

Note:- As in table 19



1. Acaulospora laevis
2. Gigaspora margarita
3. Glomus fasciculatum
4. Glomus intraradices
5. Glomus monosporum
6. Glomus mossease
7. Glomus calectonicum (M_7)
8. Glomus sp. (M_1)
9. Glomus sp. (M_2)
10. Glomus sp. (M_3)
11. Glomus sp. (M_6)
12. Uninoculated

Fig. 12. Influence of VA mycorrhiza on phosphorus uptake in Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala.

Root Iron content

Glomus monosporum inoculation resulted in maximum iron uptake in root (0.657 mg/plant) followed by Glomus fasciculatum (0.621 mg/plant). The lowest iron content in root was recorded in control plants (0.244 mg/plant) (Table 24).

Total Iron content

The best fungi which resulted in enhanced iron content in plant were in the order of Glomus monosporum (3.446 mg/plant), followed by Glomus fasciculatum (3.194 mg/plant), native VA mycorrhizal strain Glomus caledonicum (M_7) (2.954 mg/plant) and Glomus mosseae (2.697 mg/plant). All the above four treatments differed significantly from each other and from other treatments (Table 24). The lowest iron content of the plant was recorded in uninoculated plants (1.613 mg/plant).

Shoot Copper content

Maximum shoot copper content was recorded in plants inoculated with Glomus monosporum (0.200 mg/plant) followed by Glomus fasciculatum (0.185 mg/plant) and native VA mycorrhizal strain Glomus caledonicum (M_7) (0.173 mg/plant) (Table 25). Promising isolates from the primary screening performed better in improving the shoot copper content compared to most of the native fungi and they significantly differed from uninoculated control plants which had the least copper content in shoot(0.075 mg/plant).

Table - 24

Influence of VA mycorrhiza on iron content in Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Iron content (mg/plant)		
		Shoot	Root	Total
1.	Acaulospora laevis	1.744 cd	0.320 abcd	2.064 cd
2.	Gigaspora margarita	2.158 fg	0.428 e	2.586 gh
3.	Glomus fasciculatum	2.573 ij	0.621 fg	3.194 j
4.	Glomus intraradices	2.024 efg	0.394 de	2.418 efg
5.	Glomus monosporum	2.789 j	0.657 g	3.446 k
6.	Glomus mosseae	2.242 gh	0.455 e	2.697 h
7.	Glomus caledonicum (M_7)	2.407 hi	0.547 f	2.954 i
8.	Glomus sp. (M_1)	1.618 bc	0.296 abc	1.914 bc
9.	Glomus sp. (M_2)	1.872 de	0.345 bcd	2.217 de
10.	Glomus sp. (M_3)	1.937 de	0.375 cde	2.312 ef
11.	Glomus sp. (M_6)	1.514 ab	0.275 ab	1.789 ab
12.	Uninoculated	1.369 a	0.244 a	1.613 a
	SEM ±	0.078	0.027	0.079
	CD (0.05)	0.227	0.080	0.233
	CV %	6.646	11.474	5.648

Note:- As in table 19

Root Copper ontent

Plants inoculated with Glomus monosporum had the maximum copper content in root (0.041 mg/plant) which is closely followed by plants inoculated with Glomus fasciculatum (0.038mg/plant) both being statistically on par with each other but significantly differed from other treatments. The roots of uninoculated plants had the least copper content (0.013 mg/plant) (Table 25).

Total Copper content

In gener. VA mycorrhizal inoculation resulted in increased copper uptake by plants. Maximum plant copper was recorded in plants inoculated with Glomus monosporum (0.241 mg/plant) followed by Glomus fasciculatum (0.223mg/plant) both being statistically on par with each other. Among the native VA mycorrhizal fungi Glomus caledonicum (M_7)was found to be the best in improving the plant copper content (0.206mg/plant) (Table 25). Uninoculated plants had the lowest copper content (0.088 mg/plant).

Shoot Zinc content

Maximum shoot zinc content was recorded in plants inoculated with Glomus monosporum (0.572 mg/plant) which differed significantly from other treatments (Table 26). The next best treatments which improved zinc content in shoot were Glomus fasciculatum (0.523 mg/plant), native VA mycorrhiza Glomus caledonicum (M_7) (0.491 mg/plant) and Glomus mosseae (0.460 mg/plant). The lowest zinc content in shoot was observed in uninoculated plants (0.243 mg/plant).

Table - 25

Influence of VA mycorrhiza on copper content in Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Copper content (mg/plant)		
		Shoot	Root	Total
1.	Acaulospora laevis	0.108 bc	0.019 abcd	0.127 bc
2.	Gigaspora margarita	0.150 ef	0.025 de	0.175 ef
3.	Glomus fasciculatum	0.185 gh	0.038 gh	0.223 hi
4.	Glomus intraradices	0.132 de	0.023 de	0.155 de
5.	Glomus monosporum	0.200 h	0.041 h	0.241 i
6.	Glomus mosseae	0.157 f	0.027 ef	0.184 fg
7.	Glomus caledonicum (M_7)	0.173 fg	0.033 fg	0.206 gh
8.	Glomus sp. (M_1)	0.093 ab	0.016 abc	0.109 ab
9.	Glomus sp. (M_2)	0.118 cd	0.020 bcd	0.138 cd
10.	Glomus sp. (M_3)	0.122 cd	0.022 cde	0.144 cd
11.	Glomus sp. (M_6)	0.084 a	0.015 ab	0.099 a
12.	Uninoculated	0.075 a	0.013 a	0.088 a
	SEM ±	0.008	0.002	0.009
	CD (0.05)	0.023	0.006	0.026
	CV %	10.339	14.019	9.929

Note:- As in table 19

Root Zinc content

Glomus monosporum inoculation resulted in maximum zinc content in root (0.144 mg/plant) followed by Glomus fasciculatum (0.128 mg/plant) both being statistically on par with each other but differed significantly from other treatments (Table 26). Inoculation with native VA mycorrhiza Glomus caledonicum (M_7) (0.108 mg/plant) was found to be the next best. The lowest zinc content in root was recorded in control plants (0.038 mg/plant).

Total Zinc content

The four best fungi which enhanced the plant zinc content were Glomus monosporum (0.716 mg/plant) Glomus fasciculatum (0.651 mg/plant), native VA mycorrhizal strain Glomus caledonicum (M_7) (0.599 mg/plant) and Glomus mosseae (0.545 mg/plant). All the above four treatments differed significantly from each other and from other treatments (Table 26). The lowest plant zinc content was observed in uninoculated plants (0.281 mg/plant).

VA mycorrhizal spore count

Rhizosphere soil of inoculated plants had significantly more number of mycorrhizal spores compared to the uninoculated plants (Table 27). Maximum number of spores were encountered in the rhizosphere of plants inoculated with Glomus monosporum (90/25 ml) followed by Glomus fasciculatum (87/25 ml) and native VA mycorrhizal fungus Glomus caledonicum (M_7) (82/25 ml), all the three

Table - 26

Influence of VA mycorrhiza on zinc content in Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Zinc content (mg/plant)		
		Shoot	Root	Total
1.	*Acaulospora laevis*	0.343 cd	0.060 bc	0.403 cd
2.	*Gigaspora margarita*	0.441 fg	0.081 de	0.522 fg
3.	*Glomus fasciculatum*	0.523 i	0.128 g	0.651 i
4.	*Glomus intraradices*	0.407 ef	0.075 cde	0.482 ef
5.	*Glomus macrosporum*	0.572 j	0.144 g	0.716 j
6.	*Glomus mosseae*	0.460 gh	0.085 e	0.545 g
7.	*Glomus caledonicum* (M_7)	0.491 hi	0.108 f	0.599 h
8.	*Glomus* sp. (M_1)	0.316 bc	0.056 b	0.372 bc
9.	*Glomus* sp. (M_2)	0.374 de	0.064 bcd	0.438 de
10.	*Glomus* sp. (M_3)	0.396 e	0.067 bcd	0.463 e
11.	*Glomus* sp. (M_6)	0.282 ab	0.050 ab	0.332 b
12.	Uninoculated	0.243 a	0.038 a	0.281 a
	SEM ±	0.015	0.006	0.016
	CD (0.05)	0.044	0.017	0.046
	CV %	6.403	12.484	5.663

Note:- As in table 19

Table - 27

VA mycorrhizal spore numbers in the root zone and percent mycorrhizal root colonization in Cv. Mysore of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Spore count (per 25 ml soil)		Percent colonization	
1.	*Acaulospora laevis*	57	bc	26.7	abc
2.	*Gi spora margarita*	72	de	40.0	def
3.	*Glomus fasciculatum*	87	fg	50.0	fg
4.	*Glomus intraradices*	65	cd	36.7	cde
5.	*Glomus monosporum*	90	g	56.7	g
6.	*Glomus mosseae*	74	def	43.3	ef
7.	*Glomus caledonicum* (M_7)	82	efg	48.3	fg
8.	*Glomus* sp. (M_1)	55	bc	23.3	ab
9.	*Glomus* sp. (M_2)	60	bcd	30.0	bcd
10.	*Glomus* sp. (M_3)	62	bcd	35.0	cde
11.	*Glomus* sp. (M_6)	48	b	21.7	ab
12.	Uninoculated	28	a	16.7	a
	SEM ±	4.98		3.43	
	CD (0.05)	14.62		10.07	
	CV %	13.28		16.66	

Note:- As in table 19

being statistically on par with each other. The lowest number of spores were found in the rhizosphere of uninoculated plants (28/25 ml).

Percent VA mycorrhizal colonization

Maximum root colonization was observed in plants inoculated with Glomus monosporum (56.7%) (Table 27). Next higher colonization was observed in plants inoculated with Glomus fasciculatum (50.0%) and the native VA mycorrhizal fungus Glomus caledonicum (M_7) (48.3%). Statistically no significant difference was found between these three treatments. Uninoculated plants had the least percent mycorrhizal colonization (16.7%).

Screening trial with cultivar Vazukka

Plant height

Significant increase in plant height due to VA mycorrhizal inoculation was observed at all the three stages of plant growth viz., 3, 6 and 9 months after transplanting (Table 28; Fig.13). Nine months after transplanting plants inoculated with Glomus monosporum attained maximum plant height (84.3 cm). The next best fungi being Glomus fasciculatum (81.8 cm) and Glomus mosseae (80.0 cm). These three treatments were statistically on par with each other. Among the native VA mycorrhizal fungi, plants inoculated with Glomus caledonicum (M_7) (78.4 cm) showed maximum plant height. The least plant height was recorded in uninoculated plants (68.2 cm).

Table - 28

Influence of VA mycorrhiza on plant height of Cv. Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Plant height (cm) -MAT*		
		3M *	6 M *	9 M *
1.	*Acaulospora laevis*	21.3 abc	56.5 abcd	74.0 bcd
2.	*Gigaspora margarita*	24.0 cde	58.8 cde	77.6 cde
3.	*Glomus fasciculatum*	28.2 fg	62.0 e	81.8 ef
4.	*Glomus intraradices*	22.6 bc	57.5 abcde	74.7 bcd
5.	*Glomus monosporum*	29.7 g	62.5 e	84.3 f
6.	*Glomus mosseae*	26.4 ef	61.5 de	80.0 ef
7.	*Glomus caledonicum* (M_7)	26.0 ef	59.6 de	78.4 de
8.	*Glomus* sp. (M_1)	20.1 ab	53.8 abc	73.4 bc
9.	*Glomus* sp. (M_2)	23.2 cd	58.1 bcde	77.0 cde
10.	*Glomus* sp. (M_3)	25.7 def	59.0 de	77.8 cde
11.	*Glomus* sp. (M_6)	19.6 a	53.7 ab	71.5 ab
12.	Uninoculated	18.8 a	53.0 a	68.2 a
	SEM ±	1.00	1.82	1.77
	CD (0.05)	2.78	5.04	4.89
	CV%	13.32	9.92	7.29

Note:- As in table 19

Plate 5. Response of Cardamom Cv. Vazukka to inoculation with *Glomus monosporum* - Secondary screening conducted at Myladampara, Kerala

Notations:-

4 = *Glomus monosporum*

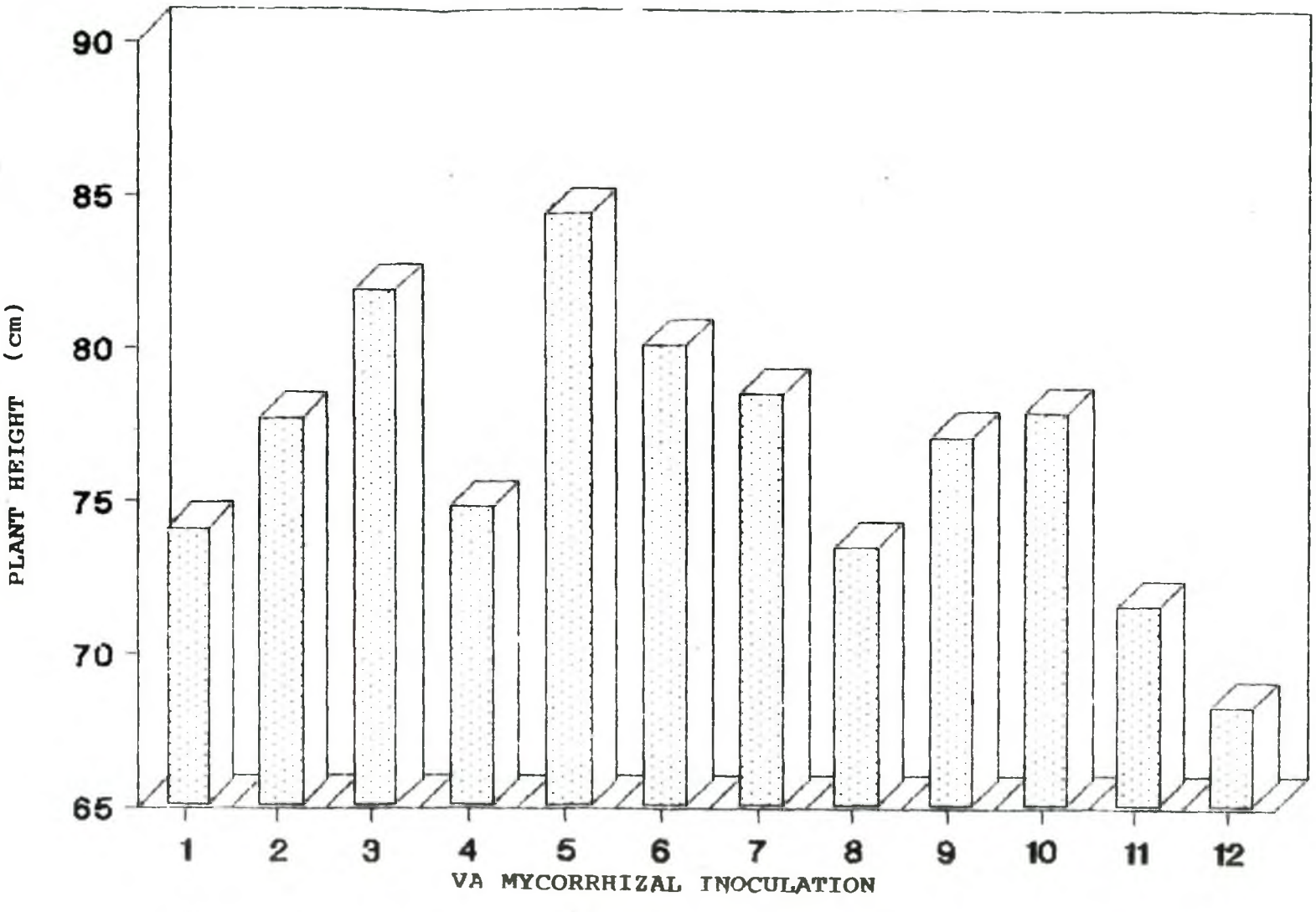
C = Uninoculated control

(a) Shoot

(b) Root


CARDAMOM
(Cv. VAZHUKKA) + VAM
4
C


CARDAMOM
(Cv. VAZHUKKA) x VAM
4
C



1. Acaulospora laevis
2. Gigaspora margarita
3. Glomus fasciculatum
4. Glomus intraradices
5. Glomus monosporum
6. Glomus mosseae
7. Glomus caledonicum (M_7)
8. Glomus sp. (M_1)
9. Glomus sp. (M_2)
10. Glomus sp. (M_3)
11. Glomus sp. (M_6)
12. Uninoculated

Fig. 13. Influence of VA mycorrhiza on plant height of Cv. Vazukka of cardamom at 9 months after transplanting - secondary screening conducted at Myladampara, Kerala.

Number of leaves

Most of the treatments were statistically on par with the control plants with respect to production of leaves at all the three stages of plant growth (Table 29). Plants inoculated with Glomus monosporum had the maximum number of leaves at all the three stages of growth. At nine months after transplanting, plants inoculated with Glomus monosporum had the maximum number of leaves (12.0) which differed significantly from the control plants (10.5).

Leaf area

Not much difference in leaf area was observed between the treatments other than control. In general inoculated plants had significantly more leaf area compared to control plants (Table 30). Maximum leaf area was recorded in plants inoculated with Glomus monosporum (145.6 cm^2).

Number of tillers per plant

Tiller number was maximum in plants inoculated with Glomus monosporum (2.2) which differed significantly from all other treatments (Table 30; Fig.14). Next to this treatment, plants inoculated with Glomus fasciculatum had the highest number of tillers (1.8). The lowest number of tillers occured in uninoculated plants (1.0).

Root length

Significant differences were noticed between the treatments with respect to root length. Maximum root length

Table - 29

Influence of VA mycorrhiza on the number of leaves in Cv. Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	No. of leaves/pl^{-1} - MAT*		
		3 M *	6 M *	9 M *
1.	*Acaulospora laevis*	5.5 a	9.2 abc	10.7 ab
2.	*Gigaspora margarita*	5.8 abc	9.4 bc	11.2 abcde
3.	*Glomus fasciculatum*	6.3 d	9.7 cd	11.8 ef
4.	*Glomus intraradices*	5.6 ab	9.3 abc	10.9 abc
5.	*Glomus monosporum*	6.3 d	10.3 d	12.0 f
6.	*Glomus mosseae*	6.2 cd	9.6 bcd	11.7 def
7.	*Glomus caledonicum* (M_7)	6.1 cd	9.5 bcd	11.5 cdef
8.	*Glomus* sp. (M_1)	5.5 a	9.0 abc	10.6 ab
9.	*Glomus* sp. (M_2)	5.6 ab	9.3 abc	11.0 abcd
10.	*Glomus* sp. (M_3)	6.0 bcd	9.5 bcd	11.3 bcdef
11.	*Glomus* sp. (M_6)	5.5 a	8.8 ab	10.6 ab
12.	Uninoculated	5.4 a	8.5 a	10.5 a
	SEM ±	0.17	0.31	0.28
	CD (0.05)	0.47	0.85	0.78
	CV%	9.26	10.43	8.00

Note:- As in table 19

Table - 30

Influence of VA mycorrhiza on leaf area, number of tillers and root length in Cv. Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Growth parameters - 9 MAT		
		leaf area (cm^2)	No. of tillers per plant	Root length (cm)
1.	*Acau' spora laevis*	122.7 abcd	1.2 abc	25.5 abc
2.	*Gigaspora margarita*	133.3 bcde	1.5 def	30.0 def
3.	*Glomus fasciculatum*	142.4 de	1.8 g	37.3 hi
4.	*Glomus intraradices*	131.7 bcde	1.3 bcd	27.5 bcd
5.	*Glomus monosporum*	145.6 e	2.2 h	40.0 i
6.	*Glomus mosseae*	142.0 cde	1.7 fg	34.2 gh
7.	*Glomus caledonicum* (M_7)	135.2 bcde	1.6 efg	32.8 fg
8.	*Glomus* sp. (M_1)	121.6 abc	1.1 ab	24.7 abc
9.	*Glomus* sp. (M_2)	132.4 bcde	1.4 cde	28.1 cde
10.	*Glomus* sp. (M_3)	133.6 bcde	1.5 def	31.9 efg
11.	*Glomus* sp. (M_6)	115.1 ab	1.0 a	23.8 ab
12.	Uninoculated	110.3 a	1.0 a	22.2 a
	SEM ±	7.37	0.08	1.49
	CD (0.05)	20.42	0.21	4.12
	CV%	17.85	16.65	15.79

Note:- As in table 19

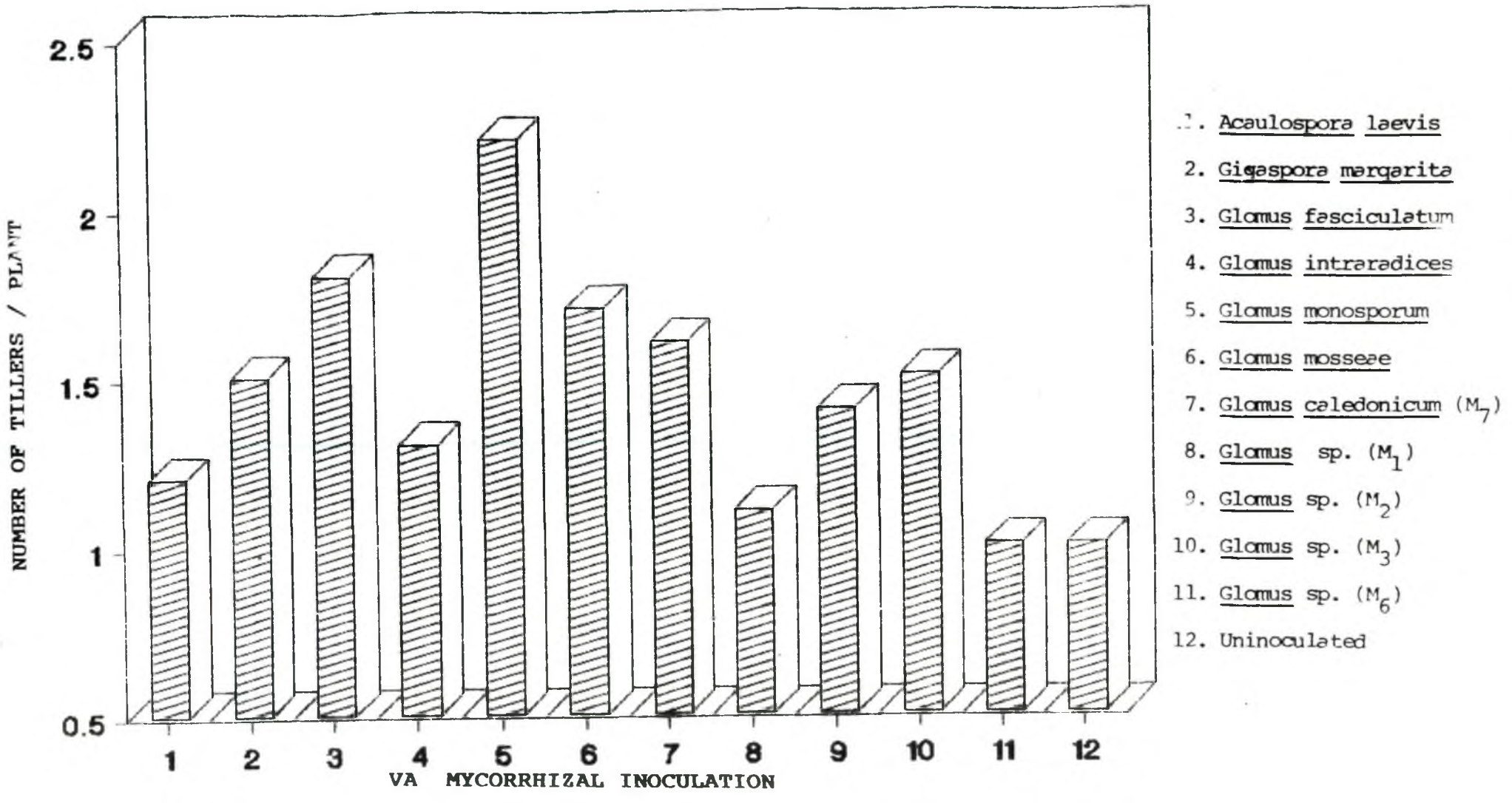


Fig. 14. Influence of VA mycorrhiza on number of tillers in Cv. Vazukka of cardamom at 9 months after transplanting - secondary screening conducted at Myladampara, Kerala.

was observed in plants inoculated with Glomus monosporum (40.0 cm) followed by Glomus fasciculatum (37.3 cm) both being statistically on par with each other but differed significantly from other treatments (Table 30). The shortest root length was observed in plants inoculated with Acaulospora laevis (25.5 cm), native VA mycorrhizal strains Glomus sp. (M_1) (24.7 cm), Glomus sp. (M_6) (23.8 cm) and in uninoculated plants (22.2 cm) and all the values were statistically on par with each other.

Shoot dry weight

Maximum shoot biomass was recorded in plants inoculated with Glomus monosporum (13.7 g/plant) followed by Glomus fasciculatum (12.4 g/plant) both being statistically on par with each other but differed significantly from the uninoculated plants which had the lowest shoot biomass (7.8 g/plant) (Table 31; Fig. 15).

Root dry weight

The results were more or less similar to that of the shoot biomass, being the highest in plants inoculated with Glomus monosporum (8.8 g/plant) and the lowest with uninoculated control plants (3.9 g/plant) (Table 31;Fig.15).

Total plant dry weight

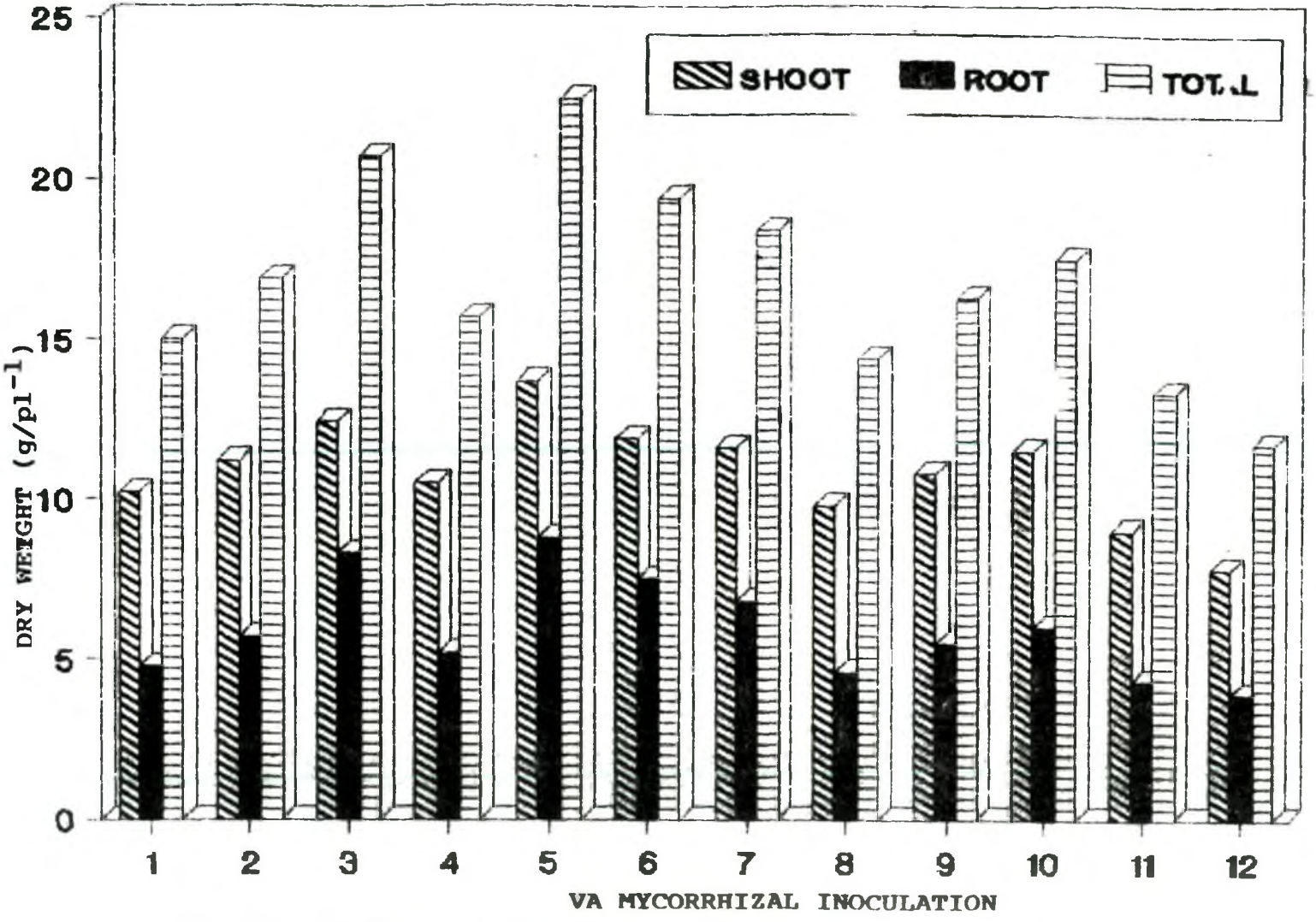
By and large all the inoculated plants had significantly higher plant biomass compared to the control plants (Table 31;Fig.15). Maximum plant biomass was observed in plants inoculated with Glomus monosporum (22.5g/plant)followed by Glomus fasciculatum (20.7 g/plant).

Table - 31

Influence of VA mycorrhiza on dry weight of Cv. Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Dry weight (g/pl^{-1})		
		Shoot	Root	Total
1.	*Acaulospora laevis*	10.2 bcd	4.8 abcd	15.0 bcd
2.	*Gigaspora margarita*	11.2 defg	5.7 cde	16.9 def
3.	*Glomus fasciculatum*	12.4 gh	8.3 gi	20.7 hi
4.	*Glomus intraradices*	10.5 cde	5.2 bcd	15.7 cde
5.	*Glomus monosporum*	13.7 h	8.8 i	22.5 i
6.	*Glomus mosseae*	11.9 fg	7.5 fg	19.4 gh
7.	*Glomus caledonicum* (M_7)	11.6 efg	6.8 ef	18.4 fg
8.	*Glomus* sp. (M_1)	9.8 bc	4.6 abc	14.4 bc
9.	*Glomus* sp. (M_2)	10.8 cdef	5.5 bcd	16.3 cde
10.	*Glomus* sp. (M_3)	11.5 defg	6.0 de	17.5 efg
11.	*Glomus* sp. (M_6)	9.0 ab	4.3 ab	13.3 ab
12.	Uninoculated	7.8 a	3.9 a	11.7 a
	SEM ±	0.47	0.43	0.65
	CD (0.05)	1.37	1.25	1.90
	CV%	7.46	12.44	6.67

Note:- As in table 19



1. Acaulospora laevis
2. Gigaspora margarita
3. Glomus fasciculatum
4. Glomus intraradices
5. Glomus monosporum
6. Glomus mosseae
7. Glomus caledonicum (M_7)
8. Glomus sp. (M_1)
9. Glomus sp. (M_2)
10. Glomus sp. (M_3)
11. Glomus sp. (M_6)
12. Uninoculated

Fig. 15. Influence of VA mycorrhiza on dry weight of Cv. Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala.

Both these treatments were statistically on par with each other but differed significantly from other treatments. Uninoculated plants had the lowest plant dry weight (11.7 g/plant).

Shoot phosphorus

The uptake of phosphorus in shoot varied differently with VA mycorrhizal treatment. Inoculated plants generally had more P content in shoot than the control. Maximum phosphorus content in shoot was observed in plants inoculated with Glomus monosporum (109.60mg/plant) followed by Glomus fasciculatum (96.72 mg/plant) both being statistically on par with each other (Table 32; Fig.16). The next best treatment was Glomus mosseae inoculated plants (90.44 mg/plant) which was statistically on par with Glomus fasciculatum (96.72 mg/plant) and Glomus caledonicum (M_7) (82.36 mg/plant) treated plants. Uninoculated plants had the least shoot P content (36.66 mg/plant).

Root Phosphorus

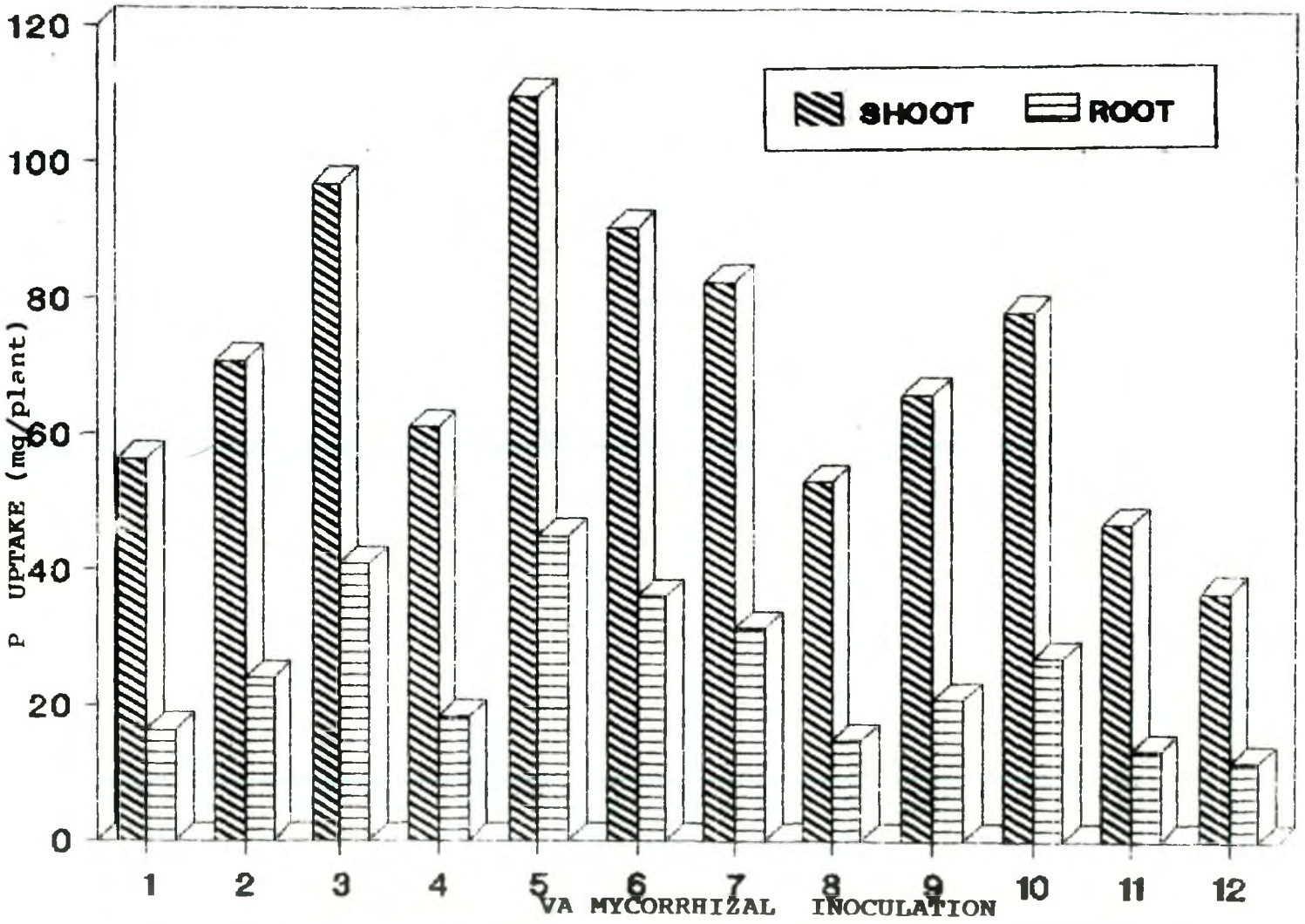
Phosphorus content in root was also maximum in plants inoculated with Glomus monosporum (44.88 mg/plant) which differed significantly from all other treatments except with Glomus fasciculatum (40.67 mg/plant) which was found to be the next best (Table 32; Fig.16). Uninoculated plants had the least phosphorus content in root (11.70 mg/plant).

Table - 32

Influence of VA mycorrhiza on phosphorus uptake in Cv. Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	P uptake			
		Shoot		Root	
		% p	mg/plant	% P	mg/plant
1.	*Acaulospora laevis*	0.55 abcd	56.10 bc	0.34 bc	16.32 abc
2.	*Gigaspora margarita*	0.63 def	70.56 def	0.42 e	23.94 de
3.	*Glomus fasciculatum*	0.78 hi	96.72 hi	0.49 gh	40.67 hi
4.	*Glomus intraradices*	0.58 bcd	60.90 cd	0.35 cd	18.20 bc
5.	*Glomus monosporum*	0.80 i	109.60 i	0.51 h	44.88 i
6.	*Glomus mosseae*	0.76 ghi	90.44 gh	0.48 fgh	36.00 gh
7.	*Glomus caledonicum* (M_7)	0.71 fgh	82.36 fg	0.46 fg	31.28 fg
8.	*Glomus* sp. (M_1)	0.54 abc	52.92 bc	0.32 abc	14.72 ab
9.	*Glomus* sp. (M_2)	0.61 cde	65.88 cde	0.38 d	20.90 cd
10.	*Glomus* sp. (M_3)	0.68 efg	78.20 efg	0.45 ef	27.00 ef
11.	*Glomus* sp. (M_6)	0.52 ab	46.80 ab	0.31 ab	13.33 ab
12.	Uninoculated	0.47 a	36.66 a	0.30 a	11.70 a
	SEM ±	0.03	4.58	0.01	1.81
	CD (0.05)	0.08	13.42	0.03	5.30
	CV%	7.23	11.23	5.16	12.56

Note:- As in table 19



1. A ulospora laevis
2. Gigaspora margarita
3. Glomus fasciculatum
4. Glomus intraradices
5. Glomus monosporum
6. Glomus mossea
7. Glomus caledonicum (M_7)
8. Glomus sp. (M_1)
9. Glomus sp. (M_2)
10. Glomus sp. (M_3)
11. Glomus sp. (M_6)
12. Uninoculated

Fig. 16. Influence of VA mycorrhiza on phosphorus uptake in Cv. Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala.

MICRONUTRIENT ANALYSIS

Shoot Iron content

The uptake of iron in shoot varied significantly with the treatments. Plants inoculated with Glomus monosporum had the maximum iron content in shoot (2.658 mg/plant) followed by Glomus fasciculatum (2.393 mg/plant) both being statistically on par with each other (Table 33). Plants inoculated with Glomus intraradices, Acaulospora laevis and native VA mycorrhizal strains Glomus sp M_1 and M_6 did not improve the shoot iron content compared to the uninoculated plants (1.310 mg/plant).

Root Iron content

Most of the treatments did not differ significantly from each other with respect to iron content in root (Table 33). The best three VA mycorrhizal fungi which enhanced the iron content in root were Glomus monosporum (0.634 mg/plant), Glomus fasciculatum (0.589 mg/plant) and Glomus mosseae (0.525 mg/plant). Uninoculated plants had the least iron content in root (0.222 mg/plant).

Total Iron content

The two best fungi which enhanced the iron content in plant were Glomus monosporum (3.292 mg/plant) and Glomus fasciculatum (2.982 mg/plant) both being statistically on par with each other (Table 33). Next best fungi were Glomus mosseae (2.798 mg/plant) and native VA

Table - 33

Influence of VA mycorrhiza on iron content in Cv. Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Iron content (mg/plant)		
		Shoot	Root	Total
1.	*Acaulospora laevis*	1.785 bcd	0.288 abcd	2.073 bcd
2.	*Gigaspora margarita*	2.050 def	0.371 def	2.421 def
3.	*Glomus fasciculatum*	2.393 gh	0.589 hi	2.982 hi
4.	*Glomus intraradices*	1.869 bcde	0.328 bcde	2.197 cde
5.	*Glomus monosporum*	2.658 h	0.634 i	3.292 i
6.	*Glomus mosseae*	2.273 fg	0.525 gh	2.798 gh
7.	*Glomus caledonicum* (M_7)	2.192 efg	0.462 fg	2.654 fgh
8.	*Glomus* sp. (M_1)	1.686 bc	0.276 abc	1.962 bc
9.	*Glomus* sp. (M_2)	1.944 cdef	0.352 cde	2.296 cde
10.	*Glomus* sp. (M_3)	2.128 efg	0.396 ef	2.524 efg
11.	*Glomus* sp. (M_6)	1.539 ab	0.254 ab	1.793 ab
12.	Uninoculated	1.310 a	0.222 a	1.532 a
	SEM ±	0.115	0.031	0.122
	CD (0.05)	0.337	0.091	0.357
	CV%	10.032	13.798	8.874

Note:- As in table 19

mycorrhizal strain Glomus caledonicum (M_7) (2.654 mg/plant). All the above four treatments differed significantly from uninoculated plants (1.532 mg/plant).

Shoot Copper content

Maximum shoot copper content was recorded in plants inoculated with Glomus monosporum (0.192 mg/plant) followed by Glomus fasciculatum (0.172 mg/plant). These two treatments have not differed significantly from each other. Among the native strains, plants inoculated with Glomus caledonicum (M_7) had the highest copper content in shoot (0.153 mg/plant) (Table 34). Control plants had the lowest shoot copper content (0.070 mg/plant).

Root Copper content

Similar to shoot maximum root copper content was recorded in plants inoculated with Glomus monosporum (0.040 mg/plant) followed by Glomus fasciculatum (0.037 mg/plant) and Glomus mosseae (0.033 mg/plant) (Table 34). The lowest root copper content was observed in uninoculated plants (0.012 mg/plant).

Total Copper content

Plants inoculated with Glomus monosporum (0.232mg/plant) and Glomus fasciculatum (0.209mg/plant) had the maximum plant copper content both being statistically on par with each other but differed significantly from other treatments (Table 34). The next best were plants inoculated with Glomus mosseae (0.192 mg/plant) and native VA

Table - 34

Influence of VA mycorrhiza on copper content in Cv.Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Copper content (mg/plant)		
		Shoot	Root	Total
1.	Acaulospora laevis	0.109 cd	0.018 bcd	0.127 cd
2.	Gigaspora margarita	0.134 efg	0.023 de	0.157 ef
3.	Glomus fasciculatum	0.172 ij	0.037 hi	0.209 hi
4.	Glomus intraradices	0.117 cde	0.020 bcde	0.137 de
5.	Glomus monosporum	0.192 j	0.040 i	0.232 i
6.	Glomus mosseae	0.159 hi	0.033 gh	0.192 gh
7.	Glomus caledonicum (M_7)	0.153 ghi	0.029 fg	0.182 g
8.	Glomus sp. (M_1)	0.096 bc	0.017 abc	0.113 bc
9.	Glomus sp. (M_2)	0.124 def	0.021 cde	0.145 de
10.	Glomus sp. (M_3)	0.146 fgh	0.025 ef	0.171 fg
11.	Glomus sp. (M_6)	0.086 ab	0.015 ab	0.101 ab
12.	Uninoculated	0.070 a	0.012 a	0.082 a
	SEM ±	0.007	0.002	0.008
	CD (0.05)	0.022	0.005	0.023
	CV%	10.053	11.977	8.788

Note:- As in table 19

mycorrhiza Glomus caledonicum (M_7) (0.182 mg/plant). Uninoculated plants had the lowest plant copper content (0.082 mg/plant).

Shoot Zinc content

Treatments differed significantly with respect to shoot zinc content. Plants inoculated with Glomus monosporum had the maximum shoot zinc content (0.548 mg/plant) and the lowest was recorded in control plants (0.234 mg/plant) (Table 35).

Root Zinc content

Maximum zinc content in root was recorded in plants inoculated with Glomus monosporum (0.132 mg/plant) fo owed by Glomus fasciculatum (0.116 mg/plant). These two treatments were statistically similar but significantly differed from other treatments (Table 35). Uninoculated plants had the lowest root zinc content (0.035 mg/plant).

Total Zinc content

The total zinc uptake was maximum in plants inoculated with Glomus monosporum (0.680 mg/plant) followed by Glomus fasciculatum (0.612 mg/plant). Among the native VA mycorrhiza Glomus caledonicum (M_7) (0.529 mg/plant) was found to be the best (Table 35). The least zinc content was recorded in uninoculated control plants (0.269 mg/plant).

VA mycorrhizal spore count

The rhizosphere soil of inoculated plants had more number of mycorrhizal spores compared to that of the

Table - 35

Influence of VA mycorrhiza on zinc content in Cv.Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala

Sl No	Inoculation treatment	Zinc content (mg/plant)		
		Shoot	Root	Total
1.	*Acaulospora laevis*	0.337 bcd	0.053 bc	0.390 bcd
2.	*Gigaspora margarita*	0.403 defg	0.068 cd	0.471 efg
3.	*Glomus fasciculatum*	0.496 hi	0.116 gh	0.612 ij
4.	*Glomus intraradices*	0.357 cde	0.057 bc	0.414 cde
5.	*Glomus monosporum*	0.548 i	0.132 h	0.680 j
6.	*Glomus mosseae*	0.452 gh	0.105 fg	0.557 hi
7.	*Glomus caledonicum* (M_7)	0.441 fgh	0.088 ef	0.529 gh
8.	*Glomus* sp. (M_1)	0.314 bc	0.051 abc	0.365 bc
9.	*Glomus* sp. (M_2)	0.378 cdef	0.066 cd	0.444 def
10.	*Glomus* sp. (M_3)	0.414 efg	0.078 de	0.492 fgh
11.	*Glomus* sp. (M_6)	0.279 ab	0.043 ab	0.322 ab
12.	Uninoculated	0.234 a	0.035 a	0.269 a
	SEM ±	0.023	0.006	0.025
	CD (0.05)	0.068	0.017	0.074
	CV%	10.354	13.865	9.456

Note:- As in table 19

Table - 36

VA mycorrhizal spore numbers in the root zone and percent mycorrhizal root colonization in Cv. Vazukka of cardamom - secondary screening conducted at Myladampara, Kerala

Sl. No.	Inoculation treatment	Spore count (per 25 ml soil)	Percent colonization
1.	*Acaulospora laevis*	53 bc	25.0 bcd
2.	*Gigaspora margarita*	69 def	36.7 ef
3.	*Glomus fasciculatum*	83 fg	51.7 hi
4.	*Glomus intraradices*	56 bcd	28.3 cd
5.	*Glomus monosporum*	86 g	55.0 i
6.	*Glomus mosseae*	81 fg	46.7 gh
7.	*Glomus caledonicum* (M_7)	75 efg	41.7 fg
8.	*Glomus* sp. (M_1)	49 b	21.7 abc
9.	*Glomus* sp. (M_2)	66 cde	30.0 dc
10.	*Glomus* sp. (M_3)	73 efg	38.3 f
11.	*Glomus* sp. (M_6)	46 b	20.0 ab
12.	Uninoculated	25 a	15.0 a
	SEM ±	4.80	2.62
	CD (0.05)	14.07	7.69
	CV%	13.08	13.30

Note:- As in table 19

uninoculated plants (Table 36). Maximum number of VA mycorrhizal spores were encountered in the rhizosphere of plants inoculated with Glomus monosporum (86/25 ml) followed by Glomus fasciculatum (83/25 ml) and Glomus mosseae (81/25 ml). These three treatments differed significantly from uninoculated plants which had the least number of chlamydospores (25/25 ml).

Percent VA mycorrhizal root colonization

Inoculated plants had more mycorrhizal root colonization compared to the uninoculated plants (Table 36). Maximum root colonization occured in plants inoculated with Glomus monosporum (55.0%) followed by Glomus fasciculatum (51.7%) both being statistically on par with each other but differed significantly from other treatments. The control plants had the least percentage of mycorrhizal colonization in roots (15.0%).

Isolation of dominan types of VA mycorrhizal fungi from the rootzone of cardamom

Soil samples were collected from the rhizosphere of cardamom from different cardamom plantations of Karnataka and Kerala. The soil samples were subjected to wet sieving and decantation. Three dominant native spore types from Karnataka and five dominant spores from Kerala were brought in to pot culture by the single spore funnel technique. Spores from those pot cultures were identified using the synoptic key proposed in the manual for

identification of VA mycorrhizal fungi by Schenck and Perez (1987). All the eight native VA mycorrhizal spore types identified belonged to the genus Glomus. However only the best performed native spore types were identified upto species level.

Description of the genus Glomus

1. Sporocarp

1.1 Presence : Absent

2. Spores

2.1 Shape : Globose or ellipsoid or obovoid.

2.2 Longest dimension at maturity: 300 µm (m = 262.4 µm)

2.3 Surface ornamentation at maturity: Smooth to dull roughened with surface layer flaking or sloughing away.

2.4 Dextrinoid reaction of inner membranous wall(s) in Melzer's reagent: Absent.

3. Sporogeneous hypha

3.1 Number : One

3.2 Form : Mostly aseptate, cylindric to flaring, some times inflated or constricted, hypha bears single blastic spore at apex.

Identification of native VA mycorrhizal fungi

Only the best native VA mycorrhizal fungi were identified upto species level.

1. **Isolate M_7** - Isolate from Kerala cardamom plantations.

Spore description :

1. Sporocarps : present

2.	Spores (colour and shape) :	Dull yellow to brown with Globose in shape
3.	Diameter :	130 µm
4.	Spore walls and colour :	Hyaline outer layer and thick yellow brown inner layer.
5.	Wall thickness :	8.4 µm.

Hyphal description :

1.	Thickness of hyphal wall	: Thin walled hyphae.
2.	Attachment of hyphae	: single, cylindrical usually one occassionally two.
3.	Diameter at the point of attachment:	15 µm
4.	Wall colour	: Hyaline

Based on the above characters fungus was identified as Glomus caledonicum (Nicol & Gerd).

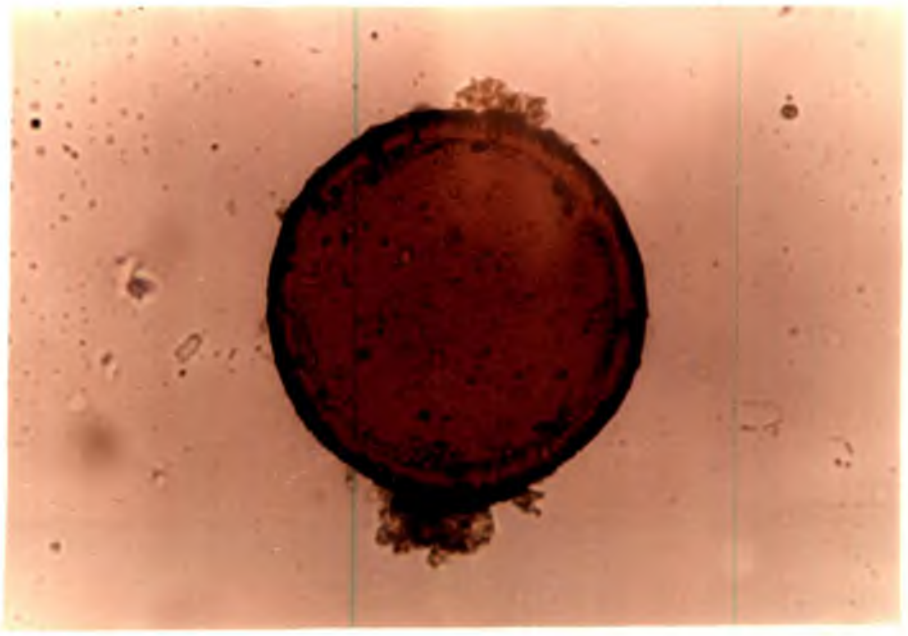
2. **Isolate S_2** - Isolate from cardamom plantations Sakleshpur, Karnataka.

1.	Sporocarps :	Present in the form of loose aggregates.
2.	Spore (colour and shape) :	Yellow or yellow brown with Globose in shape
3.	Diameter :	71.12 µm.
4.	Spore walls and colour :	Two wall layers, light yellow and hyaline. Light yellow hyaline outer wall. Yellow brown inner thick walls.

Plate 6. Identified efficient native VA mycorrhizal spores

(a) Glomus caledonicum (isolated from Kerala Cardamom plantations)

(b) Glomus fasciculatum (isolated from Karnataka Cardamom plantations)



5. Wall thickness: 7.0 µm

6. Spore contents: Light yellow oil globules.

Hyphal description :

1. Thickness of hyphal wall : Thin walled hyphae

2. Attachment of hypha : Cylindrical in shape.

3. Diameter at the point of attachment : 10 µm.

4. Wall colour : Yellow brown.

Based on the above characters the fungus was identified as Glomus fasciculatum (Thaxter sensu Gerdemann).

DISCUSSION

DISCUSSION

Vesicular arbuscular mycorrhizal fungi are known to form a mutualistic symbiotic association with a great majority of crop plants. It is well documented that these fungi enhance plant growth through increased uptake of diffusion - limited nutrients and alleviating various plant stresses including diseases (Linderman 1988, Sharma *et al*. 1992, Vaast and Zasoski 1992, Zhi 1993).

Research findings in the last three decades have shown that VA mycorrhizal inoculation is very useful in transplantable crops as it results in healthy vigorously growing seedlings with a profuse sturdy root system (Linderman and Hendrix 1982, Fogher *et al* 1986, Vidal *et al* 1992). Many research studies have indicated that VA mycorrhizal endophytes form a preferential association with certain hosts (Mosse 1975, Reena and Bagyaraj 1990).

Selection of efficient VA mycorrhizal fungi is a prerequisite to obtain maximum response under defined soil conditions. Many workers in their study have observed varied effects of different VA mycorrhizal fungi on plant growth (Plenchette *et al* 1982, Nalini *et al* 1986). This emphasizes the need for selecting efficient VA mycorrhizal fungi for inoculating mycotrophic crop plants. No research study has been made earlier to know the symbiotic response of cardamom to these beneficial fungi. Hence it was contemplated to screen an efficient VA mycorrhizal fungus

for inoculating the highly priced spice crop of India, the cardamom.

In order to study the response of cardamom to VA mycorrhizal fungi a primary screening trial was conducted at UAS, GKVK Bangalore. The study was done under mat house condition using thirteen different VA mycorrhizal fungi obtained from various sources around the world and maintained at germplasm bank of the university.

I Primary screening trial

The various VA mycorrhizal fungi used in primary screening trial influenced the growth of cardamom (cultivar Malabar) differently. In general plants inoculated with VA mycorrhizal fungi grew taller and had more number of leaves, increased leaf area and root length and had more number of tillers compared to the uninoculated plants. However, among the 13 different VA mycorrhizal fungi tested, Gigaspora margarita and Glomus monosporum inoculation resulted in better plant growth compared to other VA mycorrhizal treatments and control. Such kind of enhanced plant growth due to VA mycorrhizal inoculation has also been earlier repc ted on important plantation crops like cacao, coffee and oil palm (Cabala Rosand and Santa 1987, Saggin et al. 1992, Blal and Gianinazzipearson 1990).

Studies conducted by Antunes et al. (1988) in coffee revealed the preferential association with certain VA mycorrhizal fungi. In their studies they found that inoculation of coffee with Gigaspora margarita or Glomus

leptotichum significantly improved plant growth than the plants inoculated with Glomus macrocarpum or Gigaspora heterogama. The results of the present study clearly showed that plants inoculated with Gigaspora margarita, Glomus monosporum and Glomus fasciculatum had nearly twice the plant dry weight compared to uninoculated plants. This kind of increased plant biomass, because of VA mycorrhizal inoculation, has been reported earlier in pepper (Piper nigrum. L) by Sivaprasad et al. (1990). Their study brought out that preinoculation of pepper plants with Glomus fasciculatum and Glomus etunicatum resulted in increased plant height and had more shoot and root dry weight. A similar report on increase in root dry weight due to inoculation with efficient VA mycorrhizal fungi was reported by Krishna et al. (1983). They found that the root dry weight of cashew (Anacardium occidentale) was significantly increased following inoculation with Glomus fasciculatum but not with Gigaspora calospora though both formed good mycorrhizal association. In the present study inoculation of plants with Gigaspora margarita and Glomus monosporum resulted in maximum plant biomass though all the VA mycorrhizal fungi used formed mycorrhizal colonization of the roots.

The main effect of VA mycorrhizal fungi in improving plant growth is through increased uptake of diffusion limited nutrients, especially phosphorus. Increased p uptake has been attributed not only to increased

surface area of absorption (Sanders and Tinker 1971) but also due to enhanced translocation (Hatting et al 1973). In general it was found that plants inoculated with VA mycorrhizal fungi had higher phosphorus content in both shoot and root than the uninoculated plants. More so plants inoculated with Gigaspora margarita, Glomus monosporum and Glomus fasciculatum resulted in higher shoot and root p content. These results brought out that the VA mycorrhizal fungi which resulted in enhanced plant biomass also resulted in enhanced plant p content. A similar trend was observed by Sirohi and Singh (1983) on Mentha piperita (Peppermint) when it was inoculated with Glomus fasciculatum. They found increased mycorrhizal root infection, total root length, shoot dry weight, p uptake (both organic and inorganic) and oil yield.

In the present study, inoculated plants, in general, had significantly more iron, copper and zinc compared to uninoculated plants. The most efficient mycorrhizal fungi enhancing uptake of iron, copper and zinc were Gigaspora margarita, Glomus monosporum, Glomus fasciculatum and Glomus mosseae. These results support the earlier findings of Zhi (1993) who found enhanced uptake of K, Cu and Fe in tea plants inoculated with Glomus fasciculatum.

In the present study inoculated plants had more number of VA mycorrhizal spores and had higher percentage of mycorrhizal colonization in root compared to uninoculated

plants. However the extent of colonization varied with the endophyte. Cardamom plants inoculated with Gigaspora margarita and Glomus monosporum had the maximum number of chlamydospores and per cent mycorrhizal root colonization than all other treatments. These results show that a direct relationship exists between plant dry weight, uptake of nutrients especially P and the endophyte association in terms of per cent root colonization and spore numbers in the rhizosphere soil.

Taking into consideration all the growth parameters, six VA mycorrhizal fungi were selected as promising fungi to be used in the secondary screening trials for further selecting an efficient VA mycorrhizal fungus suitable for inoculating cardamom. The fungi selected were Gigaspora margarita, Glomus monosporum, G. fasciculatum, G. mosseae, G. intrar ices and Acaulospora laevis.

Isolation of native VA mycorrhizal fungi

Soil samples collected from the root zone of cardamom grown in different parts of South India were wet sieved and based on spore morphology eight fungi of predominent occurrence were brought into pot culture. Out of the 8 native fungi brought in to pot culture 3 were from Karnataka and 5 were from Kerala. All the native VA mycorrhizal fungi belonged to the genus Glomus. Two fungi which fairly improved cardamom growth were identified upto species level. They were Glomus fasciculatum from Karnataka and Glomus caledonicum from Kerala. These native VA

mycorrhizal fungi were mass multiplied and used in the secondary screening along with the fungi selected from the primary screening trial.

II Secondary screening trial at Sakleshpur, Karnataka

Six promising VA mycorrhizal fungi selected from the primary screening trial and three predominent native fungi of the region were used in this trial. In general cardamom plants (Cv. Malabar) inoculated with isolates selected from primary screening performed better in improving plant height, number of leaves, leaf area, root length, number of tillers and plant biomass compared to the native isolates. Among the nine VA mycorrhizal fungi tested plants inoculated with Glomus monosporum was the best in improving the plant growth attributes. The next best fungi were G. mosseae, G. fasciculatum and Gigaspora margarita. Increased plant growth due to introduced endophyte has earlier been reported by Barea et al. (1980) in Medicago sativa. They found that the introduced VA mycorrhizal fungi became successfully established and improved plant growth and nutrition better than the indigenous mycorrhizal fungi. The present study supports their finding as the introduced VA mycorrhizal fungus Glomus monosporum successfully established and improved the growth of cardamom compared to the native isolates.

Increased plant growth due to VA mycorrhizal inoculation has also been reported in important plantation and spice crops (Raon 1986, Iqbal and Nasim 1986a).

Ikram (1990) in his trial with Hevea brazilensis found 70 percent increased dry weight due to VA mycorrhizal inoculation in a sandy clay loam soil where no P was supplemented.

The research findings of the present study upholds the view of Tinker (1983) that mycorrhiza plays an important role in plant nutrition specially in the uptake of P and minor nutrients like Zn and Cu. In the present study plants inoculated with VA mycorrhizal fungi had more shoot and root phosphorus compared to the uninoculated plants. Maximum shoot and root P content was recorded in plants inoculated with Glomus monosporum followed by Glomus mosseae. This increased uptake of nutrients may be due to well developed root system together with the extensions of fungal hyphae which increase the surface area of absorption.

Treeby (1992) found that VA mycorrhizal inoculation increased the supply of iron to citrus plant in an acidic soil. Ezeta and Santos (1981) found that cacao plants grown in sterile soil were stunted and showed zinc deficiency symptoms. When these plants were inoculated with Gigaspora margarita they recovered after 15 weeks and showed more zinc uptake compared to uninoculated plants which remained stunted. In the present study cardamom plants inoculated with Glomus monosporum resulted in increased uptake of micronutrients like iron, copper and zinc.

Inoculated plants harboured more number of extramatrical chlamydospores in the root zone soil and also had higher percentage of mycorrhizal root colonization. Maximum number of spores and per cent colonization occurred in plants inoculated with Glomus monosporum. The results of the Sakleshpur trial has clearly elucidated that the introduced VA mycorrhizal fungus Glomus monosporum can establish well in a new soil ecosystem and can compete well with the native strains in improving the growth and nutrition of Malabar cultivar of cardamom.

Myladampara Trials

The secondary screening at Myladampara, Kerala was done with two important cardamom cultivars, Mysore and Vazukka. Six promising VA mycorrhizal fungi selected from primary screening and five dominant native endophytes isolated from the root zone of cardamom plantations of Kerala were used in this trial.

Cultivar Mysore

In general a positive response in plant growth was observed due to VA mycorrhizal inoculation. Most of the isolates selected from primary screening trial were found to be more efficient in improving the growth of cardamom seedlings compared to the the native isolates. Among the different fungi used in this study, Glomus monosporum was the best in improving plant growth and nutrition of cardamom cultivar Mysore.

Cultivar Vazukka

In contrast to Mysore cultivar, Vazukka cultivar responded significantly to inoculation with native VA mycorrhizal fungi also. However, the response of cardamom to inoculation with exotic fungi selected through primary screening trial was much more compared to the response to inoculation with native endophytes.

Cultivars of crop plants varying in response to inoculation with different fungi has been reported earlier (Bagyaraj and Sreeramulu 1982, Sreenivasa and Rajashekara 1989, Tewari et al. 1993). However, maximum response of Vazukka was encountered when inoculated with Glomus monosporum. The next best fungus was Glomus fasciculatum.

An interesting finding of the present study is that Glomus monosporum enhanced the growth and nutrition of 'Malabar' cultivar of cardamom grown at Sakleshpur, Karnataka and also that of 'Mysore' and 'Vazukka' cultivars grown at Myladampara, Kerala. While selecting an efficient fungus for inoculation, important criteria to be taken are -

i) its ability to enhance the growth of the popular varieties of a crop plant commonly cultivated by the farmers and

ii) its ability to enhance the growth of the crop grown in different soils and agroclimatic regions. Glomus monosporum can thus be selected as the most efficient VA mycorrhizal fungus for inoculating cardamom nursery in Karnataka and Kerala. This fungus can be mass

multiplied and supplied as an inoculant strain for cardamom. The simple technology of introducing the mycorrhizal inoculum at the nursery can easily be followed by the farmers.

Cardamom now - a - days is multiplied through tissue culture. The ex-plants coming out of the flasks are hardened in small cups in pro-trays before transferring them to polybags or planting in the field. Glomus monosporum which has been selected as the best fungus for inoculating cardamom can be inoculated to the substrate in small cups or polybags at the time of hardening so that healthy, vigorously growing seedlings can be produced. This aspect needs to be examined in future. Further, field performance of seedlings inoculated with Glomus monosporum versus uninoculated seedling planted in the field, especially for fruit yield, needs further investigation. This can be an interesting area for future study.

SUMMARY

A primary screening trial to test the response of cardamom to 13 different VA mycorrhizal fungi, maintained at the culture collection bank of the university was conducted under mat house conditions in the Department of Agricultural Microbiology, University of Agricultural Sciences, GKVK Campus, Bangalore. Based on the primary screening results 6 promising VA mycorrhizal fungi for inoculating cardamom were selected. VA mycorrhizal fungi associated with cardamom were isolated from cardamom plantations of Karnataka and Kerala and brought in to pot culture. Thus 3 native VA mycorrhizal fungi from Karnataka and 5 native fungi from Kerala were obtained. Using the 6 promising isolates from the primary screening and the native fungi, secondary screening trials were conducted. The secondary screening trial was conducted at Sakleshpur, Karnataka with cardamom cultivar Malabar and 9 VA mycorrhizal fungi (6 from the primary screening plus 3 native fungi). Secondary screening at Myladampara, Kerala was done with cardamom cultivars Mysore and Vazukka and 11 VA mycorrhizal fungi (6 promising fungi from primary screening plus 5 native fungi).

In general the results brought out that cardamom plants respond well to VA mycorrhizal inoculation. Significant increase in plant height, number of leaves, leaf area, number of tillers per plant, root length and total

plant dry weight were noticed in inoculated plants. Enhanced P, Zn, Cu and Fe content were also found in the inoculated plants compared to the uninoculated plants.

Based on the results of the secondary screening studies, taking in to consideration the various plant biometric parameters and symbiotic efficiency, it was concluded that Glomus monosporum is the most efficient fungus for inoculating cardamom irrespective of cultivars and agroclimatic zones. Glomus fasciculatum was the next best fungus that can be used both in Kerala and Karnataka.

Since cardamom is a transplanted crop the research findings of this study is of much help to the cardamom planters for the routine usage of small quantities of efficient VA mycorrhizal inoculum in their cardamom nurseries. Transfer of this simple low cost input agricultural technology among the cardamom planters will play an important role in getting healthy and vigorous seedlings which will perform better when planted in the field site.

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APPENDICES

Appendix A

Export of cardamom (small) from India

Year	Quantity (Tonnes)	Value (Rs. million)	Unit Value (Rs./kg.)
1975-76	1941	193.8	99.88
1980-81	2345	347.5	148.18
1981-82	2325	302.0	129.87
1982-83	1032	163.7	158.60
1983-84	258	55.4	210.90
1984-85	2383	648.1	271.92
1985-86	3272	535.6	163.39
1986-87	1447	185.0	127.80
1987-88	270	35.0	125.80
1988-89	787	103.7	131.76
1989-90	173	31.4	181.50
1990-91	400	108.7	271.75
1991-92	544	155.7	286.21
1992-93	190	75.1	395.04
1993-94 (P)	338	136.7	404.47
1994-95 (E)	255	73.7	289.08

(P) - Provisional ; (E) - Estimate

Source : Upto 1987-88 : Daily lists of exports from customs.

From 1988-89 : DGCI&S, Calcutta/Shipping bills/ Exporters' returns.

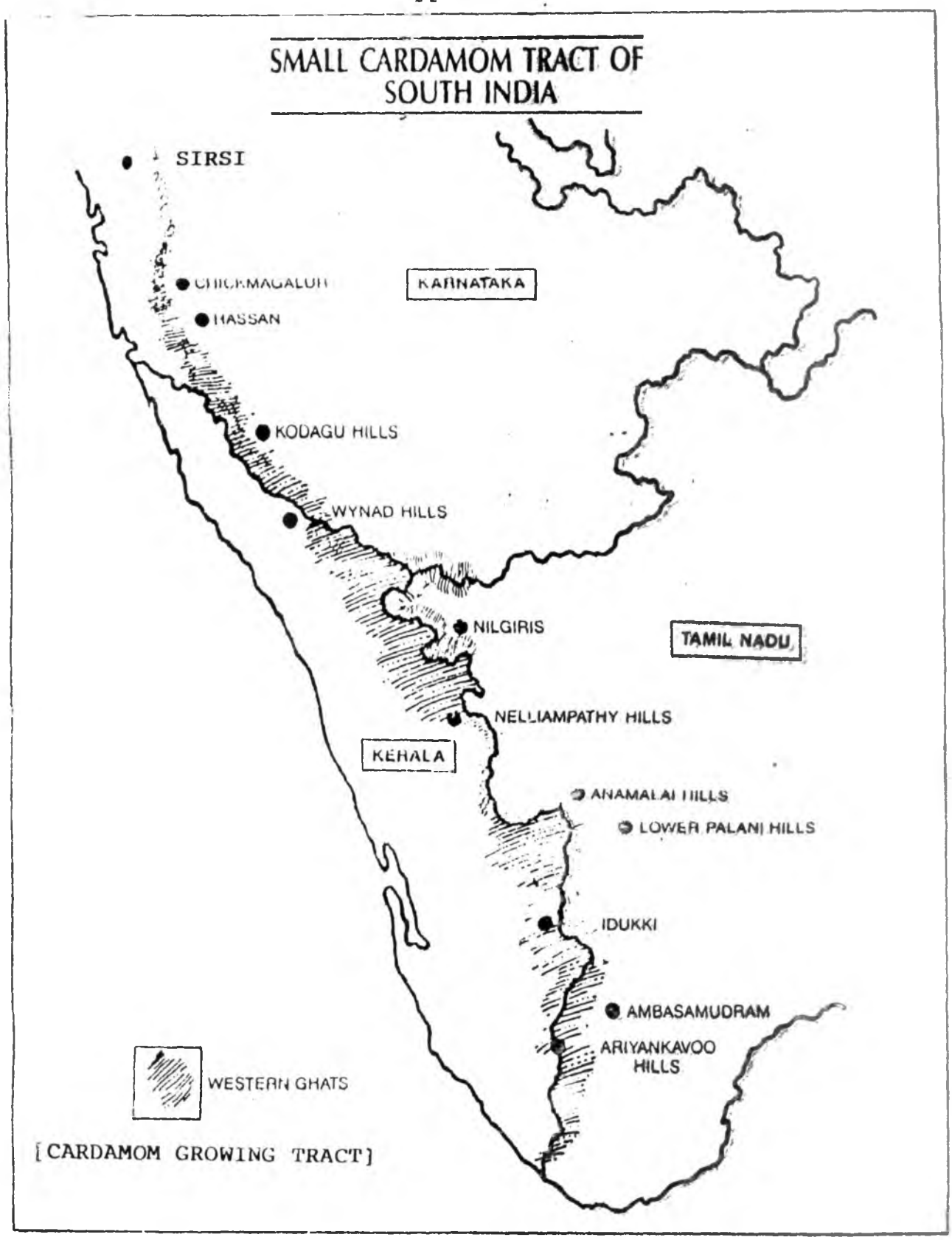
Appendix B

District-wise area under small cardamom in India in 1989-90

State / District	Total Area (Ha)	% share in state	% share in India	Yielding area (Ha)
Kerala State (Districts)				
Idukki	32139.270	73.03	39.62	575.028
Wynad	4350.012	9.88	5.36	2280.803
Palakkad	3994.059	9.07	4.93	2684.820
Kozhikode	1193.849	2.71	1.47	-
Pathanamthitta	912.537	2.07	1.13	885.548
Kasargod	839.741	1.91	1.04	218.130
Kottayam	204.858	0.47	0.25	103.167
Thiruvananthapura	173.905	0.40	0.21	95.969
Kannur	129.502	0.30	0.16	40.469
Malapuram	70.822	0.16	0.09	30.352
Total :	**44008.555**	**100.00**	**54.26**	**33914.286**
Karnataka State (Districts)				
Kodagu	14344.237	46.38	17.68	10602.363
Hassan	6657.234	21.52	8.21	3036.621
Chickmagalur	6332.668	20.47	7.81	4225.841
Dakshina Kannada	1636.244	5.29	2.02	1227.908
Uttar Kannada	1497.145	4.84	1.84	599.584
Shimoga	456.951	1.48	0.56	203.443
Mysore	6.475	0.02	0.01	6.475
Total :	**30930.954**	**100.00**	**38.13**	**19902.235**
Tamilnadu State (Districts)				
Madurai	1951.910	31.62	2.41	1186.070
Nilgiris	1068.693	17.31	1.32	872.440
Tirunelveli	1038.255	16.82	1.28	652.929
Coimbatore	856.724	13.88	1.06	631.188
Anna	463.278	7.50	0.57	412.489
Kamarajar	435.091	7.04	0.53	306.584
Kanyakumari	322.070	5.22	0.40	259.747
Salem	37.604	0.61	0.04	34.577
Total :	**6173.625**	**100.00**	**7.61**	**4356.024**
Grand Total :	**81113.134**		**100.00**	**58172.545**

Source : Report of the survey for Assessment of area under small cardamom in India 1991. Spices Board, Ministry of commerce, GOI, Cochin - 682 018.

Appendix C


SMALL CARDAMOM TRACT OF SOUTH INDIA
SIRSI
CHICKMAGALUR
HASSAN
KARNATAKA
KODAGU HILLS
WYNAD HILLS
NILGIRIS
TAMIL NADU
NELLIAMPATHY HILLS
KERALA
ANAMALAI HILLS
LOWER PALANI HILLS
IDUKKI
AMBASAMUDRAM
ARIYANKAVOO HILLS
WESTERN GHATS
[CARDAMOM GROWING TRACT]

Appendix D

Area, production and productivity of cardamom(small) in India

Year	Total area (Ha)	Effective Yielding area (Ha)	Production (Tonnes)	Productivity (Kg.per Ha)
1984-85	100000	51350	3900	76
1985-86	100000	61040	4700	77
1986-87	100000	66670	3800	57
1987-88	105000	69050	3200	46
1988-89	105000	69750	4250	61
1989-90*	81113	58170	3100	53
1990-91	81554	61240	4750	78
1991-92	81845	62831	5000	80
1992-93	82392	61134	4250	70
1993-94	82960	60845	6600	108
1994-95	83651	61930	7000 (P)	113

(P) - Provisional.

* The area under cardamom has been revised in 1989-90 based on a complete enumeration survey. Area for subsequent years has been updated based on field sample survey.

Appendix E

Nutrient status of Different soils

Sl. No.	Soil Characters	GKVK	Sakleshpur	Myladampara
1.	Coarse sand (%)	34	51.13	50.02
2.	Fine sand (%)	40	32.83	30.00
3.	Silt (%)	6	7.17	9.11
4.	Clay (%)	20	6.13	8.00
5.	Texture	Sandy clay loam	Sandy loam	Sandy loam
6.	pH	5.6	5.5	5.8
7.	OC (%)	0.45	1.25	1.40
8.	P (kg/ha)	13.50	9.0	13.0
9.	K (kg/ha)	158.89	145.00	162.40
10.	Zn (ppm)	0.65	0.84	1.17
11.	Cu (ppm)	0.58	0.66	0.72
12.	Fe (ppm)	8.50	12.9	14.57
13.	B (ppm)	0.48	0.40	0.52