Lemongrass

P.P. Joy
Kerala Agricultural University

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P. P. Joy
Baby P. Skaria
Samuel Mathew
Gracy Mathew
Ancy Joseph
P.P. Sreevidya

KERALA AGRICULTURAL UNIVERSITY
AROMATIC AND MEDICINAL PLANTS RESEARCH STATION
Odakkali, Asamannoor-683 562, Ernakulam District, Kerala, India
Tel: 0484-2658221, Fax: 0484-2659881
Email: amprs@satyam.net.in, Website: www.kau.edu/amprs

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Preface

Lemongrass is a tropical perennial plant which yields aromatic oil. Aromatic or essential oils are highly concentrated secondary metabolites of diverse functions in plant system. They constitute hundreds of organic compounds including terpenoids, benzenoids, organic sulphur and nitrogenuous compounds, which work at different levels. The name lemongrass is derived from the typical lemony odour of the essential oil present in the shoot. Lemongrass oil of commerce is popularly known as Cochin oil in the world trade, since 90% of it is shipped from Cochin port. The state of Kerala in India had the monopoly in the production and export of lemongrass oil. The annual world production of lemongrass oil is around 1000 t from an area of 16000 ha. In India, it is cultivated in about 4000 ha and the annual production is around 250 t. The crop is extensively cultivated in poor, marginal and waste lands and also along the bunds as live mulch. The well ramified root system of the plant helps in soil and water conservation.

Dried lemongrass leaves are widely used as a lemon flavour ingredient in herbal teas, prepared either by decoction or infusion of 2-3 leaves in 250 or 500 ml of water and other formulations. Lemongrass tea is a diuretic and imparts no biochemical changes to the body in comparison with the ordinary tea. Lemongrass iced tea is prepared by steeping several stalks in a few quarts of boiling water. This can also be combined with green or black teas.

Lemongrass is commonly used in Asian cookery. When Thai food was embraced in the US, lemongrass became a household name. A little experimentation with this delightfully fragrant herb is all it takes to realize that it can be used in many more ways than just in Asian dishes. A simple syrup made by steeping lemongrass in a mix of equal parts hot water and sugar can be used to enhance fruit salads or to make home made soda by mixing it with seltzer. A blend of lemongrass, garlic, ginger and oil will be stable in the freezer during winter. This paste can be fried until fragrant and then cooked down with a can of coconut milk (strain to remove tough lemongrass fibres) for delicious sauce for noodle, vegetable or seafood dishes.

Lemongrass oil is used in culinary flavouring. It is used in most of the major categories of food including alcoholic and non alcoholic beverages, frozen dairy desserts, candy baked foods, gelatines and puddings, meat and meat products and fat and oils. It is used to improve the flavour of some fish and can be used to flavour wines, sauces etc. Lemongrass oleoresin is mainly used in flavouring foods, drinks and bakery preparations.

Traditionally lemongrass is developed for perfumery with emphasis on citral content. The largest collection of lemongrass germplasm at AMPRS, Odakkali offers immense scope for the identification and development of types most suitable for flavouring. This promotes product diversification in lemongrass industry necessitating increased area and production under lemongrass. The growers are also benefited as the crop serves dual functions of producing both essential oil and oleoresin required by the fragrance and flavouring industry fetching better net returns. As these products have higher export demand, it will also benefit the national exchequer.

This is a compendium of information on lemongrass collected from varying sources. We hope that this will serve as a concise and authentic source of basic information on all aspects of lemongrass cultivation and utilization. It is intended to be an excellent practical manual and reference material for students, researchers, entrepreneurs, extension personnel, farmers and all concerned with lemongrass.

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Authors

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1 Introduction

Lemongrass is a tropical perennial plant which yields aromatic oil. The name lemongrass is derived from the typical lemon-like odour of the essential oil present in the shoot. The herb originated in Asia and Australia. Lemongrass was one of the herbs to travel along the spice route from Asia to Europe. Lemongrass oil of commerce is popularly known as Cochin oil in the world trade, since 90% of it is shipped from Cochin port. The state of Kerala in India had the monopoly in the production and export of lemongrass oil. The annual world production of lemongrass oil is around 1000 t from an area of 16000 ha. In India, it is cultivated in an area of 4000 ha and the annual production is around 250 t. The crop is extensively cultivated in the poor, marginal and waste lands and also along the bunds as live mulch. The well ramified root system of the plant helps in soil and water conservation.

2 Species and varieties

Lemongrass belongs to the family *Graminae* (Poaceae) and the genus *Cymbopogon*. Generally, three species are identified (Gupta, 1969; Chandra and Narayanan, 1971).

2.1 *Cymbopogon flexuosus* (Nees ex Steud) Wats. (2n=20, 40)

It is known as East Indian, Cochin or Malabar grass. *C. flexuosus* is a tufted robust perennial grass of about 2 m height. The leaves are linear and lanceolate. It flowers freely. The inflorescence is very large and highly branched terminal drooping panicle bearing paired spikes on tertiary branches. The spikes bear spikelets in pairs of which one is sessile and the other pedicellate. The sessile spikelet is an awned bisexual floret where as the pedicellate is an awnless staminate floret. Under this species two varieties or types are identified based on the colour of stem.

C. flexuosus var. *flexuosus* – It is red grass. The stem and leaf sheath are reddish or purple in colour. It is recognized as the true lemongrass and is commercially cultivated (Fig. 1.1-3). The essential oil contains more than 75-80% citral, exhibits good solubility in alcohol and hence is superior in quality (Guenther, 1950). The geranial rich variants of *C. flexuosus* with high oil content could be useful as additional sources of geraniol and not as an alternative to geraniol from *C. martinii* (Kulkarni *et al,* 1996).

C. flexuosus var. *albescens* – This white grass is characterized by the white colour of the stem. The plant is normally seen wild. The essential oil contains less than 65-70% citral, exhibits poor alcohol solubility and is hence considered inferior in quality.

2.2 *Cymbopogon citratus* (DC) Stapf. (2n=40, 60)

It is known as West Indian or American lemongrass. It is a stemless perennial grass with numerous stiff tillers arising from short rhizomatous rootstock, making large tussocks. It seldom flowers under cultivation. Leaf blade is narrow, linear, glaucous, drooping with scabrous margin, ligule truncate, inflorescence rarely produced, a large loose panicle; spathe bracts long and narrow, sessile spikelets, awnless , linear, lanceolate. The essential oil contains 74-76% citral and exhibits poor solubility.

2.3 *Cymbopogon pendulus* (Nees ex Steud) Wats.

It is Jammu lemongrass and is white stemmed and dwarf in nature. The plant is frost resistant and suited to Sub-Himalayan areas of North India. The essential oil contains around 75-80% citral and exhibits medium solubility in alcohol (Joy *et al,* 2001).

1. Lemongrass
in full bloom

2. A lemongrass plant
with leaves, leaf sheath, stem
and inflorescence separated

3. Lemongrass seed

4. Lemongrass planting
in progress

5. Lemongrass plantation
ready for cutting and distillation

6. Field distillation unit

7. Clevenger
apparatus for
lab distillation

8. SOXTEC SYSTEM 2043
FOSS Analytical AS, France
for solvent extraction of oleoresin

9. HPLC and GLC systems
for quality evaluation

Fig. 1 Lemongrass plant, cultivation, extraction and quality evaluation systems

3 Origin and distribution

Lemongrass is distributed in Africa, Indian subcontinent, South America, Australia, Europe and North America. In India, they grow wild in all regions extending from sea level to an altitude of 4200 m. Several species are endemic to India. East Indian Lemongrass grows wild in India and is cultivated well in Kerala, Assam, Maharashtra and Uttarpradesh. It is also distributed in Guatemala and China. West Indian lemongrass is believed to have originated either in Malaysia or in Sri Lanka. It is widely distributed throughout the tropics and is grown in West Indies, Guatemala, Brazil, Congo, Tanzania, India, Thailand, Bangladesh, Madagascar and China. Jammu lemongrass is mostly confined to North Indian states such as Jammu and Kashmir, Sikkim, Assam, Bengal and Madhya Pradesh (Handa, 2001). Lemongrass is cultivated on large scale at Chinnar wildlife sanctuary in the Western Ghats of India (Nair and Jayakumar, 1999).Traditionally lemongrass is grown in high rainfall area as a rainfed crop in Kerala state. But under semi-arid tropical conditions, it is grown as irrigated crop (Singh, 1999).

4 Cultivation and production

4.1 Climate

C. flexuosus and *C. citratus* flourish in sunny, warm, humid conditions of the tropics. In Kerala, lemongrass grows well between 900 and 1250 m from mean sea level. Both species produce highest oil yield per tonne of herbage where the rainfall averages 2500-3000mm annually. *C. citratus* is more drought tolerant (Weiss, 1997). In areas where rainfall is poor, it can be grown with supplemental irrigation. Day temperature of 25-30°C is considered optimum for maximum oil production, with no extremely low night temperature. Short periods above 30°C have little general effect on plants, but severely reduce oil content. The plant is hardy and resistant to draught. Maximum plant height was recorded during rainy season and least during second harvest non- rainy season. The yield of oil fluctuates greatly with the season, the condition of the plant material, its moisture content and the age of planting (Singh, 1999). The effect of seasonal changes in oil content of lemongrass was investigated during the year 1979-1980. The role of many environmental components like temperature, rainfall, relative humidity and soil moisture on the variation of oil content under the agroclimatic condition of North Eastern region is discussed. The monsoon span is characterized by higher oil content, while the winter and autumn by comparatively lower oil content. However, the above major environmental components individually seem to have no direct relationship with the oil content. The influence exerted by the climatic factors is cumulative in exertion (Handique *et al*, 1984).

Four field experiments were conducted under the semi-arid tropical climate of Andhra Pradesh to study the response of different varieties of lemongrass to NPK fertilizer applications under different spacings. The improved cultivars *Cauvery* and *Pragati* outyielded the existing, widely cultivated variety OD-19 in respect of essential oil yield consecutively for two years, hence could be recommended for large scale cultivation under irrigated conditions in the semi-arid tropical climate. Lemongrass responded to application of 100 kg N/ha under irrigated conditions and 75 to 80 kg N/ha under rainfed condition. Essential oil concentrations and quality were not affected by N application. Lemongrass did not respond to application of P and K fertilizers or to different plant spacing under rainfed condition. Biomass and essential oil recovery was maximum during summer season harvest in all the varieties and the results were identical for two consecutive years (Rao *et al*, 1998).

4.2 Soil

Lemongrass flourishes in a wide variety of soil ranging from rich loam to poor laterite. In sandy loam and red soils, it requires good manuring. Calcareous and water-logged soils are unsuitable for its cultivation (Farooqi and Sreeramu, 2001). Both species can be grown on a range of soils and it appears that good drainage is the most important factor. Plants growing in sandy soils have higher leaf oil yield and citral content. Although *C. flexuosus* flourishes in well drained sandy loams but in India, it is grown in almost all types of land available from very light sandy soil to upland laterites. Soils of pH 5.5 to 7.5 are utilized. *C. citratus* is more commonly grown on soils with higher acidity than *C. flexuosus*. In India, the highest herb and oil yields per hectare of *C. flexuosus* are obtained in soils of pH 7.5. Lemongrass will grow and produce average herbage and oil yields on highly saline soils. In pot trials *C. flexuosus* grown in soils with electrical conductivity of 11.5,10 and 5.5 mmhos/cm showed no significant reduction in herb and oil yield and the citral content was unaffected by increasing salinity levels up to 15 mmhos/cm (Weiss, 1997). It grows well on poor soils along hill slopes (Ranade, 2004). Behura *et al* (1991) studied the performance of five aromatic *cymbopogon* species – palmrosa, jamrosa, citronella, *C. pendulas* and *C. flexuosus* in chromite overburden soil of Kaliapani, Orissa. The findings on growth parameters, herb and oil yield of this species for six successive cuttings at RRL Bhuveneswar showed that in herb yield and economics of oil production, the natural hybrid jamrosa was found to be the suitable cymbopogon grass for plantation in chromite overburden area.

Some essential oil yielding plants (*Cymbopogon* sp., *Pogostemon* sp. *and Matricaria* sp.) have been tried to introduce in the agro climatic conditions of the Gangetic plains of Hooghly district, West Bengal. Agrotechnological studies clearly revealed the possibility of commercial cultivation of *Cymbopogon* (*C. flexuosus, C. martinii and C. winterianus)*. *C. flexuosus* (OD-19) crop proved to be promising, showing better growth, oil yield and oil quality and the crop might be commercially exploited in this area for diversification of crop pattern and upliftment of rural economy (Ghosh, 1989).

4.3 Cultivated varieties

Lemongrass varieties released for cultivation are Sugandhi, Pragati, Praman, RRL-16, CKP-25, RRL-39, Kavery, Krishna, SD-68, GRL-1 (Farooqi and Sreeramu, 2001) and SB-9 (Patra *et al*, 1999).

Sugandhi (OD-19): Released from the Aromatic and Medicinal Plants Research Station (AMPRS), Odakkali, Kerala, India. A red stemmed variety adapted to a wide range of soil and climatic conditions and most popular in India. The plant grows to a height of 1-1.75 m with profuse tillering, yielding 35-40 t/ha/year herb containing 0.3% oil (125 kg/ha) with 80-85% citral under rain-fed condition (Joy *et al*, 2001).

Pragati (LS-48): Evolved through clonal selection from OD-19 at Central Institute of Medicinal and Aromatic Plants (CIMAP), Lucknow, India. It is tall growing with dark purple leaf sheath, adapted to North Indian Plains and Tarai belt of subtropical and tropical climate. Average oil content is 0.63% with 86% citral (Sharma *et al,* 1987).

Praman (Clone 29): It is evolved through clonal selection at CIMAP, Lucknow and belongs to species C. *pendulus*. It is a tetraploid type with profuse tillering. Leaves are erect and medium in size. Oil yield is 227 kg/ha/annum with 82% citral content (Anon, 1988).

RRL-16: It is evolved from C. *Pendulus* and released for cultivation from Regional Research Laboratory (RRL), Jammu, India. Average yield of herb is 15 to 20 t/ha/annum giving 100 to 110 kg oil. Oil content varies from 0.6 to 0.8% and citral content is 80% (Anon, 1983).

SD-68: Developed by SC Datta, using ionizing radiation yielded up to 375 kg of oil/ha/year with a citral content of 90-92 % (Nair, 1977).

RRL-39: Released from RRL, Jammu.

Kavery and Krishna: Released from CIMAP Regional Station, Bangalore, India. Krishna has longer and narrow looking leaves when compared with other *C. flexuosus* varieties, Cauvery, pragati and OD-19 (Kulkarni *et al,* 1997).

Chirharit: A high yielding variety, developed by systematic breeding for genetic improvement at Pantnagar, Chirharit, India. It is frost resistant and the essential oil contains 81% citral (Patra *et al*, 2001).

RLJ-TC-7, RLJ-TC-8, RLJ-TC-11: Released from RRL Jorhat. These three accessions shows higher percentage of geraniol and oil, and may be considered as geraniol rich varieties, that can be grown under North – East Indian climatic conditions for production of oil. (Sharma, Sarma and Handique, 2005)

Lemongrass germplasm consisting of about 406 accessions is maintained at AMPRS, Odakkali. There are 17 other types in the germplasm in which the major constituent of the oil is not citral.

4.4 Propagation

Lemongrass is generally propagated through seeds. Seed is mixed with dry river sand in the ratio of 1:3 and sown in the field at the rate of 20 to 25 kg/ha. Alternatively, seedlings can be raised in a nursery in one-tenth of the area of the main field and transplanted after 45 days. This method which requires 3-4 kg seeds/ha is ideal for uniform stand and better growth of the plants. Small plantation of lemongrass can be established by planting of slips.

C. flexuosus is propagated through seeds while *C. citratus* is propagated through division of clumps (Anon, 1981). Hussain and co-workers (1988) reported that propagation through vegetative means from selected clones was considered better as seed propagation tended to cause considerable genetic heterogeneity resulting in deterioration of yield and oil quality and clonal proliferation played a very important role in the propagation of lemongrass. In a number of field experiments, the growing population of geranium, menthol-peppermint and palmrosa, citronella and lemongrass were sprayed with varying amount of salicylic acid once or twice. It was observed that salicylic acid application did not affect the herbage and essential oil yields as well as the quality of essential oil in all these essential oil crops examined (Ram *et al,* 1997).

Genetic variability and trait interrelationship were studied in an open pollinated seed population produced from the OD-19 variety of lemongrass. Large amount of variability was found to exist with regard to oil content, herb yield, plant height, number of tillers, leaf length and breadth, leaf pubescence and pigmentation on leaf base sheath. Studies indicated that oil content was not related in its expression to any of the above traits. It was found that herb yield was positively correlated with tallness, larger number of tillers/plant and long and broad leaves (Nair *et al,* 1984).

Seeds of lemongrass variety OD-19 were subjected to gamma irradiation at a dose range of 0-30 k rad and its effect on yield attributes was studied. Among the six doses tried, 20 k rad dose effected significant increase in citral percentage than achieved by 10 k rad dose (Shylaraj and Thomas, 1988).

A study was conducted for two years to test the performance of clonal and seedling progenies of lemongrass type, OD-440. From a two year study of the comparative performance of the seedlings progenies and clonal progenies raised using the slips of parents; it was conclusively proved that this type was a stabilized one. Hence the fluff of the type could also be used for cultivation just like slips without affecting the quality of the type (Shylaraj, 1988)

Field trials on lemongrass *C. citratus and C. flexousus* were conducted from 1979 to 1983 to test the effect of plant to plant spacings of 15 cm and 22.5 cm with four levels of nitrogen viz, 0, 20, 40 and 60 kg/ha. There was no significant effect of spacings on *C. citratus*. Increasing levels of N increased the yield up to 60 kg N/ha. In *C. flexousus* closer spacing of 15 cm significantly gave higher yield. Increasing levels of nitrogen up to 60 kg N /ha significantly increased the herbage yield (Prasad and Rao, 1986).

Studies at CIMAP Lucknow showed that cultivation of perennial lemongrass, palmrosa and Indian basil could be suggested for the efficient utilization of natural resources and higher economic returns from rain fed areas of sub- tropical North India (Singh *et al*, 1999).

4.5 Nursery raising

For one hectare of land, 1000 m^2 nursery has to be raised. The area is made to good tilth by repeated ploughing. Beds of 1 to1.5 m width and convenient length are prepared. The recommended seed rate is 3-4 kg/ha. The seeds are uniformly broadcasted on the beds and are covered with a thin layer of soil. The seed bed is irrigated frequently. Lemongrass seeds have a dormancy of a few weeks and they lose viability in a few months. The seeds collected during the months of January-February are usually sown in the nursery during April-May. Seeds germinate in 5-7 days. Seed viability will be lost in a few months. Germination is very poor if sown after October.

4.6 Transplanting

The seedlings raised in the nursery beds are transplanted in the field at 6-7 leaf stage. 50-70 days old seedlings are planted during the monsoon season (Fig.1.4). A spacing of 30 cm x 30 cm with a plant density of 111 000/ha is recommended. A wider spacing of 60 cm x 45 cm for seedlings and 90 cm x 60 cm for slips has been recommended for fertile, irrigated land under North Indian conditions (Farooqi *et al*, 1999). Lemongrass was tested with three spacings and different fertility levels under poplar for its performance in Kumaon foot hills for two years. The spacing of 45 cm x 45 cm and fertility level of N_{250} P_{100} K_{180} were proved to be superior in respect of number of tillers , plant height, herbage yield and oil yield when compared to other treatments in the first and second year, respectively. The oil content and quality of the oil was similar in all the treatments (Yadava and Singh, 1996).

4.7 Manuring

Spent lemongrass compost at 10 t /ha and wood ash at 2 t /ha, which are obtained as by-products of grass distillation, are applied at the time of bed formation (Hussain *et al*, 1998). Lemongrass requires 275 kg N, 50 kg P_2O_5 and 175 kg K_2O/ha/annum. Under rainfed conditions of Kerala, application of 100 kg N in 3 to 4 split doses was found to be optimum though a response up to 200 kg was recorded. The application of 50 kg/ha each of P_2O_5 and K_2O as a basal dose gave encouraging results in West Bengal. It is recommended to apply 60:45:35 kg /ha N, P_2O_5 and K_2O basally and 60 kg N in 3 to 4 splits /annum as top dressing during the growing season as an optimum dose. It also responds well to the application of copper, iron, calcium and sulphur. It was reported from CIMAP, Lucknow that a lower dose of boron (2.5 ppm) in combination with chloride salts (chloride salinity) can be beneficial for the crop (Farooqi and Sreeramu, 2001).

In chromate overburdened soil, application of lime at 6 t/ha and fertilizer at 100 kg N, 50 kg P_2O_5 and 50 kg K_2O/ha produced higher plant height, tiller number and herb yield of *C. pendulus* (Behura *et al,* 1998).

Soluble nitrogen fraction and total carbohydrate content increased essential oil content. Pattern of formation of citral in *C. flexuosus* oil revealed that the constituents increased up to reproductive phase and then declined, it again increased after post-reproductive phase of the plant. Optimum application of fertilizers increased the citral content of the oil (Ghosh and Chatterjee, 1991). Excess fertilizer application is undesirable as it promotes more vegetative growth and oil with less citral content (Joy *et al*, 2001). The content and chemical composition of lemongrass oil were not affected by nitrogen application. Performance of lemongrass varieties at varying nitrogen level showed that application of 200 kg N/ha and variety *Krishna* gave significantly higher yield than other varieties. Application of nitrogen fertilizers increased the herb yield significantly in all the five years (Singh, 2000).

A simple randomized field experiment was conducted at Aligarh, with eight levels of basal nitrogen doses and three harvests to study the effects on height, culms, leaves, fresh and dry weight, herb yield, oil content, oil yield and citral content of lemongrass (*Cymbopogon flexuosus Nees ex Steud wats. var. flexuosus*). Application of nitrogen showed significant effect with 300 kg N/ha proving optimum for almost all characters under study (Samiullah *et al*, 1988).

A field experiment was conducted during 1991-1993 at Banglore to study the response of lemongrass cv. Cauvery (*C. flexuosus* Steud. Wats.) to nitrogen applications (0, 50, 100, and 150 kg N/ha/year)under irrigated conditions in a semi-arid tropical climate. Growth attributes namely plant height, leaf area index and tiller production per clump, herbage and oil yield were significantly increased with 100 kg N/ha. Oil content and quality of oil were not affected by nitrogen (Singh and Singh, 1998).

4.8 Irrigation

In case of drought, the crop should be irrigated every alternate day for about a month after planting. It is recommended that 4 to 6 irrigations are given during the period from February to June under North Indian conditions, for optimum yield. Soil moisture regimes maintained at 0.80 IW: CPE ratio significantly increased crop growth, herbage and essential oil yields. Quality of the essential oil is not affected by soil moisture regimes (Singh *et al*, 1997). A study at CIMAP field station Bangalore showed that growth, herbage, oil yield and nitrogen uptake increased due to increased levels of water regimes except nitrogen utilization efficiency during rainy season (Singh, 1997). Another study at CIMAP field station Bangalore showed that plant growth characters, herbage and oil yield were influenced by the irrigation level (Singh, 2000). Eleven genotypes belonging to three species of *Cymbopogon -flexousus, pendulas* and *martin*i var.motia were subjected to unirrigated and irrigated conditions of soil and compared for their performance of economic traits and pooled divergence. Herb yield and oil yield suffered the most and leaf width and citral content of oil the least under stress (Pandey *et al*, 1998).

At CIMAP Luknow, fourteen genotypes belonging to five species of *Cymbopogon C. flexusous, C. pendulas, C. martinii. var. motia, C. winterianus* and *C. caesius* were subjected to irrigated and non- irrigated moisture regimes, to screen out potential genotypes having tolerance to water stress and understand the behaviour of stress tolerance. The interspecific comparison to stress tolerance revealed reduction of performance for early vigour, tillering vigours, growth vigours and production vigour in all the species except *C. martini* for oil yield. The response of different varieties / genotypes to unirrigated regime in terms of percentage loss in vigour was -21.1 to -42.7% for early vigour and -10.5 to -51.2 % for tillering vigour(Misra *et al*, 1999).

4.9 Weed control

The first 25-30 days after planting (or harvest) is the crop-weed competition period. For a good establishment of the crop, the field should be kept weed free for the initial period of 3-4 months after planting. Once the crop is well established, it can compete with weeds.

Generally, 2-3 weeding are necessary in a year. Among herbicides, diuron at 1.5 kg ai/ha and oxyfluorfen at 1.5 kg ai/ha are effective for weed control (Hussain *et al*, 1988). Duhan and Gulati (1973) and Khosla (1979) observed a significant control of dicot weeds with the application of 2-4-D (sodium salt). They also suggested spraying paraquat at 2-2.5 l/ha in 500 l of water immediately after cutting the grass as an excellent method of weed control.

Under rain-fed conditions, the field gives a dried appearance during the summer months of Dec – May. The dry grass and stubbles of the crop is set on fire in May, prior to the onset of monsoon. This practice kills the termites attacking crop stubbles and also helps to rejuvenate the old clumps.

4.10 Intercropping

The plant does not tolerate shade and oil yield is drastically reduced when the crop is grown under diffused light (Pareek and Gupta, 1985). Studies at AMPRS, Odakkali indicated poor tillering, lean and lanky growth and reduced oil yield when the crop is grown as intercrop in coconut gardens; the oil content was also found to be reduced by 20%. In contrast, intercropping in cinnamon plantation which is regularly pruned for extraction of bark and leaf oil was found to be profitable. In new plantations of cashew, mango and coconut, lemongrass is cultivated during the initial 4 to 5 years of plantation establishment. *C. citratus* is seldom intercropped or under-planted. An interesting method of integrating *C. flexuosus* into plantations of other crops was proposed for Bangladesh, but not widely implemented (Khan, 1979). *C. citratus* has been under-planted in young rubber plantations in Malaysia and elsewhere to help defray cost of plantation establishment. Pratibha and Korwar (2003) suggested lemongrass for crop diversification in semi-arid regions.

Agroforestry trials were conducted at the CIMAP field station Pantnagar, Nainital, for five consecutive years on performance of aromatic crops such as lemongrass (*C. flexuosus*), citronella java (*C. winterianus*), palmrosa (*C. martini*) and japanese mint (*Mentha arvensis*) in eucalyptus plantation. Results indicated that performance of lemongrass was the best with respect to sustained herb and oil productivity during entire growth period. This raised the possibility of co-cultivation of poplar and aromatic crops especially lemongrass would be an ideal adjunct to ensure high nutrient recycling in soil for a productive and sustained agro-forestry system. (Chauhan *et al*, 1997).

4.11 Plant protection

4.11.1 Pests and their management

Few pests are reported in this crop. The infestation by the spindle bug (*Clovia bipunctata*) has been observed at Odakkali and severe damage by a stem boring caterpillar of *Chilotrea* sp. under North Indian conditions have been reported. Spraying malathion (0.2%) can control the insects. Nematodes like *Tylenchorhynchus vulgaris*, *Rotylenchulus reniformis*, *Helicotylenchus* spp. and *Pratylenchus* spp. have also been found to infect the grass.

4.11.2 Diseases and their management

The common diseases and their causal agents are given in Table 1. These leaf diseases can be managed by prophylactic sprays of dithane Z-78 @ 3g/l thrice, at intervals of 15 days.

Table 1. Common diseases of lemongrass and their causal agents

Disease	Causal organism
Little leaf (malformation of inflorescence)	*Balensia sclerotica* (Pat) Hohnel
Leaf spot (eye spot)	*Helminthosporium saccharii*, *H. leucostylum*, *Drechslera victoria* and *D. helm*
Leaf spot	*Curvularia andropogonia* (CLS)
Leaf spot	*C. veruciformis*, *C. trifolii* and *Collitotrichum graminicola*
Leaf spot and clump rot	*Fusarium equiseti* and *F. verticillium*
Leaf blight	*Curvularia andropogonia* (CLB)
Leaf blight	*Rhyzoctonia solani*.
Grey blight	*Pestalotiopsis magniferae*
Smut	*Tolyposporium christensenni* and *Ustilago andropogonis*
Root rot	*Botrydiplodia theobromae*

Helminthosporium cymbopogi caused very serious disease in the low lands of Guatemala. Brown top disease causes browning and curling of affected leaves. This is a physiological disease resulting from the low water content of the grass at the end of the dry season. Symptoms of rust disease of lemongrass causing elongated, stripe like, dark brown lesions on both sides of leaf surfaces have been described. The causal organism is *Puccinia nakanishikii* (Koike and Molinar, 1999). Root segment of lemongrass were heavily infested with multiple vesicular arbuscular mycorrhiza (VAM). Moreover, brown septate hyphae of non-mycorrhizal fungus also co-existed with VAM in 50% of root segments (Hussain and Ali, 1995). Burning of stubbles in summer is practised in some areas to ward off pests, diseases and weeds. Fifteen resistant and one susceptible accessions were identified among the available genetic stocks of lemongrass against rust, *Puccinia nakanishikii*. The behaviour of the F_2 generation plants arising from spontaneous crosses between the resistant and susceptible accession showed that the susceptible accession harboured recessive alleles of the genes present in dominant allelic forms in the resistant accession (Singh *et al,* 1999)

4.12 Harvesting of the herb

Harvesting is done by cutting the grass 10 cm above the ground level, with the help of sickles. The number of harvests in a year depends on the climatological factors such as temperature, rainfall and humidity and level of soil fertility. Generally the crop thrives best in humid condition (Handa, 1997).

Cutting can begin as soon as the nights dews have evaporated from the plants, as wet grass left for later distillation quickly ferments. Sunny days are preferable, since cloudy and misty conditions tend to depress leaf oil content.

Chandra *et al* (1970) have suggested first harvest at 75 days after planting, second at 120-130 days after first harvest and the third at150-160 days after second harvest. However, Nair *et al* (1979) and Shiva (1998) have suggested that first harvest can be taken at 90 days after planting and subsequent harvest at 50-55 days interval up to 5-6 years from the same crop (Fig.1.5). Rao *et al* (2005) reported five months for the citral content to reach a maximum for the first and the sixth harvest.

During the first year of planting, three cuttings are obtained and subsequently 5-6 cuttings per year (Subramanyam and Gajanana, 2001). The harvesting season begins in May and continues till the end of January. An herbage yield of 10-15 t/ha/harvest may be obtained. The herb yield of lemongrass differed significantly between years. The yield in the second year was significantly higher than that of the first, third, fourth and fifth year (Singh, 2000).

4.13 Seed collection

Lemongrass kept for seed purpose is not cut as yield of seeds from plants subjected to regular harvest is very low. Generally, the plant flowers during November/December in plains and mature seeds are collected during January / February. A healthy plant gives 10 to 20 g of seeds. The whole inflorescence is cut and dried in the sun and seeds are collected by thrashing against the floor or beating with sticks. Fresh seeds are recommended for use in raising a plantation since the seeds lose viability beyond six months of storage. Seed germination is very poor till May, increases up to July and thereafter decreases. Germination is meager beyond October (Thomas, 1995).

4.14 Processing

4.14.1 Distillation

Lemongrass oil is collected by steam distillation of the herbage. Experiments with the Western Indian type of lemongrass in Florida, Hood found that drying of the grass prior to distillation result in only small loss of oil. The solubility of oils distilled from dried grass decreased more rapidly on aging than the solubility of oils distilled from fresh material (Guenther, 1950). There are three types of distillation.

Hyrodistillation: This method is used when plant material is dried and will not be damaged by boiling. In this method the material comes in direct contact with water (Guenther, 1958). The material to be distilled is put in a vessel partly filled with water. It may float on the water or be completely immersed, depending on the specific gravity of herb. The vessel is heated by any of the usual methods *i.e.*, direct fire, steam jacket, closed steam coil, *etc*.

Hydro and Steam distillation: This method is used for either fresh or dried plant material that would be damaged by boiling. The most important aspect of this method is that the steam remains at low pressure which keeps the process cooler than the other method of distillation (Ranade, 2001). In this method, the plant material is loaded on a grid fitted at some distance above the bottom of the still. The lower part of the still is filled with water to a level below the grid. The typical features of this method are (a) the steam is always fully saturated, wet and never superheated and (b) the plant material is in contact with the steam only and not with the boiling water.

Steam distillation: In this method, no water is added to the still. Instead, saturated or superheated steam is introduced through open or perforated steam coils below the charge.

The distillate separates out as a layer of oil, distinct from a layer of water (Fig.1.6). For obtaining good quality oil, steam distillation in stainless steel units is preferred with a steam pressure of 18-32 kg/cm^2 in the boiler. The grass is distilled either fresh or after wilting. Wilting herbage prior to distilling reduces moisture content and increases oil recovery. Drying in the sun reduces oil recovery but has little effect on oil composition. Generally, Clevenger apparatus (Fig.1.7) is used for distilling small quantities (up to 1.0 kg) of the herb in the laboratory. Large field scale distillation units (Fig.1.6) could be fabricated to distill 500 kg or more of the herb at a time. On an average the herbage of *C. flexuosus* contains 0.2-0.4% oil and the oil yield is 100-125 kg/ha/year.

Oil of lemongrass is a viscous liquid, yellow to dark yellow or dark amber in colour turning red with age. Presence of water makes a turbid appearance. Differentiation of lemongrass oils as West Indian or East Indian in trade is not significant as oils from both the species are produced in both the areas. The main difference is that West Indian oil has less citral and more myrcene than the East Indian oil. Both oils have a pronounced fresh lemony odour but that of East Indian is stronger (Kamath *et al*, 2001). East Indian is considered fresher, lighter and sweeter. Whole oil is mainly used as a source of citral.

Morphological characters like plant height, number of tillers/plant and number of leaves/plant exhibited significant correlation with essential oil yield/plant at flowering stage. Maximum elimicin content of 50%, as a major chemical constituent of oil had also been observed at flowering stage. Among the physiological characters, a significant correlation was observed between essential oil content and crop growth rate (r=0.6018) as well as net assimilation rate (r=0.9474).

Gupta *et al* (1987) reported that oil content in lemongrass was 0.29% and 0.63% on fresh and dry weight basis, respectively. Nair and Shekharan (1974) also observed similar oil content in this crop. Values of specific gravity and refractive index of oil are comparable to Indian standard for oil of lemongrass, IS327. Citral content (82%) is higher than that of the recommendation of Indian Standard.

Studies of Kurian *et al* (1984) on the effect of antioxidant on the preservation of citral content in lemongrass oil showed that most of the anti-oxidants change the colour of the oil to some darker shade making it difficult to measure the optical activity. This change was found to be aggravated on aging. The odour is also found to be modified to some extent with the effect of these anti-oxidants. The specific gravity in most of the treatments was enhanced above the specific range also this was true with the control. Refractive Index and solubility of the oil in 70 % alcohol were not much volatile.

If stored in aluminium or stainless steel vessel out of contact of air, water and light, the quality of oil is stable for long periods of time. The following care is taken to protect the essential oil from deterioration on long time storage.

1. The essential oil should be pre- treated to remove metallic impurities.
2. The oil should be clarified by NaCl treatment.
3. Small amount of oil may be stored in hard or dark coloured glass bottles, while large quantities should be stored in heavily tinned metal containers.
4. The oil should be stored at a place away from light (Raina *et al*, 1998).

The study of the effect of seasonal changes on essential oil yield, growth, absicic acid content and ^{14}C acetate incorporation in the oil of lemongrass showed that growth was inhibited in the winter season. ABA content and ^{14}C acetate incorporation increased during winter but was at a low level in the actively growing plants in summer. However, variations in essential oil content were not observed (Farroqi *et al*, 1998).

Absorption and emission spectra of the oil of Cymbopogon species (*C. martini, C. winterianus. C. flexuosus, C. microstachys and C. jwarnacusa*) have been recorded in the visible and ultraviolet region using Beckmann DU 70 spectrophotometer and JY 3cs spectrofluorometer respectively. Results reveal that although the same group of organic compounds dominate in all the oil, *C. flexuosus, C. microstachys and C. jwarnacusa* contain some additional organic compounds. Two different natures of the excited states have been identified (Rai and Singh, 1991).

Ten different essential oils were taken for testing them against eight dermatophytes, which were known to cause skin infections. First of all the essential oils were tested separately for their efficacy against dermatophytes and then they were tested in different combinations. It was concluded that the antifungal activity of the essential oils increased remarkably in combination against dermatophytes (Saksena and Saksena, 1984).

4.14.2 Solvent extraction

Lemongrass oleoresin can be extracted by following methods using different solvents.

Maceration- This involves macerating the plant material in a suitable solvent (eg. hexane), filtering and concentrating the extract. The advantage of this method is that it uses cold solvent, which reduces the chances of decomposition. However, it takes longer time and consumes greater volume of solvent.

Percolation- In this method, the solvent is made to percolate through a column of the material. It is quicker and uses less solvent, but decomposition due to heat may occur. *Soxhlet extraction* is a form of continuous percolation with fresh solvent, and uses special glassware. The plant material is separated from the extract by encasing in a paper 'thimble'. When full, the solvent in the thimble siphons off into the main vessel containing the extract and the process continues. The advantage is that fresh solvent continuously extracts the marc more efficiently with a minimum of solvent; however, heating is again a disadvantage (Fig.1.8).

Choice of solvent

If the type of compounds being isolated is known, selective solvent extraction will make the process safer. If not, the usual way is to start with a non-polar solvent and exhaustively extract the marc, followed by a series of more polar solvents, until several extracts of increasing solute polarity are obtained. These may then be used for further evaluations (Williamson *et al,* 1996).

4.14.3 Spent grass

The residue obtained after extraction of the oil is called spent grass. It can be used fresh as roughage for cattle or used for ensilaging. It can be used for mulching or manuring crops as such or after enriched composting. In some plantations in India, the spent lemongrass after drying is used as a fuel for distillation. It is also a cheap packaging material. The spent lemongrass contains 7.4% crude protein, 0.17% Ca and 0.09% P. It is also used for the manufacture of cardboard and paper (Nair, 1977).

5 Physiology and Biochemistry

A quick and non- destructive method of leaf area estimation has been worked out by Joy and Thomas (1990). A direct relationship between chlorophyll (influencing primary metabolism) and odour bearing constituents (secondary metabolites) was noted (Sharma *et al,* 1988). Maffei *et al* (1988) suggested that lemongrass may possess a C_4 photosynthetic mechanism. The differential oil and citral synthesis in specific genotypes over diverse seasons may be due to physiological homeostasis as production of essential oil is the criterion of the homeostatic features of bioenergetic balance as well as developmental feed back mechanism (Sharma *et al*, 1988). Application of Well Bloom, a tricontanol containing growth regulator had no significant effect on oil yield and citral content though a favourable effect on herbage yield was recorded (Sankar and Thomas, 1990). Repeated application of 10 to 100 ppm of IAA, IBA, NAA or GA_3 increased oil content significantly though herbage yield and citral content were not affected. It was suggested that these growth substances influenced the enzymes of carbohydrate metabolism which in turn ensured high demand of hexoses required for essential oil synthesis (Anon, 1983).

Synthesis of terpenoids in plants takes place in secretory cells in leaves. It has been claimed that the precursors of essential oils are obtained by the degradation of carbohydrate and proteins. Ghosh and Chatterjee (1976) highlighted the phenomenon of decrease in total and protein nitrogen in the plant concomitant with the increase in essential oil content as evidence to the above hypothesis. Steps involved in the biosynthesis of monoterpenes were reviewed by Akhila and Nigam (1983). Activities of mevalonate kinase and phosphomevalonate kinase in lemongrass leaves were reported by Lalitha and Sharma (1986) which suggested the possibility of mevalonoid route to citral synthesis. Verma *et al (*1987) suggested the presence of a geraniol citral enzyme complex controlled by independent genes which have no competitive influence on each other in lemongrass. Singh *et al (*1989) have shown that young expanding leaves are biogenetically more active and that the leaf age and the leaf position are important factors for the amount and composition of the essential oil. Singh and Luthra (1987) reported that the ability to synthesise oil and citral from ^{14}C-sucrose by lemongrass leaves decreased greatly much before full expansion. Soluble acid invertase was the major enzyme in sucrose break down.

In order to specifically locate the sites of citral accumulation, the Schiff's reagent that stains aldehydes has been used. Using this technique, single oil accumulating cells were detected in the abaxial side of leaf mesophyll, commonly adjacent to the non-photosynthetic tissue and between vascular bundles. The cell walls of these cells are lignified (Lewinson *et al,* 1997).

6 Chemical composition

6.1 Chemical composition of herb

The spent grass on an average contains N 0.74%, P 0.07%, K 2.12%, Ca 0.36%, Mg 0.15%, S 0.19%, Fe 126.73 ppm, Mn 155.82 ppm, Zn 35.51 ppm and Cu 56.64 ppm (Joy, 2003).

6.2 Chemical composition of essential oil

East Indian lemongrass oil contains 75-85% of aldehydes consisting largely of citral. Other constituents in the oil are linalool (1.34%), geraniol (5.00%), citronellol, nerol (2.20%), 1,8 cineole, citronellal (0.37%), linalyl acetate, geranyl acetate (1.95%), α-pinene (0.24%), limonene (2.42%), caryophyllene, β- pinene, β- thujene, myrcene (0.46%), β- ocimene (0.06%), terpenolene (0.05%), methyl heptanone (1.50%) and α-terpineol (0.24%) (Weiss, 1997; Ranade, 2004).

The essential oil of *C. citratus* contains approximately α-pinene (0.13%), β-pinene, delta-3-catrene (0.16%), myrcene (12.75%), dipentene (0.23%), β-phellandrene (0.07%), β-cymene (0.2%), methyl heptanene (2.62%), citronellal (0.73%), β-elemene (1.33%), β-caryophyllene (0.18%), citronellyl acetate (0.96%), geranyl acetate (3.00%), citral b (0.18%), citral a (41.82%), geraniol (1.85%), elemol (1.2%) and β-caryophyllene oxide (0.61%) (Saleem *et al*, 2003a, b).

The average composition of *C. pendulus* oil is reported to be pinene (0.19%), camphene (0.01%), β-pinene (0.16%), car-3-ene (0.04%), myrcene (0.04%), dipentene (0.35%), phellandrene (0.3%), p-cymene (0.36%), methyl heptanone (1.05%), citronellal (0.49%), linalool (3.07%), β-elemene (0.7%), β-caryophyllene (2.15%), citronellyl acetate (0.72%), geraniol acetate (3.58%), citral b (32.27%), citral a (43.29%), geraniol (2.6%), elemol (2.29%) and β-caryophyllene oxide (1.56%) (Shahi, 1997; Sharma *et al*, 2002).

The experiment conducted at CIMAP, Bangalore showed that young leaves of lemongrass oil contained more oil but less citral in the oil than old leaves. During winter months formation of citral appeared to be slow (Rao *et al*, 2005).

Experimenting with the Western Indian type of lemongrass oil at the Puerto Rico experiment station, U.S. Department of agriculture, found that samples of lemongrass oil exposed to air and light suffered the most physical and chemical changes. Their solubility was lowered considerably, the citral content decreased and the specific gravity increased (Guenther, 1950).

The chemical structures of important constituents of lemongrass essential oil are given in Fig. 2 and a gas chromatogram of the oil in Fig. 3.

Citral has a citrus flavour. As a component of fragrance formulations, the use of citral is limited due to its strong tendency to get polymerise, oxidise and discolour. But in spite of all these disadvantages, citral is used in many formulations due to its strong capability to undergo a vast number of interesting reactions (Mestri, 2006).

The geraniol, linalool and citronellol are the most important acyclic terpene alcohols used as flavour and fragrance substances. In flavour compositions, geraniol is used in small quantities to accentuate citrus notes. Nerol is used for bouquetting citrus flavours. Citronellol is added for bouquetting purposes to citrus compositions. Pinene is an important starting material in the fragrance and flavour industry.

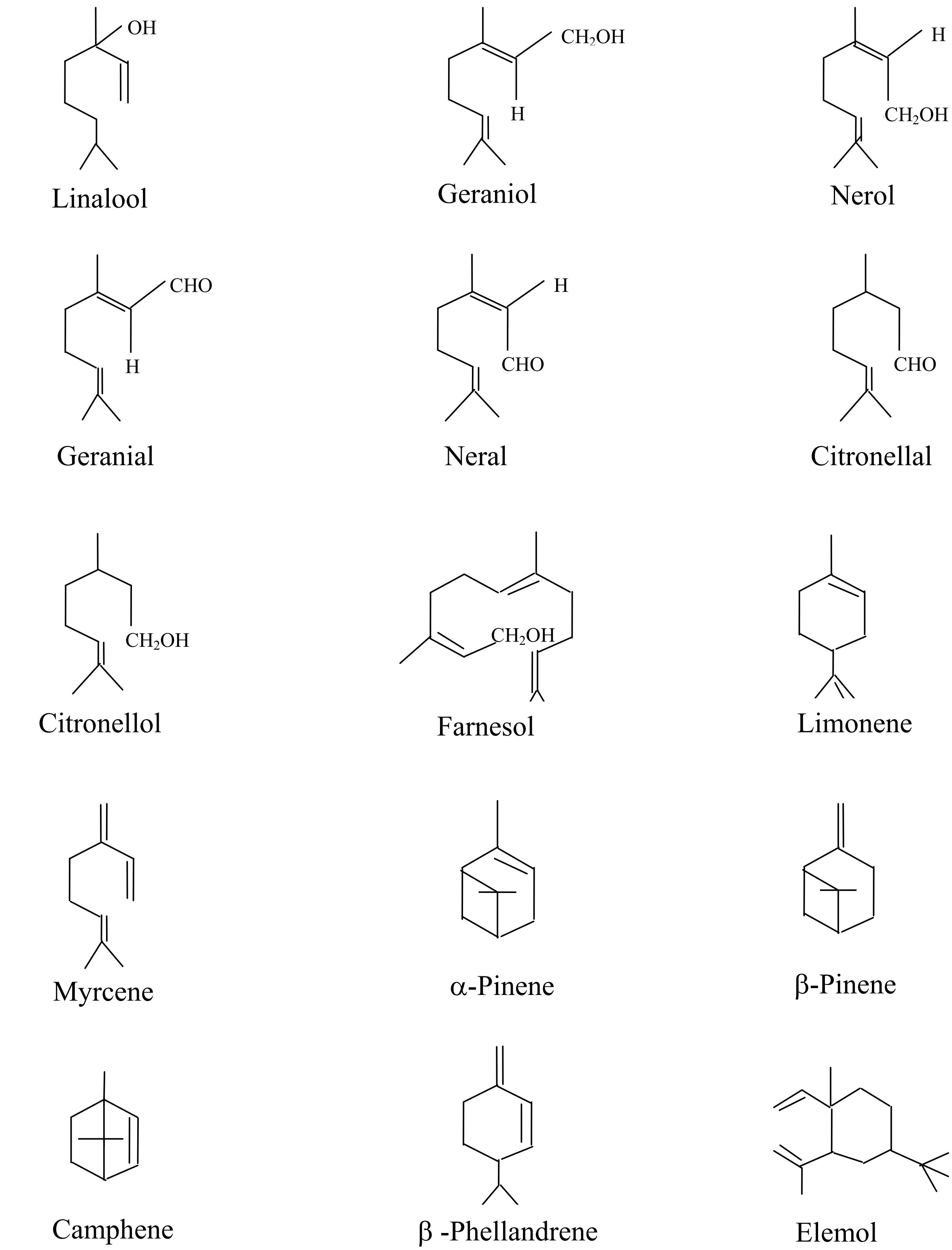

Fig. 2 Chemical structures of important constituents of lemongrass essential oil

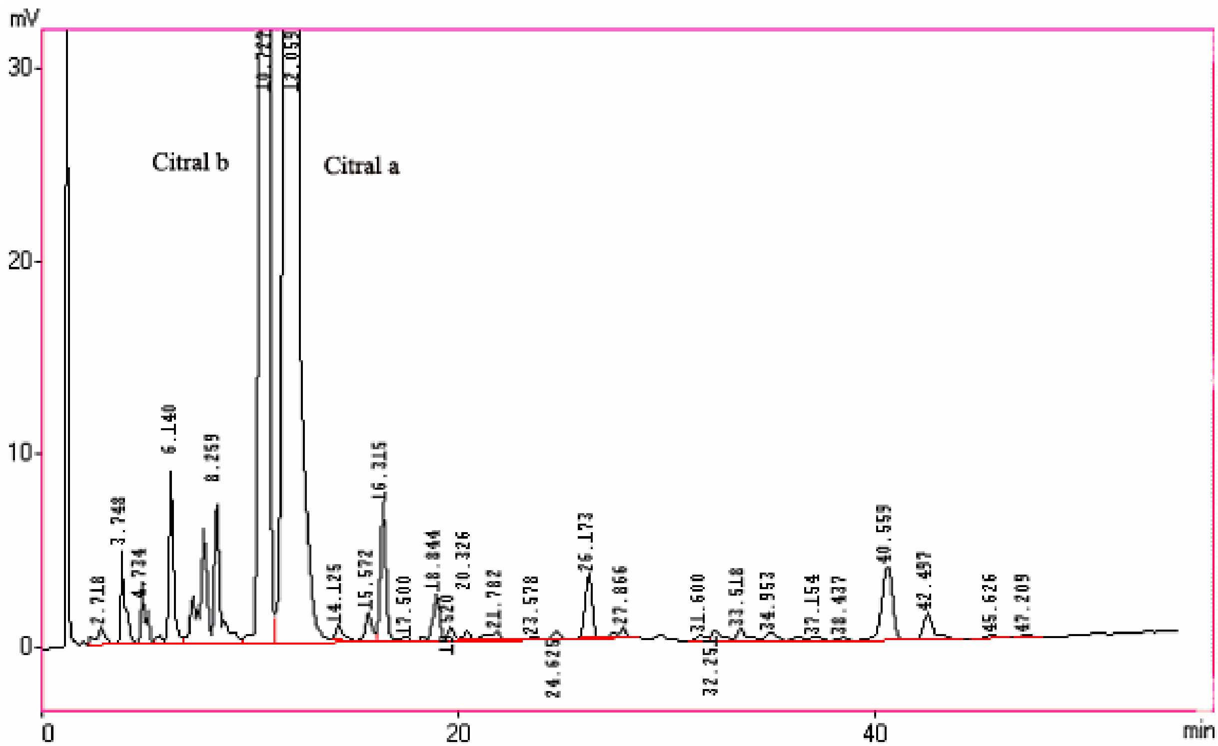

Fig. 3 Gas chromatogram of lemongrass oil (*Cymbopogon flexuosus*)

GC conditions:- column : 3.2 mm diameter, 3 m long stainless steel column filled with 5% OV-17 on 80-100 mesh Chromosorb W (HP), oven temperature programmed to rise from 110°C to 230°C at 2°C min^{-1}, injector and detector temperature: 250°C, nitrogen flow rate: 30 ml min^{-1}, injection volume: 2 µl

6.3 Chemical composition of oleoresin.

Oleoresins are total extracts of the natural spice or herb, representing their volatile and non-volatile components. As these are the concentrated extracts, they are used as a diluted dispersion plated on a neutral dry carrier or as a diluted blend in a solubilizing medium such as vegetable oil, to match the desired strength of the ground spice or herb. Oleoresin essentially contains the oil and the resin. When spice oleoresins are used instead of raw spices, the quantity required is generally lower, because of better release and availability of the active principles. The essential oils in these spices give the main flavour attribute to these oleoresins (Mathulla *et al*, 1996). Advantages of oleoresin include instant flavour, standardized flavour and aroma to meet the processed food specifications, good economy and sterilization through the manufacturing process (Mariwala, 2001).

7 Uses in food processing

7.1 Uses of herb

7.1.1 Herbal teas

Dried lemongrass leaves are widely used as a lemon flavour ingredient in herbal teas, prepared either by decoction or infusion of 2-3 leaves in 250 or 500 ml of water (Wannmacher *et al,* 1990) and other formulations. Lemongrass tea is a diuretic and imparts no biochemical changes to the body in comparison with the ordinary tea. Lemongrass iced tea is prepared by steeping several stalks in a few quarts of boiling water. This can also be combined with green or black teas.

7.1.2 Health food

Lemongrass is commonly used in Asian cooking. When Thai food was embraced in the US, lemongrass became a household name. A little experimentation with this delightfully fragrant herb is all it takes to realize that it can be used in many more ways than just in Asian dishes. A simple syrup made by steeping lemongrass in a mix of equal parts hot water and sugar can be used to enhance fruit salads or to make home made soda by mixing it with seltzer. A blend of lemongrass, garlic, ginger and oil will be stable in the freezer during winter. This paste can be fried until fragrant and then cooked down with a can of coconut milk (strain to remove tough lemongrass fibres) for delicious sauce for noodle, vegetable or seafood dishes. Lemongrass flavours meat, chicken and seafood dishes of South Asia and South East Asia. It gives Sri Lankan, Thai, Malaysian, Vietnamese and Indonesian dishes their distinctive lemony tang. These countries on the rim of the Indian Ocean have seafood as staple food, and lemongrass takes the edge off the fishy odour.

In Thailand and Indonesia, freshly ground lemongrass is added to spice pastes. The Vietnamese like to prepare their food at the dinner table, mixing meat with fresh herbs, and lemongrass is an essential herb at the table. Vietnamese add the fresh grass to broth in which mutton and beef are cooked. They also smoke meats with chopped grass.

The cuisines of Southeast Asia use coconut milk extensively, and lemongrass goes well with this and other commonly used herbs and spices like ginger, lime leaves, bay leaves, coriander, black pepper, mint and nutmeg. The herb's popularity comes from the mildness of its fragrance, which does not overpower the senses the way lime does. The grass also spices soups and herbal teas. Lemon grass, along with black pepper, is also a remedy for menstrual disorders. The herb decoction is a tonic and digestive (Anon, 2006).

Spiced carrot soup with ginger and lemongrass

Ingredients	*Approximate measure*
1. Carrots, scrubbed and chopped	2 small sized
2. Leek, coarsely chopped	2-3 small sized
3. Onion, diced	2- 3 small sized
4. Celery, diced	1 or 2
5. Ginger, minced	half inch piece
6. Lemongrass	2- 3 stalks
7. Honey	1 tbsp
8. Curry	1 tbsp
9. Cloves, garlic, minced	2 of each
10. Oil	2 tbsp
11. Water	1 cup
12. Lemon juice	half lemon
13. Salt and pepper	to taste

Method:

Sauté leeks, carrots and celery in oil till translucent. Add garlic, curry and ginger. Sauté for several minutes. Add water and bring to a boil. Add honey, lemongrass, outer leaves removed and inner core minced, salt and pepper. Simmer until vegetables are tender. Puree until smooth. Add lemon juice and adjust seasoning. It can be served hot or cold Garnish with thinned yogurt or crème fraiche and parsley or cilantro.

Lemongrass coconut rice

Ingredients	*Approximate measure*
1. Long grain rice	1 cup
2. Lemongrass	2-3 Stalk
3. Coconut milk	three by fourth
4. Bay leaves	2
5. Turmeric	half tsp
6. Salt	to taste

Method:
Wash rice under cold water. Bruise lemongrass by banging it with a heavy knife handle or skillet. Put all ingredients into a saucepan. Slowly bring down to a boil, stirring occasionally. Lower the heat and cover. Simmer for 25 minutes or until all liquid is absorbed. Let sit for 5 minutes with the cover on and then fluff with a fork. Remove bay leaves and serve.

Vegetarian Pad Thai

Ingredients	*Approximate measure*
1. Rice noodles	8 oz
2. Fresh bean sprouts	half cup
3. Peanuts (chopped)	half dry roasted
4. Lemongrass	two stalks
5. Cilantro	seven sprigs
6. Cloves garlic	four
7. Jalapeno	one stemmed and seeded
8. Carrot (diced small)	one medium size
9. Egg	two
10. Peanut oil	one by fourth cup
11. Green onions (thinly sliced)	four
12. Sugar	two tbsp.
13. Lemon juice	three tbsp
14. Catsup	two tbsp.
15. Thai fish sauce (nam pla)	two tbsp
16. Lime	one

Method

The creamy coconut and lemongrass base is loaded with chunks of white meat chicken.

Other Thai lemongrass preparations

Tom Yum Koong – Thai traditional jumbo shrimp soups with lemongrass, lime leaf, mushrooms, chilies paste and lime juice. Garnished with cilantro.

Tom Ka Kai – Sliced chicken breast cooked in coconut milk with mushrooms, galangal, lemongrass, lime leaf and chilies paste. Garnished with cilantro.

Tom Yum Poh Tak – Seafood combination in spicy soup with lemongrass, lime leaf, mushrooms, chilies paste and lime juice. Garnished with cilantro.

Tom Yum Kai – Sliced chicken breast in spicy soup with lemongrass, lime leaf, mushrooms, chilies paste and lime juice. Garnished with cilantro.

Yum – Grilled B.B.Q. beef, pork or chicken steak, sliced and tossed with lime dressing, chilies, red onions, tomatoes, cucumbers and lemongrass. Garnished with lettuce, scallions and mint leaf or sweet basil.

Yum seafood – Combination seafood and tossed with lime dressing, chilies, red onions, tomatoes, cucumbers and lemongrass. Garnished with lettuce, scallions and mint leaf or sweet basil.

7.2 Uses of essential oil

Lemongrass is cultivated for its oil which is used in culinary flavouring. It is used in most major categories of food including alcoholic and non alcoholic beverages, frozen dairy desserts, candy baked foods, gelatins and puddings, meat and meat product and fat and oils. It is used to improve the flavour of some fish and can be used to flavour wines, sauces etc. It is used for the isolation of citral for vitamin A and many other aroma chemicals. The oil has very good smell of natural citral and can be used in citrus perfumes as such. It can be used for flavouring chicken and rice preparation. It is unique flavour for Green tea. The oil has very good aroma therapeutic properties and good medicinal properties (Ranade, 2004). Lemongrass oil was a traditional source of citral. This oil was used as a raw material for the manufacture of ionones and methyl ionones. Lemongrass oil has bactericidal properties. No limit is specified in the use of lemongrass oil in flavours and fragrances. However, citral has certain restrictions as per IFRA guidelines (Ranade, 2004).

Citral, the major component of essential oil in lemongrass, is commonly used in soaps, perfumes, detergents, cosmetics, and candles. Most soaps and aftershaves with a fresh lime fragrance use citral. The essential oil is a popular ingredient in aromatherapy (Anon, 2006).

Lemongrass oil has no adverse effects on the blood, liver function, kidney function, protein, and carbohydrate and lipid metabolism of rats. Studies have failed to detect mutagenic or toxicological reactions in humans (Leung and Foster, 1996).

7.3 Uses of oleoresin

Lemongrass oleoresin is mainly used in flavouring foods, drinks and bakery preparations.

8 Functional properties

8.1 Functional properties of herb

Leaves of lemongrass can be used as a source of cellulose in the manufacture of paper and cardboard. Reduction in root-knot nematode disease was observed in soil amended with leaves of *C. flexuosus*. In the Carribbean, lemongrass is primarily regarded as a fever reducing herb (especially where there is significant catarrh). It is applied externally as a poultice to ease pain and arthritis. In India, a paste of leaves is smeared on patches of ringworm (Chevallier, 2001).

8.2 Functional properties of essential oil

Lemongrass oil is one of the most important essential oils widely used for the isolation of citral. Citral is the starting material for the preparation of ionones. α-ionone is used in flavours, cosmetics and perfumes. β-ionone is used for the synthesis of vitamin A. Citral b, the most common constituent of oil, could be a good inhibitor of β-glucuronidase. The oil has other uses as bactericide, as insect repellant and in medicine (Alam *et al*, 1994; Atal and Kapur, 1997; Rodriguez *et al*, 1997; Sasidharan, 1998; El-Kamali *et al*, 1998; Balz, 1999; Saikia, 1999). Antimicrobial cream, Wisprec made of *Ocimum sanctum* and *C. citratus* remains intact in its activity up to three years from the date of manufacturing (Tiwari *et al*, 1997; Prashanth *et al*, 2002). Its mosquito repellent activity lasts for 2-3 hrs (Oyedele *et al*, 2002). It exhibits significant antifeedant and larvicidal activity against H. *armigera* (Rao *et al*, 2000). It is effective against storage pests (Rajapakse and Emden, 1997). The whole oil has fungicidal properties to plant and human pathogens (Yadav and Dubey, 1994; Mehmood *et al*, 1997; Handique and Singh, 1990; Dubey *et al*, 2000; Cimanga *et al*, 2002) and is potentially anticarcinogenic (Zheng *et al*, 1993; Vinitketkumnuen *et al*, 2003). The essential oils from *C. citratus* have been tested for their cytotoxic activity against P_{388} leukemia cells (Dubey *et al,* 1997). It also exhibited antioxidant activities comparable with α-tocopherol and butylated hydroxyl toluene (Baratta *et al*, 1998, Lean and Mohammad, 1999). It retards mould growth in butter cakes thereby increasing storage life. Oil of *C. citratus* caused egg hatch inhibition (Yadav and Bhargava, 2002). Oil of *C. pendulus* is used for the synthesis of antibacterial drug trimethoxyprim. Z-asarone, a component of oil is used as antiallergic compound. It is used for the development of designer beverages and blends of oils with the desired odour characteristics. It strengthens stomach, stimulates appetite, promotes digestion, and regulates nervous system and vascular expansion. It is a stimulant, antiseptic, febrifuge, carminative, diuretic, anti-inflammatory, anti-diabetic and useful against rickets.

8.3 Functional properties of oleoresin

Oleoresin is preferred over conventional spices due to many advantages

1. Sterile product- Free from pathogens and microbiological contaminants.

2. Standardized product- Active ingredients, colour, flavour and physical properties are standardized and hence facilitate consistency in end-use which is not always possible in raw spices.

4. Versatality and ease of use- The concentrated extract can be diluted to varying strengths to meet the required end-use flavour, colour, taste, etc. The extract can be delivered in multiple forms:

   a) as dry dispersion on appropriate carrier

   b) as liquid dispersion in appropriate media such as oil or water.

5. Uniform dispersion of extract provides

   a) instant flavour release

   b) full release of flavour resulting in lower cost due to higher relative replacement than the ground spice.

6. Concentrated forms reduce storage space and bulk handling and transport requirements.

7. Concentrated and virtually moisture free forms of oleoresin ensure longer shelf life due to minimal oxidative degradation or loss of flavour and eliminate deterioration due to pest, mould etc.

8. Flexibility to develop multiple spice blends if required.

9 Quality issues

9.1 Quality of essential oil

The result of routine physico-chemical analysis and chromatographic examination (Fig.1.9) of the recovered oil are of greater value as criteria of authenticity and source (Humphrey, 1973; Rhyu, 1979). A method of fingerprinting essential oil has been described (AMC, 1980) and is widely accepted not only as a reliable method for determining the quality, source and authenticity of the raw material, but, particularly, whether oil purchased in the bulk are genuine or adulterated.

From a sensory point of view, essential oils collected under laboratory conditions are of little value in indicating the quality of the bulk distilled under commercial conditions from the material under examination. The odour pattern and taste of small scale distilled oils are not reliable and should not be used as a basis for quality judgment.

Laboratory stills: Various types of apparatus for the determination of essential oil proposed by Clevenger (1935) are available (Fig.1.7). That recommended by the Council of Europe Pharmacopoeial Commission represents current laboratory practice as it is convenient to use and facilitates the standardization of distillation conditions to enable the achievement of consistent results. A method for the analysis of small amounts of essential oils by distillation in a microversion of a modified Marcusson apparatus, followed by capillary GC is described by Bicchi *et al* (1980).

The degree of quality control applied to essential oils depends to a large extent on their source, whether they are unprocessed, have been concentrated or de-terpenated and on their intended use. Their sampling analysis and quality assessment demands considerable expertise, a close attention to test procedures and a good understanding of the relationship between physico-chemical characteristics and sensory attributes. Quality judgments should be based on the combined data obtained by physical, chemical and sensory analyses, particularly at the aromatic profile observed under defined conditions (Varghese, 1986).

The sensory qualities of essential oils should be paramount in any evaluation of quality and suitability for use. The evaporation pattern of oil exposed on a smelling strip over a period of time gives very valuable information about its source, age and often its authenticity. For most samples, the odour assessment should be carried out and a judgment made at the following intervals: immediately after dipping, after 1hr, 2hr and 6hr and after standing overnight or for a period of not less than 18 hr. The flavour of the oil should be assessed at an appropriate dilution in diluted sugar syrup or some other appropriate medium (Heath, 1978). In each case, the material under examination should be compared directly with a reserve sample, regularly replaced from acceptable material and maintained under optimum storage conditions, usually refrigerated. Obviously, there will be natural variation between different lots of oils, but these should be within acceptable limits judged by the experience of the assessor. Many of the commercially available essential oils originate in countries remote from those in which they are used so that control is of prime importance in both the selection and acceptance of these materials, particularly for use in food products.

9.1.1 Routine physical tests

Moisture content (ISO 939-1980)
Specific gravity/ Relative density
Optical rotation
Refractive index
Freezing or congealing point
Solubility in diluted alcohol of a stated strength (a table for the preparation of diluted alcohol is given in British Standard BC 2073: 1976).

9.1.2 Chemical tests

Acid value
Ester value before acetylation (for calculation of esters and combined alcohols)
Ester value after acetylation (for calculation of free alcohols)
Ester value after formulation (for calculation of free tertiary alcohols)
Carbonyl value
Phenol content

There are specific tests which should only be used in commercial transactions after full agreement by both parties. In any event, the method employed must be clearly indicated in the test report.

9.1.3 Test methods defined in food chemicals codex III

Determination of: - Acetals
Acid value
Total alcohols
Aldehydes
Aldehydes and ketones
-Hydroxylamine method,
-Hydroxylamine- tert- butyl alcohol method.
-Neutral sulfite method
Chlorinated compound
Esters
Linalool content
Phenols, free phenols,
Residue on evaporation
Solubility in alcohol
Volatile oil content.

9.1.4 Industrial methods

Chromatographic techniques -TLC, Paper chromatography, GLC (Humphry, 1973), Column chromatography, HPLC (Lego, 1984).

Spectrophotometric techniques- Visible range, UV range, IR range

Spectroscopic methods- NMR, mass spectroscopy (MS), usually coupled with GLC (Thomas *et al* 1984).

Kumar and Madan (1979) have described a rapid method for the detection of adulteration in essential oils using an iodide monobromide / mercuric acetate to establish iodine values which can be directly compared with those for genuine oils.

The conventional method used for the determination of citral, the major constituent of lemongrass oil is sodium bisulphite method (Guenther, 1948).

9.1.5 Determination of citral in lemongrass oil (Sodium metabisulphite method)

Materials required

1. Cassia flasks: 100 ml, accuracy: 0.1 ml
2. Water bath
3. Sodium metabisulphite: Prepare saturated solution (approximately 50%) and filter before use. This is to be prepared just prior to use.

Procedure

Add approximately 50 ml freshly prepared saturated solution of sodium metabisulphite into the cassia flask, using a graduated cylinder. Pipette exactly 5 ml of the lemongrass oil into the flask. Shake thoroughly till the contents become a semi solid mass. Immerse the flask in a boiling water bath and shake occasionally until the semi solid compound has gone completely into solution. Add approximately 20 ml of sodium metabisulphite solution, mix well and leave the flask in the bath with intermittent shaking. After 15 minutes, add an additional 20 ml sodium metabisulphite, shake well and keep on the bath undisturbed to allow the oil layer to get separated. After a lapse of about 15 minutes, carefully add few ml of sodium metabisulphite solution to allow the separated oil layer to rise completely into the graduated portion of the stem of the cassia flask.

Any droplets of oil adhering to the sides are made to rise into the neck by gently tapping the flask, and by rotating it rapidly between the palms of the hands. After cooling the flask to room temperature, measure the volume of unreacted oil (V ml).

Calculation

Citral content of the lemongrass oil sample = 100 – (20 x V) % (volume by volume)

Notes

1. After cooling to room temperature, a small amount of precipitate will often be formed at the junction of the oil and the aqueous layers, rendering it difficult to note reading. The difficulty can be overcome by carefully adding a few drops of water with a medicine dropper in such a way that the water runs down along the inside of the neck of the flask and remains temporarily on top of the bisulphite solution.

2. If the oil contains heavy metals, it should be removed by shaking the oil thoroughly with about 1% of powdered tartaric acid and filtering off the residue prior to the determination of citral.

3. The stock of sodium metabisulphite should be fresh. Once opened, use the lot completely or refrigerate the leftover chemical.

4. Citral content obtained by this method will be often 2-5% greater than that obtained in gas chromatographic analysis.

9.1.6 Determination of assay of sodium metabisulphite

Take 0.2 g of sodium metabisulphite in a conical flask of500 ml capacity with a ground in joint stopper (preferably iodine value flask). Add 50 ml of 0.1N iodine solution in KI (for iodine solution, ratio of I_2 to KI should be 1:2 w/w). Keep it for 5 minutes in darkness. Add 5 ml of Con. HCl. Titrate with 0.1 N sodium thiosulphate solution using starch as indicator. Run a blank with 50 ml iodine in KI solution and other reagents as in the above and titrate it against the same 0.1N sodium thiosulphate and find out the iodine solution which has reacted with the metabisulphite and calculate the percentage purity as follows

$$\text{Purity of metabisulphite (\%)} = \frac{(\text{Blank-Titre value}) \times 0.004753 \times 100}{\text{Weight of sample}}$$

Indian Standard Specification for oil of Lemongrass (East Indian oil of lemongrass)

The revised Indian Standard was adopted by The Indian Standards Institution on 20 July 1961, after the draft finalized by the Essential oils and Allied products Sectional Committee had been approved by the Chemical Division Council.

The method for determination of citral content presently being used is the one recommended in the original version of this standard and given under 13.13.1 of IS: 326-1952 Methods of Test for Essential oils, employing a freshly prepared, saturated aqueous solution of sodium bisulphite, approximately 35% (w/v) strength. The committee responsible for the preparation of this standard has agreed to change the strength of the sodium bisulphite solution to the internationally used 30% (w/v) strength.

Terminology

For the purpose of this standard, the definitions of the terms given under 2 of IS: 326-1952 Methods of test for Essential oils shall apply.

Sampling

Representative samples of the material, each sample containing not less than 50 ml, shall be drawn as prescribed under 3 of IS: 326-1952 Methods of Test for Essential Oils.

Requirements

Description- Oil of lemongrass shall be obtained by water or steam distillation of the freshly cut and partially dried grass botanically known as *Cymbopogon flexuosus* Stapf. Family: Graminae.

Oil of lemongrass shall be a clean liquid, free from sediment, suspended matter, separated water and added adulterants.

The oil shall be examined for its colour, clarity, separated water by notes and sediment, as prescribed under 4.1 of IS 326-1952 Methods of Test for Essential Oils.

Solubility- Unless otherwise agreed to between the purchaser and the supplier, oil of lemongrass shall be soluble in 2 to 3 volumes of ethyl alcohol (70% by volume), occasionally with slight turbidity, when tested as prescribed under 8 of IS: 326-1952 Methods of Test for Essential Oils.

9.2 Quality of oleoresin

Oleoresin is extracted by a process of solvent extraction, followed by removal of the solvent to extremely low levels typically less than 25-30 ppm. The quality of the oleoresin is generally evaluated on the basis of presence of active ingredients in desired level.

(a) The "bite" giving resin portion containing combinations of alkaloids, gums, pigments etc.

(b) The "aroma" giving volatile or essential oil component.

The following parameters of the flavour/aroma profile of the oleoresin can be compared with the natural spice application.

i) the case of use in terms of pourability, dispersibility, blending etc

ii) the consistency of flavour, colour, viscosity over repeated batches.

10 References

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