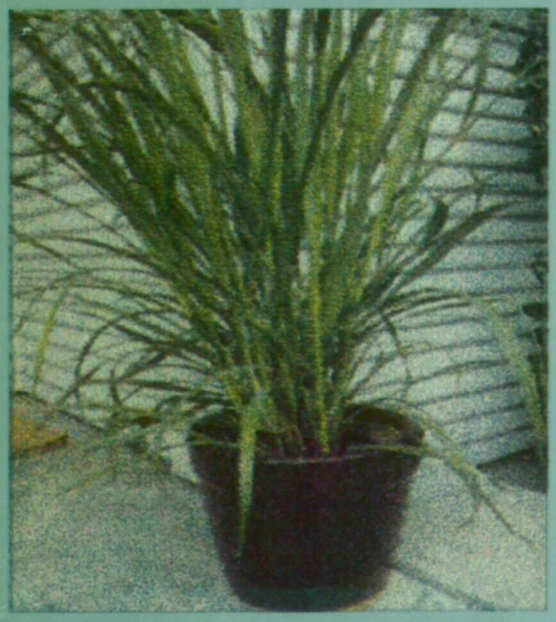
ISSN 1399-5622
ISBN 955-8394-09-2

Medicinal and Aromatic Plant Series, No.9



LEMONGRASS

(*Cymbopogon citratus*)

Information Services Centre
Industrial Technology Institute
(Successor to CISIR)
Colombo, Sri Lanka

Medicinal and Aromatic Plant Series; No: 9

LEMONGRASS

- a literature survey –

Compiled by :
Purnima Jayasinha

Supervised by :
Dilmani Warnasuriya
and
Harshani Dissanayake

National Science Foundation Grant RG/IS/96/01

Published by :
Industrial Technology Institute
363 Baudhaloka Mawatha, Colombo 7, Sri Lanka

1999

First Published in 1999

National Library of Sri Lanka – Cataloguing – In – Publication Data

Jayasinha, Purnima
Lemongrass (*Cymbopogon citratus*) / Purnima Jayasinha; Dilmani Warnasuriya; Harshani Dissanayake .-
Colombo : Information Services Centre, Industrial Technology Institute, 1999
Vol. 9 .- p. ; 28cm. .- (Medicinal and Aromatic Plants series)

ISBN 955-8394-09-2 Price : Rs.200.00

i. 615.321 DDC 21 ii. Title
iii. Series
iv. Warnasuriya, Dilmani jt.au.
v. Dissanayake, Harshani jt.au.
1. Aromatic plants 2. Botany, Medical

ISSN 1399-5622
ISBN 955-8394-09-2
Published by Information Services Centre, Industrial Technology Institute

Acknowledgements

The financial assistance by the National Science Foundation (grant number RG/IS/96/01) for the project is gratefully acknowledged. Sincere thanks are due to Mrs. Wathmanel Seneviratne and Mrs. Neranjani Mohottala for preparing the database. Grateful thanks are also due to Dr. U. M. Senanayake for editing. The assistance and support given by the industries during visits are greatly appreciated. The secretarial assistance of Mrs. Srimani Senanayake is acknowledged. Thanks are also due to Ms. Roshani Fernando for designing the cover.

Contents

Lemongrass

1.0 INTRODUCTION

Lemongrass is an aromatic grass belonging to the family Gramineae and genus *Cymbopogon*, which consist of about 80 species. Lemongrass is well known for its oil and it is one of the world's best known essential oils. There are two main types of lemongrass namely East Indian and West Indian.

The East Indian lemongrass oil is obtained from *Cymbopogon flexuosus* Stapf and is the genuine oil of commercial importance. The species is considered to have originated in Kerala, the southern most state of India. According to the colour of the stem, this is again divided into two types. The 'red grass' which is true *Cymbopogon flexuosus* is known as `choomanna poolu' in Tamil; and 'white grass' known as 'wella poolu'has been identified as *Cymbopogon flexuosus* var. *albescens*. The oil obtained from this plant has very low aldehyde content and is poor in solubility.

The West Indian oil is extracted from *Cymbopogon citratus* (DC) Stapf that is mainly cultivated in Central and South America and also known in parts of Africa, South East Asia and the Indian Ocean Islands.

The name lemongrass has been given because of its typical strong lemon - like odour, which it due to the high citral content. The two oils were formerly the main source of natural citral. The essential oil are used in perfumery, cosmetic and pharmaceutical preparations. However, lemon-grass oil has declined in commercial importance due to the competitive synthesis of citral and isolation of natural citral from *Litsea cubeba* oil. Nevertheless, more than 1000 t/a are still produced.

A third species, *Cympobogon pendulus* (Nees ex Steud) Wats has been recently distilled in India to a limited extent. This grass also contains 70 – 80% citral. However it is much hardier than the two previous species and can be cultivated in adverse soil and climatic conditions. It is popularly known as Jammu Lemongrass or RRL – 16.

2.0 HISTORY

Lemongrass has been used in medicine in India for more than 2000 years. However, its first recorded distillation is in Philippines in the 17th century, and in 1799 it was introduced to Jamaica. In 1917 it was grown for the first time in USA by Hood and during the World War I, grown in Guatamala by Julia Samayoa. Although the oil has been known, since very early times in India, the systematic cultivation and distillation of the grass were started in Kerala only about 100 years ago. Cultivation has assumed the status of a plantation crop after World War II.

3.0 BOTANY [40,67,68,100,118]

3.1 TAXONOMY

Family : Gramineae
Genus : *Cymbopgon*
Species : *citratus*
flexuosus

Botanical names
Lemongrass, West Indian type : *Cymbopogon citratus* (D.C.)(Stapf); *Andropogon nardus* var. *ceriferus* (Hack); *Andropogon citratus* (D.C.)

Lemongrass, East Indian type : *Cymbopogon flexuosus* (D.C.)(Stapf); *Andropogon flexuosus* (Nees)

Other names

Sinhala	:	Sereh
English	:	Lemongrass
Tamil	:	Wella poolu, Ondapoolu (White grass), Choomana poolu (Red grass)
Sanskrit	:	Bhustrina, Takratani

3.2 PLANT DESCRIPTION

Cymbopogon flexuosus:
About 3 m tall grass arising from a woody rhizome. Leaf sheath glabrous, hairy at the junction blade. Leaf blade 1 m long, 1.5 cm wide, linear, acuminate, glaucous. Panicles are very large, drooping, lax, greyish or greyish green, rarely with a purple tinge, with raceme pairs in dense masses, spreading, 100 – 135 cm tall, slightly hairy, lower glumes of the sessile spilelets 3-4, rarely 4 – 5 mm long, 1mm wide with 1-3 definite or obscure introcrainal nerves, shallowly concave with one or two depressions.

Cymbopogon citratus:
It is a perennial aromatic grass having dense fasicles of leaves from a short/oblique annulate, sparingly branched rhizome. Leaf blade is linear, long – attenuated towards the base and tapering upwards, approx. 90 cm long, 5 cm wide, smooth or rough upwards and along the margins, glabrous, glaucus green, base narrow. Sheaths are terete, those of the barren shoots much widened at the base.

Inflorescence spatheate panicle, decompound to sub-decompound, lose, 30 – 60 cm long, internodes 4 to over 6, spatheoles very narrow, linear lanceolate to almost subulate when inrolled. Peduncles 6 – 10 mm long , glabrous. Fertile spikelets linear, lanceolate, acuminate, 5-6 mm long, reddish glaborus, lower floral glume hyaline, linear, oblong or almost linear.

Cymbopogon pendulus :
It is a perennial robust grass. Clump is erect, 120 – 150 cm high and glabrous. Leaf-blades are upto 80 cm long, 11 mm wide. Slightly rough on the low surface, glabrous,

leaf-sheaths tomentose below. Spathate is panicle, 60 cm long, more or less interrupted, each tier composed of three rays in cluster spatheole 15 to 26 mm long; rachis internodes and pedicels pilose along the margins and on the upper part. Lower glume is yellowish, lanceolate to ovate lanceolate, 1 – 1.2 mm wide; awn 11 mm long. Pedicellate spikelet, 3.8 mm long. Lower glume is 0.8 mm wide.

4.0 HABITAT [118]

Lemongrass grows wild in Sri Lanka and other tropical areas. *Cymbopogon flexuosus* is indigenous to India and is cultivated in Ethiopia, Guatemala, Indonesia, Japan, Madagascar, Seychelles, Sri Lanka and Thailand. *Cymbopogon citratus* is found in Argentina, Brazil, Cameroon, Cuba, Gautamala, Haiti, Indonesia, Jamaica, Japan, Kenya, Mexico, Philippines, Seychelles, Somalia, Surinam, Tanzania, Thailand, Uganda and Zaire.

5.0 AGRONOMY [12,61,62,67,68,118,133,135,194]

5.1 SOIL AND CLIMATE

Lemongrass grows in tropical climate. It grows on poor soil and can be planted in areas where citronella does not thrive. It is hardier than citronella and more resistant to drought.

Elevation
The plant grows best at elevations ranging from sea level to 1200m.

Rainfall
The grass prefers an annual rainfall of 200 – 250 cm. In regions of abundant rainfall, the plant may be harvested more frequently during the year, but the oil will have a lower citral content. Prolonged rain is harmful. Planting on ridges is recommended in these areas.

Temperature
The temperatures most suited for growth of this grass is from 24 – 27 °C.

Climate
A warm and humid climate with plenty of sunshine is necessary for growth. Sunshine is said to influence the citral content of the oil.

Soil
The grass is found to be good soil binders and also act as a vegetation cover over naked eroded slopes in the foothills but none of these can stand water - logged condition. The plant flourishes on a wide variety of soils ranging from rich loam to poor laterite. The red yellow podsolic soil is equally good.

Higher soil pH (7.5) significantly increases the yield of herb and oil content, total citral and citral 8 as compared to lower pH (4.8).

5.2 PROPAGATION [4,12,61,67,68,85,118,149,158,160,181,191,194,195]

Lemongrass can be grown as a catch crop for rubber. It grows in rows between trees, without interfering with rubber roots. It has also been planted in between coffee trees.

Cymbopogon flexuosus:
The plant is propagated both from seeds and rooted slips. Propagation through vegetative means from selected clones is considered better as seed propagation leads to considerable genetic heterogeneity resulting in deterioration of yield and oil quality.

Seeds are the best means for rapid and large scale cultivation of East Indian lemongrass. Seeds are collected from plants, which are not subjected to regular harvest. The whole inflorescence is cut, dried for 1 to 2 days, thrashed and the seeds separated. In direct seeding, the land is ploughed and seeds sown in March at the commencement of the rainy season.

For raising a nursery, the soil is ploughed 6 to 8 times before sowing of seeds. The seeds are sown between April and May. The seedlings produced by 10 to 12 kg of seeds will be sufficient for transplanting into an area of one hectare.

Seeds start to germinate from the 3rd day of sowing and continue for about one month. More than 90% germination was completed by the first week itself. Hence it could be assumed that the seeds which did not germinate within one week, may not be germinated later. In such cases, fresh seeds could be sown immediately to save time.

The seeds sown immediately after collecting (without storage) exhibited a comparatively low germination. After a storage period of 60 days, germination was increased suddenly.

The seedlings are transplanted when about 60 days old. The tips of seedlings are cut leaving the planting material 15 to 20 cm long. They are then planted along ridges of about 90 cm, in holes about 10 – 12 cm apart. Two or three seedlings are planted in the same hole. A spacing of 45 X 45 cm has been reported to give high yields of oil containing a high percentage of citral.

Seeds of *Cymbopogon flexuosus* var. OD 19, subjected to α - irradiation at a dose of 20 krad resulted in significant increase in herbage and oil yield whereas significant increase in citral was achieved by 10 krad dose.

Cymbopogon citratus:
Cymbopogon citratus is propagated by means of root divisions at the onset of the monsoons. The clumps of healthy mature plants are divided carefully into a number of slips, each slip containing 1 to 3 tillers. The tops and fibrous roots of the slips are trimmed off before planting. One old clump could yield as much as 50 new stools.

The soil must be loosened thoroughly by ploughing before planting. Holes about 20 cm deep are dug with a crowbar and the slips are planted 45 – 60 cm apart, in rows about 90 cm apart. One to four segments are planted in each hole depending on the fertility of soil. The planting holes are lightly filled with earth to facilitate the

development of a good root system. A 100 sq.m nursery would yield sufficient root segments to plant 1 ha, with two root segments per planting hole. Thus 15,000 to 20,000 segments can be planted/ha.

In a study it has found that it can be grown effectively in hydroponic in open. A mixture of gravel volcanic slag or gravel and pumice yields herbage of 55 tonnes/hectare and essential oil up to 204 kg/hectare.

Cymbopogon pendulus:
The crop is propagated vegetatively through slips obtained by the splitting up of individual clumps which give about 110 – 150 tillers per clump. Clumps bearing well over 200 slips have also been observed.

The crop is planted on flat beds and irrigated immediately afterwards. One to two healthy slips about 20 cm in length are planted per hold. The crop establishes itself within 30 days and thereafter tillering starts.

Results over a period of 5 years have shown that narrow spacings in between plant rows give high yield of herb and oil. Spacing between rows should be kept at 50 cm, while plant distance may vary from 30 – 50 cm.

5.3 FERTILIZER [12,21,52.52,54,61,67,68,118,135,139,147,167,193,194]

Lemongrass is not frequently manured as it is known to be a soil exhausting grass. However the application of fertilizer when the plants have become well established is said to be beneficial. It is recommended that in soils of average fertility, a mixture of 30 kg/ha N, 30 kg/ha of P and 30 kg/ha of potash is applied at the time of planting. 60 kg/ha of N is applied as top dressing in 2-3 split doses during the growth season. Fertilizer also can be applied by introducing into holes in which the grass is to be planted and covering with 3 to 6 cm. of soil. It could also be broadcast, hold or disked. Better growth has been obtained when potash was supplied as the sulphate and when part of N was organic.

The micronutrients, Bo and Cu significantly increase the grass yield as well as growth. The copper gives the maximum grass yield, while application of other micronutrients, such as Mn, Zn, Mo, Si had no significant influence on oil yield.

Eastern India:
A mixture of 60 kg/ha of N, 55 kg/ha P_2O_5 and 30 kg/ha of K_2O has been found to be effective.

West Bengal:
N:P:K: 60:50:35 kg/ha was most effective, and induced maximum vegetative growth, dry weight, accumulation and essential oil format

North India:

To get optimum yield, an adequate mixture of NPK is required to meet the needs of the crop. The crop has high requirement of nitrogen and at least 250 kg/ha should be used for economic returns. A dose of 80 kg P_2O_5 and up to 120 kg of K_2O per ha is applied at planting or at the time of first weeding. Application of N in split doses (3-4) is recommended.

Fertilizer recommendations in the literature are summarized below:

Sri Lanka:

Mixture: Grass mixture: 17:11:14 ($N:P_2O_5:K_2O$)

Dose: 750 kg/ha

Nutrients: 128 kg N/ha
83 kg P_2O_5/ha
105 kg K_2O/ha

Rate of application: (Kg/ha)

	Maha	
	Pre	Post
1st year	190	190
2nd year and later	375	375

In a microplot field experiment conducted on use of irrigation water of varying salinity and fluorine levels indicated that the uptake of major (N, P and K) and secondary (Ca and Mg) nutrients decreased significantly over control.

It was also observed that 2.5 tonnes of compost made out of the spent grass and 1.875 tonnes of wood–ash per ha per annum were sufficient to supply enough nutrients for the crop.

5.4 WEEDING AND INTER - CULTURE

Weeding and hoeing are very important for the yield and quality of oil. Generally 2 – 3 weedings are necessary during the year. Earthling up should also be done at least once in a year. During the winter, the grass is usually burnt to fertilize the soil and to strengthen the plants. In row-planted crop, inter-culturing can be done by a tractor-drawn cultivator or hand-hoe. Weeds can also be controlled through the application of oxyflureofen, diuron and simazine at the rate of 0.5, 1.5 and 2.0 kg ai/ha, respectively. Distillation waste, when applied at 3 to 5 tonnes/ha suppress weed growth and is equally effective.

5.5 DISEASES AND PESTS [26,31,61,67,68,118,144,173,194,195]

Lemongrass is subject to attack by many pest and diseases.

5.5.1 Diseases

Leaf rust disease
Prolong rain causes attack by rust. This causes serious losses to herb and oil yield.

Eye spot disease
Caused by *Helminthosphorium* organism, which attacks sugar cane. In this disease the spots appear at first as minute yellow flecks with rusty brown centre. The spot grows an oval portion and becomes a light flesh or straw colour, outside of which is a purple, narrow border surrounded by a oval zone, Spanish – raisin in colour. This is surrounded by a yellowish to flesh-coloured aureolas. Often oval spots coalesce to form irregular blocks.

Chlorosis
Iron chlorosis is due to deficiency of iron leading to loss of green colour of leaves. This results a reduction in yield of oil and concentration of major compounds. Iron chlorosis is seen, when irrigated with water containing bicarbonates or when grown on calcareous soils.
This could be controlled by foliar application of 3% ferrous sulphate.

Attack by Fungus
Foliage is susceptible to attack by the fungal pathogen.

a. The leaf tips and margins are attacked by the fungus *Curvularia andropogonis* causing 10 – 20% loss in green tissue. Infected tissue turns brown and eventually becomes necrotic, giving the appearance of scorched tips.
   Controlled by using fungicides captan, zinneb, ziram

b. Grassy Shoot Disease:
   It is prevalent in several parts of India, especially in Kerala. The disease is caused by the fungus *Balansia sclerotica*. This is caused by excessive profileration of shoots and shortening of leaves and conversion of flowering parts into leafy structures giving the typical appearance of little leaf or witches broom type of disease.

c. Leaf blight:
   Several fungi cause it, but the most severe infection is caused by *Colletotrichum graminicola*. This disease appears in the form of small brownish spots on the leaf stem and enlarges into large brown patches. It has also been found that leaf blight can also be caused by *Rhizoctonia solani*.

d. Smut:
   It is caused by the fungus, *Tolyposporium christensenii*. The symptoms appear in the form of conversion of flowering panicle into black powdery mass. Seeds and flowers are converted into smut spots.

5.5.2 Insects and Pests

The most destructive pest infecting lemongrass is a species of *Chilotrea*. The caterpillar is white in colour with a black head and black spots on the body. It bores into the stem and remains there feeding on the shoot. It is usually found at the bottom of the stem.

The first symptom of the attack is the drying up of the central leaf. Subsequently, the whole shoot dies, resulting in a significant reduction in the yield of the grass.

Control measures:

(i) The dry stubble is set on fire during the off season in summer. The caterpillars lurking inside the stubble are thus destroyed.

(ii) The affected shoots are pulled out and destroyed.

(iii) When attacks are serious, a spray of oxydemeton-methyl is used. Instructions for spray, etc. should be followed as prescribed by the manufactures.

Sugar cane borer, *Sesamia inferens* and the madagascar beetle, *Heteronychus plebejus* attack freshly planted lemongrass. Scale insect, *Duplachionapsis divergens* produces yellow spots on the stem and sucks the sap of the leaves and stem. White fly, *Tetraleurodes semileunanaria* sucks sap from the leaves causing chlorosis and withering away of leaves. The insect can be controlled by 0.5% Dimethoate.

Clovia bipunctata, a spotted bug, attacks the lemon grass in Kerala. The nymphs attack young leaves causing crinkling. It can be controlled by 0.05% Quinolphos.

Lemongrass is also attacked by the aphid, *Sipha flava*, which causes the grass to become reddish brown and dry. Although the yield of oil from infested grass is somewhat lower, the infestation does not markedly affect the quality of the oil.

Roots are attacked by nematodes. Infested clumps turn yellow, wilt and wither away.

5.6 Harvest and Yield:

The time for the first harvest varies from 3-9 months and subsequently the grass may be harvested every 3 or 4 months. When the grass is about 4 ft. high and has 4 – 5 leaves, it is ready for cutting. The higher yields of leaves and oil are obtained from the second to the sixth year, after which there is a steady decrease.

Harvesting is done by sickle by cutting the leaves 10 – 15 cm above the ground level. Plants grow rapidly after each cutting. The number of harvests depends on the climatic conditions of the place of cultivation. Time of harvest is important for good yield of oil and its quality. It was found that maximum oil yield for *Cymbopogon flexuosus* is obtained when harvested at a maximum height and the oil content was higher when harvested during night than that harvested during the daytime. It is lowest when harvested between 12.00 noon to 4.00 p.m.

Cymbopogon pendulus should be harvested before flowering. Flowering adversely affects the yield and quality of oil and is reported to reduce the oil yield by 30%.

The percentage recovery of oil was greatest in grass harvested every 30 – 35 days and declined thereafter. However, the citral content of the oil increased with increasing time intervals. Immature leaves were found to possess the greatest amount of essential oil and percentage of citral, with respect to the leaf blade.

6.0 PROCESSING [61,67,72,118,171]

6.1 PRODUCTION OF ESSENTIAL OIL

Stills used for distillation are made of tinned copper or stainless steel and often protected by a wide protruding palm- thatched roof.

In primitive stills, the retort is usually 2 m high and 1 m width with a capacity of about 757 l. On the side of the still, about 1 m above the base, there is a manhole through which the grass is charged and discharged. The manhole is closed with a cover during distillation. The cover is held fast by means of a mud paste, which dries and hardens as the metal walls become hot. The retort up to the manhole, is lagged or embedded in a hearth made of mud and bricks, housing the fire beneath the retort. Wood, spent grass, or coconut shell is used as fuel.

The condenser consists of a copper coil 5 cm diameter and 18 m long inserted into a large wooden barrel, about 2 m high, installed outside the roof. The barrel is kept filled with water. A wide, short, tin beaker serves as a sort of Florentine flask. (oil separator).

A distillation unit recommended by Fernando et. al. consists of a large cylindrical vessel made of galvanized or black iron sheet, capable of holding a charge of about 907 kg of grass. This is placed over a simple fire-place, using spent dried grass as fuel. The still body is supported by masonry structure, constructed with bricks. The vessel still body has a false bottom about 15 cm above the real bottom and the space between them contains the water which provides the steam. The vessel is closed with a cone shaped cover with a trunking, from which a goose neck is drawn. The cover at the goose neck end is connected to the condenser through a flexible pipe.

The condenser consists of an aluminium coil 14 – 45 m long and 3 cm in diameter placed in an outer shell. The condensate is collected in a 15 l bottle with a screw threaded mouth and with the bottom cut off. The bottle is boxed in an inverted position, with a siphon pipe leading from the stopper placed on the screw threaded mouth.

The CISIRILL Manakoka, designed in 1971 is also used for distillation of lemongrass. Here the condensing system is designed for water spacing, by the introduction of a two – phase condensing system,.latent heat exchange (1000 liters of water containing 15 m of 2.5 cm diameter aluminium coils) and air condenser 30 m of 2.5 cm diameter finned aluminium tubing .

The CISIR still called the CISIRILL BOITARE is also used for distillation of lemongrass. The major advance in this system of distillation is the condenser which is capable of condensing up to 1200 ml of distillate per minute.

The C.C.C still is a factory type system where one boiler provides steam under pressure (3 – 4 atm) to 4 - 5 still bodies. The superheated steam is not passed directly through the grass but is used to boil the water, which lies at the bottom of each still body. The condenser is a multitubular running water device with 12-22, 1.25 cm tubes.

Freshly cut grass should be used for distillation. It has been found that field drying of grass or storage of grass, by stacking, prior to distillation, results in losses of oil and that total acetylisable constituents decrease considerably with time, after cutting.

In a study it was found that storage of grass either in the shade or in the open during the winter and the rainy seasons affected the oil content adversely in *Cymbopogon flexuosus* from the very first day of storage. During summer it was not affected for three days when stored in shade. But storage up to 15 days produced a loss of 30% and 55% under shade and open respectively. The citral content of *Cymbopogon flexuosus* was not affected much due to storage. However, oil from shade – stored herbage was richer in citral than that obtained from open-stored herbage.

Jammu Lemongrass, *Cymbopogon pendulus* should be distilled as fresh as possible, as otherwise a disagreeable odour is obtained in the oil.

In Puerto Rico, the cut grass is raked and transported by chute or canals, in a swift current of water to the still, where the grass is caught on screens, cut and processed.

In India, the oil is produced by partly immersing the leaf material in boiling water during distillation. West Indian type of lemongrass oil, on the other hand, is obtained by steam distillation, with steam supplied from a separate steam generator.

The Federal Agriculture Station at Puerto Rico recommends the intermittent method of distillation for West Indian type lemongrass. Pressure is built up for about 5 mins. and then the grass is distilled for 15 mins. This procedure is repeated. High pressure, superheated steam may be injected into the still. Use of high pressure steam increases yield, but decreases the citral content of the oil. Increasing the vapour pressure of distillation, thereby reducing the time, is said to improve the oil. Distillation of grass from a 28% solution of sodium chloride was found to increase the yield of oil by one third.

Freshly cut grass, cut into short lengths, is tied in small bundles, introduced into the still with pitchforks and trampled down to prevent steam channelling, until the still is about 2/3 full. The still is filled with water to about one-quarter of its capacity and distillation is started. It was found that a steam pressure of 1 atm gave a higher yield of oil but, with a lower citral content than a steam pressure of .5 atm. The mixture of steam and essential oil vapour condenses to liquid in the condenser pipe and flows to the oil separator. In the oil separator, the oil being lighter than water and immiscible in water, floats to the surface. When the volume of the oil collected in the separator shows no further increase, distillation is stopped. The oil accumulated in the separator is skimmed off or tapped free of water. Distillation water is discarded. Distillation of one charge lasts about 3 h yielding ½ - ¾ bottle of oil (350 – 500 g). The bulk of the oil distils over during the first half an hour. Distillers often work 15 hours per day.

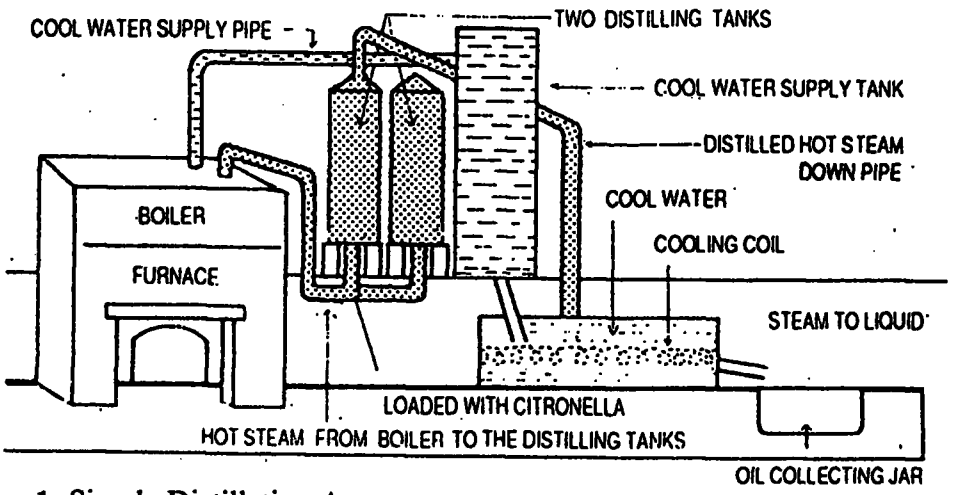


Figure 1: Simple Distillation Apparatus

6.2 DRYING

Water can be chilled out, with stirring: it separates as the bottom layer. Other methods used are: mixing with anhydrous calcium chloride, sodium sulphate or magnesium sulphate and filtering through filter paper. It has been recommended that West Indian type lemongrass oil be filtered at 10 ^{0}C to prevent development of turbidity

6.3 TERPENE – FREE LEMONGRASS OIL

Terpeneless oils have better keeping quality and are more soluble in alcohol of low concentration than the natural oil.

The differential solubility of individual chemical compounds when distributed between two immiscible solvents, one polar and the other non-polar, is the criterion used for a counter current extraction technique, where successive portions of one solvent phase moving in one direction come into contact with successive portions of a second solvent phase moving in the opposite direction. The polar solvent, which dissolves the oxygen compounds, is introduced at the upper end of the extractor, while the non-polar solvent which dissolves the terpene hydrocarbons is introduced at the lower end. The firm Naarden in Holland uses this technique.

Lemongrass oil consists mainly of citral and some terpenes. The terpenes are removed by the non-polar solvent (hexane) while, the polar solvent, (rectified spirits) extracts the oxygenated compounds. The polar solvent, after it "äbsorbed" a relatively large amount of oxygenated compounds, also serves as a solvent for the hydrocarbons. By this method, a product with citral up to 94% is obtained.

Neyberg found that on vacuum distillation of a 2-year old oil at 128 – 133 ^{0}C, an oil containing 97.5% citral was obtained in 65.7% yield.

7.0 PACKAGING AND STORAGE [88,118,195]

Lemongrass oil is stored in a dry place in the dark, in well-stoppered glass, or tin-lined or aluminium containers. Copper or iron containers discolour the oil. Light and air are detrimental. The oil undergoes gradual degradation on storage. When samples

were stored under nitrogen in well-filled tightly closed vials, in a deep freeze, for 12 months, deterioration did not occur.

Lemongrass oil is also subject to easy oxidation resulting in lower citral content and lower bactericidal potency. Crude oils are more stable than refined oils. Over a 2 year period, crude oils were found to lose 50% of their citral content and purified oils 60%. It was found that betel leaves extract has the greatest protection against deterioration of citral after storing for one year. This may be attributed to the presence of chlorophyll in the extract. The only disadvantage with this antioxidant is that the oil gets the colour green. Sodium chloride 2%, which recorded 82.5% citral and the physical properties are with in the ISI range, is also a good antioxidant. Pyrogallol (0.1, 0.5 and 1.0%) are effective in keeping up the citral content but they are confronted with the problem of toxic effects.

8.0 CHEMISTRY OF THE GRASS

8.1 PHYSICO – CHEMICAL CHARACTERISTICS [20,67,118,154]

8.1.1 ESSENTIAL OIL

The oil has an intense lemon - like odour and taste, and is yellow, reddish-yellow to reddish brown in colour. West Indian oil has an odour similar to that of Citronella.

Physical constant	*C.citratus*	*C.flexuosus*		*C.pendulus*
		Red grass oil	white grass oil	
Specific gravity 20^0C	0.8986	0.881	0.931	0.9150
Refractive index 20^0C	1.4910	1.482	1.498	1.4890
Optical rotation 20^0C	-0.62			-0.36
Acid value	5.34			7.70
Ester value	44.20			35.58
Carbonyls	74.96%			76.46%

Moisture content
One year - old oil was found to have about 0.1% moisture. The oil can retain 2.5 – 3% dissolved water at room temperature. Water when present in the oil is harmful to citral. In the presence of water, air and light, citral decomposes rapidly.

Solubility
The West Indian oil is usually less soluble in alcohol than the East Indian oil. The lower solubility in alcohol was at one time attributed to the steam distillation method, higher boiling and less soluble products being carried over during steam distillation. The lower solubility has also been explained as due to the presence of myrcene, which

on exposure to air and light readily polymerizes. According to the ISO standards solubility of the oil decreases on storage.
The oil from white grass shows poor solubility.

Surface tension

Mayotte oil	-	32.2
Madagascar oil	-	30.7

The following values have been obtained using the capillariscope method.

	Mayotte	Ivory coast	Indian oil
Increase in diameter of oil spot	0.4239	0.5163	0.4941
Original diameter of oil spot	4.49	3.95	3.90

Viscosity

Mayotte oil	2.378
Madagascar oil	2.620

Gamma irradiation
The oil decomposes on gamma irradiation but only non-volatile polymers that do not effect the flavour are formed.

Constituents [67,68,90,100,107,117,178,195]
Citral is the chief constituent in lemongrass oil. East Indian oil has the highest citral content while it has little or no myrcene.

West Indian lemongrass oil contains citral as the principal constituent, the percentage of citral varying with locality. Ceylon oil contains c.76% ; Seychelles oil 76 – 81% and Formosa oil 54 – 76% citral.

Composition of Lemongrass

	C. flexuosus	*C. citratus*	*C. pendulus*
1. allo-ocimene	✓		
2. ∝-bergamotene	✓		
3. β-bisabolene	✓		
4. borneol	0.4%	0.1-0.4%	
5. bornyl acetate	0.3%		
6. camphene	1.3%		
7. ϑ-cardinene		1.0%	
8. δ-cardinene		0.3%	
9. δ-3-careme		0.03%	0.1-0.16%
10. β-caryophyllene	0.4%	0.18%	2.15%
11. β-caryophyllene oxide	tr.	0.61%	1.56%
12. 1,8-cineole		✓	0.2%
13. citral a		41%	30-50%
14. citral b		32%	20-30%
15. citronellal	0.37-4.0%	0.1-5%	0.49%
16. citronellol	0.44-24.1%	0.1%	
17. citronellyl acetate	2.2%	0.96%	0.72%

18. β-cubebene		0.5%	
19. β-cuminyl oxide			✓
20. α-curcumene	✓		
21. β-cymene	6.6%		
22. ρ-cymene	0.04-0.13	0.20	0.36
23. ρ-cymene-8-ol	✓		
24. decanal	0.2-0.35%		2%
25. n-decylaldehyde	✓		
26. 3,7-dimethyl-oct-1-ene	✓		
27. 3,7-dimethyl-7-octen-1-ol	✓		
28. dipentene	0.15%	0.23%	0.35%
29. β-elemene	0.38%	0.42-1.33%	0.70%
30. elemicin	✓		
31. elemol	0.46%	1.20%	2.29%
32. eugenol	0.2%		
33. farnesal	2.4-8.0%		
34. farnesol	6.0 – 12.8%		
35. geraniol	1.73-30.5%	0.5-40.2%	2.60%
36. geranyl acetate	1.95-3.0%	1.0-3.0%	3.58%
37. ∝-humulene	✓		
38. limonene	1.9-2.42%	tr.	
39. linalool	1.34%	0.8-3.4%	3.07%
40. linalyl acetate	✓		
41. trans-ρ-menth-2-en-1-ol		tr.-0.1%	
42. menthone	✓		
43. methyl eugenol	✓		
44. methyl heptenone	0.07-1.43%	2.62%	1.05%
45. 6-methyl hept-5-en-2-one	0.4%	0.5-2.3%	1.0%
46. ϐ-muurolene	✓		
47. myrcene	0.02-0.46%	0.1-19.2%	0.04-1.0%
48. nerol	0.39%	0.3-4.5%	
49. nerolidol	tr.		
50. neryl acetate	✓		
51. nonanal		0.2-0,7%	
52. 2-nonanone		0.07%	
53. 4-nonanone		0.3%	
54. cis-β-ocimene	0.06%	0.2%	
55. trans-β-ocimene	0.07%	0.1-0.2%	
56. perillene	✓		
57. β-phellandrene	0.09-0.2%	0.07%	0.30%
58. ∝-pinene	0.24%	0.1%	0.19-3.5%
59. β-pinene	0.04%	0.19%	0.16-2.5%
60. piperitone	✓		
61. sabinene	✓		
62. terpinen	0.41%		
63. ∝-terpineol		0.38-2.25%	0.2-10.2%

64. β-terpineol		0.17-0.40%	
65. terpinolene		0.05%	0.1%
66. ∝-terpinyl acetate	0.90-1.20%		
67. ∝-thujene	0.03%	tr.-.01%	
68. ∝-thujone		0.1%	
69. tricyclene	0.2%		
70. undecan-2-one		0.4-0.6%	

8.1.2 ROOT OF *Cymbopogon citratus* [118]

The rhizome is said to contain 0.3% alkaloids.

Root oil:

Specific gravity	0.94
Optical rotation	$3^0 41' - -1^0 40'$
Aldehyde content	11 – 82%

8.1.3 GRASS OF *Cymbopogon citratus* [38,64,118]

Cymbopogone and Cymbopogonol have been isolated from the leaf wax of *Cymbopogon citratus*. The structural relationship between the two compounds raises the possibility that cymbopogone is an artifact formed during the isolation of cymbopogonol.

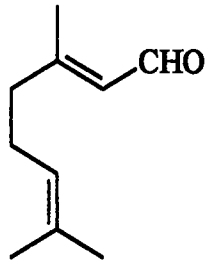
The following compounds were isolated from the leaves of *Cymbopogon citratus*: lutcolin, homoorientin, luteolin-7-0-beta- glucoside, luteolin-7-0, neohesperoside and 2"-0-rhamnosyl homoorientin. Chlorogenic acid, caffeic acid and *p*-coumarin acid were also identified by means of TLC and HPLC.

8.1.4 Spent grass

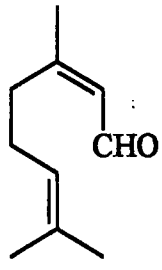
Proximate analysis (*Cymbopogon citratus*)
The dust passes through and is retained on 80 mesh.

Ash	6.2%
Solubility (cold water)	12.0
Solubility (hot water)	21.4
Solubility (1% caustic soda)	45.6
Solubility (Alc. Benzene)	9.2
Pentosans	16.6%
Lignin	21.3%
Cellulose	46.9%

Triacontane, triacentanol and β-sitosterol have been identified in the spent grass of *Cymbopogon flexuosus*. They also separated Arundoin, a tri-terpene from triacontane.

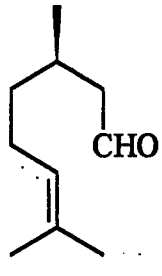


Citral A (Geranial)



Citral B (Neral)

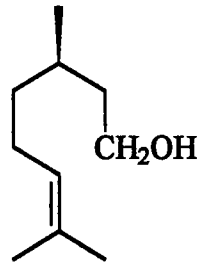
Shows antiseptic activity (5 times stronger than phenol). It has a lemon-like scent, and is used for flavouring foods, in perfumery, and in the synthesis of vitamin A.



(+ form)

Citronellal

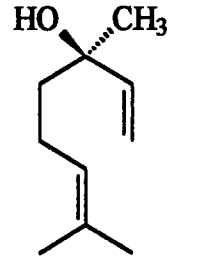
Shows antiseptic and sedative action (oil of balm). It is used in soap perfumes and as an insect repellent.



(+ form)

Citronellol

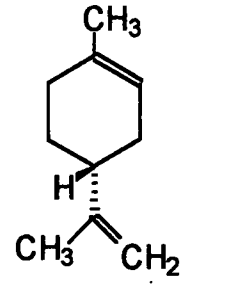
Used in perfumery.



(- form)

Linalool

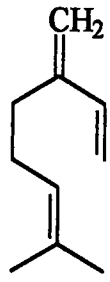
An antiseptic (five times stronger than phenol) and sedative and shows fungistatic activities. It is used in the synthesis of Vitamin A and in perfumery.



(+ form)

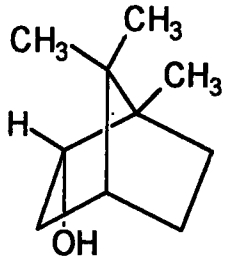
Limonene

Skin irritant, expectorant and sedative. Used for flavouring food and beverages.



Myrcene

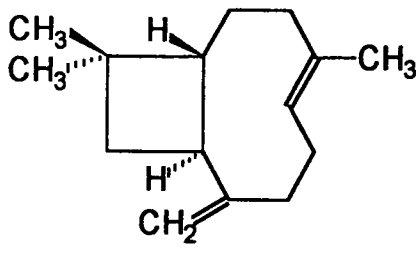
Used in the manufacture of perfumes and chemicals.



(+ form)

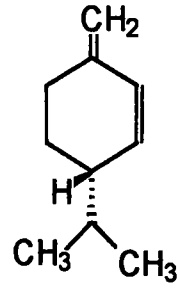
Borneol

Used mainly for the manufacture of its esters, but some free borneol is used in perfumery. It is toxic to mammals (affects the central nervous system).



β - Caryophyllene

Used in perfumery.



β - Phellandrene

Expectorant

8.2 BIOCHARACTERISTICS

8.2.1 Anti-bacterial properties [6,118,119,129,131,133,176]

Bacterial efficiency of lemongrass oil was found to be proportional to the citral content of the oil. Mycene enhanced the activity of citral when combined with them. Tests on the influence of different emulsifiers on the bactericidal action of the oil showed that of the emulsifiers, triethanolamine or potassium oleate and rosin soap were the best. No relationship has been observed between viscosity of the emulsion and bactericidal efficiency. Excess solvent lowered stability of the emulsion and also lowered bactericidal action of the emulsion

The essential oil of *Cymbopogon citratus* shows rapid bacterial activity against both Gram-negative and Gram-positive bacteria in laboratory studies. Gram-positive bacteria were the more active bacteria.

Cymbopogon citratus oil has shown detectable activity against *Bacillus subtilis, Staphylococcus aureus* and *Escherichia coli*. But when the oil was oxidized, activity reduced and was completely lost when the oil was extensively oxidized. Inclusion of antioxidants in the oil samples reduced the ratio of oxidation and enhanced the antibacterial activity.

The combined use of lemongrass oil (LGO) and phenoxyethanol can increase the spectrum of activity of phenoxyethanol whose activity is mainly against *Pseudomonas aeruginosa*. An appreciable increase in the activity of phenoxyethanol against *Escherichia coli* and *Staphylococcus aureus* has been observed when it was combined with 0.03 v/v LGO. In addition, the combination reduced the effective concentration of both components necessary for activity.

The oil of East Indian lemongrass, *Cymbopogon flexuosus* has shown the possibility of checking the growth of two human pathogens, *Vibrio cholerae* and *Salmonella paratyphi*.

On an experiment with fresh oil, as well as 2,7 and 22 years old oils of a Pakistani variety of *Cymbopogon flexuosus* activity against *Escherichia coli, Staphylococcus aureus, Shigella flexneri, Salmonella typhi, para-A* and *Klebsiella pneumoniae* was found. Oil that has been kept for 2 years, exhibited after redistillation, maximum activity due to its high citral content. *Shigella flexneri* and *Salmonella typhi* were inhibited effectively at low doses of the oil.

Lemongrass oil along with essential oils of Citronella, Palmarosa and Geranium and also with *Mentha arvensis, Anethum sowa* and *Cinnamomum zeylanicum* showed activity against the human pathogen *Salmonella typhi.*

Phenol coefficients of lemongrass oil have been determined by Rideal Walker test and Garrool's test.
The results were :

	Rideal Walker test	Garrod's test
Phenol coefficient	17.5	9.2
Commercial sample	3 – 14	

8.2.2 Anti-fungal properties [13,37,40,73,155]

The anti-fungal properties of lemongrass oil and its fractional constituent, citral A, have inhibited the growth of *Aspergillus niger* at 0.20% and 0.15% concentration respectively in agar medium. The pH of the medium was found to have no effect on inhibition of the growth of the mold. Inhibitory action of lemongrass oil is considered mainly due to its citral A content.

Lemongrass oil a shown good anti-fungal activity against *Aspergillus* species: *A. niger, A. flavus, A. fumigatus, A. nidulans* and *Fusarium oxysparum* at a concentration of 2.5 ml of oil in 1000 ml of medium.

The essential oil of *Cymbopogon flexuosus* from Pakistan and Thai cultivars showed inhibitory effect against pathogenic fungi, *Monilia sitophilia, Penicillum digclatum, Aspergillus parasiticus, Aspergillus niger* and *Aspergillus fungis.*

Steam distillate from *Cymbopogon citratus* completely inhibit the growth of *Ustilago maydis, Ustilaginoidea virens, Curvularia lunata* and *Rhizopus* species.

Application of lemongrass oil as preservative to control Blue Mould Decay by *Penicillium italicum,* in oranges is shown to be effective and dosage comparable with those chemicals used in United States.

8.2.3 Anti-viral activity [160]

Essential oil of *Cymbopogon citratus* was found to be potent in reducing Potato virus X and Potato virus Y by 100% up to a dilution of 4:1000.

8.2.4 Insecticidal and pest repellent properties [10,48,75,118,120,183]

Lemongrass repels the tsetse fly. Creams containing the oil are used as repellents against houseflies and mosquitoes. Contact toxicity of the oil in acetone solution on

insects is very high. 7.5 μg per insect was effective in killing houseflies and 30 μg per insect killed mosquitoes.

In an experiment to assess the toxicity of oil extract from *Cymbopogon citratus* against *Sitophilus zeamais*, it was found that there is an increase in mortality of this pest compared with the control at dose rates of 0.1, 0.5, 0.7, & 1.0 ml oil/50 g maize.

Cymbopogon citratus also exhibited high repellency to *Dacus dorsalis.*
Root extract of *Cymbopogon citratus*, when compared with fenamiphos (15 kg/fed) for control of *Meloidogyne javanica* on tomatoes in a pot experiment showed 55.4% reduction in nematode population and 57.1% reduction in egg masses 60 days after inoculation.

Polyolefin-paper packing laminates when treated on the paper side with lemongrass oil showed effective dog and cat repelling properties even after 7 days.
Extract of *Cymbopogon citratus* had shown significant anti-feedant and insecticidal effects on 3rd instar larvea of *Crocidolomia binotalis*, one of the most important pests of cruciferous crops in Mauritius.

The leaf extract prepared from *Cymbopogon flexuosus* showed high toxicity to *Meloidogyne incognita, Rotylenchulus reniformis, Tylenchorhynchus brassicae, Hoplolaimus indicus* and *Helicotylenchus indicus*. The toxicity was related to the concentration of leaf extract and to the exposure period. *Meloidogyne incognita* was the most affected with 100% mortality in standard solution at 12 h, while *Hoplolaimus indicus* was the least affected with 20% mortality. The extract also significantly inhibited egg hatch by *Meloidogyne incognita.*

8.2.5 Cytotoxicity [41,198]

d-limonene and geraniol from *Cymbopogon citratus* showed high gluththione-S-transferase (GST) inducing activity. D-limonene increased GST activity 2.4 – 3.0 fold higher than controls in the mouse liver and mucosa of the small intestine and large intestine. Geraniol showed high GST – inducing activity only in the mucosa of the small and large intestine. Induction of increased GST activity, which is believed to be a major mechanism for chemical carcinogen detoxification, has been recognized as one of the characteristics of the action of anticarcinogens. Thus, these compounds show promise as potential chemopreventive agents.

Citral, from the essential oil of *Cymbopogon citratus* showed cytotoxic against P_{388} mouse leukemia cells.

An oral administration of an infusion of lemongrass fresh leaves and an essential oil obtained by steam distillation have produced a dose dependent analgesic effect on rat paw hyperalgesia induced by carrageenin and prostaglandin E_2. Myrcene was the most active analgesic component of the oil.

8.3 BIOLOGICAL DATA [132]

8.3.1 Acute toxicity

Cymbopogon flexuosus – The acute oral LD_{50} value in rats was reported as 5.6 g/kg (5.1 – 6.1 g/kg). The acute dermal LD_{50} value in rabbits exceeded 2 g/kg.
Cymbopogon citratus - Both the acute oral LD_{50} value in rats and the acute dermal LD_{50} value in rabbits exceeded 5 g/kg.

8.3.2 Irritation

Cymbopogon flexuosus - Undiluted oil applied to the backs of hairless mice and swine was mildly irritating. Applied full strength to intact or abraded rabbit skin for 24 hours under occlusion, was moderately irritating. Tested at 4% in petrolatum, it produced no irritating after 48 hours close-patch test on human subjects.

Cymbopogon citratus - Oil applied undiluted to the backs of hairless mice and swine was mildly irritating. Applied full strength to intact or abraded rabbit skin for 24 hours under occlusion, was moderately irritating. Tested at 4% in petrolatum, the material produced no irritation after a 48 hours closed-patch test on human subjects.

8.3.3 Sensitization

A maximization test was carried out on 25 volunteers. The material was tested at a concentration of 4% in petrolatum and produced no sensitization reactions on both East Indian and West Indian lemongrass oil. Even at a concentration of 5% in petrolatum produced no sensitization reaction with West Indian type.

8.3.4 Phototoxicity

No phototoxicity effects were reported for undiluted lemongrass oil on hairless mice and swine.

9.0 ANALYSIS OF LEMONGRASS OIL [118,194]

9.1 CHROMATOGRAPHY

Column chromatography

Oil of lemongrass in petroleum ether was passed over a column (Silica gel : kieselguhr 4:1), and eluted with petroleum ether, benzene, ethyl acetate, ether and alcohol. Fractions were separated into individual components by re-chromatography over alumina.

Gas-liquid Chromatography

Gas or gas liquid chromatography is a method of separating a volatile complex mixture into its separate components by making use of the different partitions of the components between a mobile gas phase and a stationary liquid phase.

A stream of an inert 'carrier gas' like Argon, Helium or Nitrogen flows by way of a pressure value, through the chromatographic column which is maintained in an oven compartment. The sample to be analysed is injected into the injection port where it is flash volatilised into the stream of carrier gas prior to entering the column. The column is a coiled tube, which contains the liquid ' stationary phase'. Columns are of two main types viz: packed columns and open tubular columns. Open – tubular columns have much greater powers of resolution. They are more sensitive than packed columns, but can tolerate only minute doses of material. The selection of the type of column, the appropriate stationary phases and its temperature, play an important role in the success of analyses by GLC. Some stationary phases that have given particular good results are Carbowax 20M, FFAP, SE 30, OV 101 and OV 225. In order to achieve optimum separation the temperature of the column compartment has to be gradually increased during analysis. The separated constituents of an essential oil emerging from the column enters the 'detectors' which monitors the entry of each compound. The emergence of each separated constituent alters the electrical conductivity with respect to that of the carrier gas. These variations in each case are converted into electrical signals and recorded on a strip chart recorder. This 'gas chromatogram', takes the form of a series of peaks which correspond to each component separated by the column. Please refer SLS 572 : Part 3 : 1984; ISO 7359 and ISO 7609.

Thin layer chromatography (TLC)

TLC is a simple separation technique where a mixture is separated on a glass plate coated with a layer of silica gel powder, aluminium powder or cellulose powder. Silica gel is the most useful matrix for analysis of essential oil components. The mixture is applied to the lower edge of the coated plate of glass and then developed in a suitable solvent by being placed in a glass tank. The solvent will ascend along the plate and when a distance of about 15cm is covered the plate is removed and allowed to dry. The separated components are then visualized by spraying of a number of reagents. The most widely used reagents are;

(i) Vanillin in Ethanol containing a small amount of concentrated sulphuric acid
(ii) Anisaldehyde treated similarly
(iii) Dipping in Iodine vapour

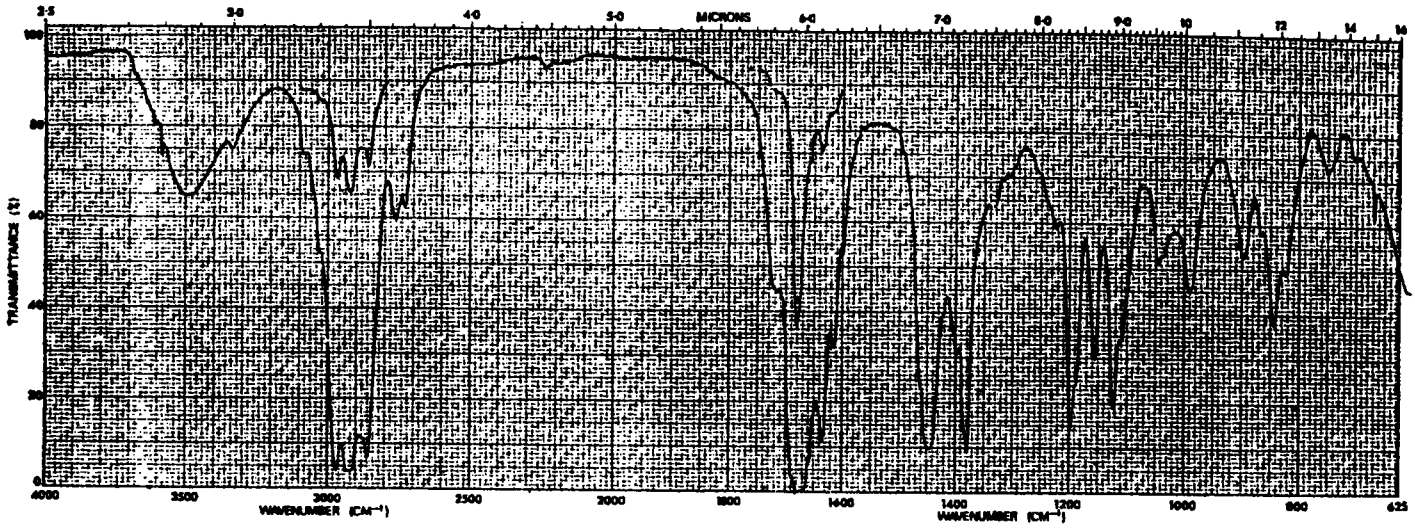
Among the other reagents , 2,4 Dinitrophenyl hydrazine in diluted hydrochloric acid will detect ketone and aldehydes, while diazotized, sulphanillic acid and nitro anillin will detect phenolic compounds.

9.2 SPECTROSCOPY

Infra red Spectrometry

One of the most characteristic properties of organic molecules is its infra red (IR) spectrum, which originates from the absorption of IR radiation by the molecule. When IR radiation strikes the bonds of molecules, the bond energy will be absorbed, when the correct energy for excitation of some bond in the molecule is present. The IR spectrometer will thus record each such absorption and intensity of which this occurs. Samples can be analysed as pure films, dilute solutions or made into transparent discs after dispersing in potassium bromide or as a paste made in Nujol (white oil). IR spectra are so characteristic for compounds that the fine structure in the spectrum is a

fingerprint of each such compound. Even for complex mixtures such as essential oils an IR spectrum would be useful for checking authenticity quickly. The spectrum which is recorded can then be compared with a similar spectrum from a genuine sample of oil.



Lemongrass oil, Guatemala

Figure 2: IR spectrum of lemongrass oil

9.3 DETERMINATION OF CITRAL

Values obtained for the citral content of standard lemongrass oil vary according to the methods used. Commercial contracts are often based on a minimum citral content of 75% (bisulphite method). The bisulphite method gives values which are generally 2-5% higher than those from the neutral sulphite method, probably because the former values include other aldehydes and methyl heptenone. Both the bisulphite and neutral sulphite methods give the % of citral by volume whereas the oximation method gives % of citral by weight, this being more accurate.

Bisulphite method

On shaking a measured quantity of oil with a hot aqueous solution of sodium disulphite, an addition compound with citral is obtained which dissolves in the hot bisulphite solution; the non-aldehyde portion of the oil separates as an oily layer which can be measured.

Neutral sulphite method

An addition compound is formed with citral, when a measured quantity of oil is shaken with a solution of neutral sodium sulphite in a slightly alkaline medium (pH 8). The sodium hydroxide liberated is periodically neutralised with acetic acid to allow the reaction to go to completion. The amount of unreacted oil is measured and the aldehyde content calculated.

Hydroxylamine method

In this method, the hydrochloride which is liberated when the oil reacts with hydroxylamine hydrochloride is neutralised with standardised alkali.

Chromatography

Citral can be determined by thin layer chromatography of oil (silicic acid 40g.,water 50ml.) solvent mixture: Ethyl acetate 15%,cyclohexane 85%. The citral is spotted using Schiff's reagent, which gives a characteristic turquoise green spot which can be determined colorimetrically.

In a simple method for the estimation of citral in lemongrass oil by column chromatography, pure citral in near quantitative yield is isolated from lemongrass oil using hexane and isopropanol as eluents. From this method 72% of citral with 99% purity can be isolated.

Colour reactions

One method is based on the red colour produced by aldehydes with Schiff's reagent. This colour fades on acidification with methanolic sulphuric acid, a green colour develops which is specific for citral.

10.0 CHEMICALS FROM THE OIL [57,146]

Citral

It is isolated from lemongrass oil using sodium bisulphite which forms a solid adduct with the citral, contained in the lemongrass oil. The solid adduct is washed free of the adhering unreacted oil and filtered through a pressure filter. After filtration, the adduct is decomposed by dilute acid and the pure citral thus liberated is recovered by extracting the aqueous phase with a suitable solvent. The organic phase is washed and distilled to obtain the pure citral. Citral is a colourless to slightly yellowish liquid, with a boiling point of 228 ^{0}C. Insoluble in water, soluble in alcohol, miscible with most perfume and flavour oils. Widely used as a powerful lemon-fragrance chemical. Very commonly used in flavour compositions.

Storing is usually in glass, aluminium or containers internally lined with an impervious lacquer in a cool dry place protected from light. The containers should be full and tightly sealed.

Citral is condensed with acetone in the presence of alkali. The condensation product thus obtained is cyclised in the presence of acid. By varying the conditions of isomerisation, different isomers can be obtained. The cyclised product is washed free of acid and carefully fractionated.

α and β ionone

α-ionone is an almost colourless or pale straw coloured to pale yellowish oily liquid. Boiling point is 237 ^{0}C. Very slightly soluble in water, soluble in alcohols and oils. Warm – woody balsamic – floral odour of deep sweetness and moderate tenacity. Its resemblance to the odour of violet flowers is legendary. α-ionone is widely used in all types of perfume compositions. It is used for modifying, blending, floralizing and mellowing of various types of fragrances. ∝– ionone is also used in flavours like blackberry, loganberry, raspberry, cherry, etc. and in spice blenols, fruit complexes, citrus flavours, floral flavours and vanilla imitation.

β-ionone is almost colourless or very pale straw coloured oily liquid with a boiling point of 239 ^{0}C. Very slightly soluble in water, soluble in alcohol and oils with a warm-woody somewhat dry odour with a fruity undertone. β-ionone is used in perfumery although not to the same extent as ∝- ionone. It is used in fragrances rich in woody notes. Beta-ionone is also used for flavour compositions like raspberry, loganberry, strawberry, cherry, grape, muscatel nut and fruit complexes, pistachio, pineapple, floral complexes and liquerer flavours.

Ionones are usually store in a glass, aluminium or containers internally lined with an impervious lacquer in a cool dry place protected from light. The containers should be full and tightly sealed.

_p_-Cymene

Lemongrass oil and iodine are heated in a flask equipped for flash distillation, with an efficient condenser, until the vigorously exothermic reaction becomes self-supporting. The organic layer of the distillate is separated, returned to the flask and mixed with the undistilled portion. More iodine is added and gentle heating applied, to drive over the water, followed by more intense heating until the *p*-cymene distillation slows down. The organic layer of the distillate is washed with saturated aqueous sodium bisulphite and then with water. The crude *p*-cymene is purified by washing with cold concentrated sulphuric acid to remove non-aromatic unsaturated compounds, then with water, dried with anhydrous calcium chloride and silica gel and refluxed overnight over sodium. Fractional distillation gives *p*-cymene, b.p. 163-165 ^{0}C.

Citronellol and Tetrahydrogeraniol

Selective reduction of lemongrass oil with hydrogen in the presence of Raney nickle catalyst, gives citronellol and tetra-hydrogeraniol.

Vitamin A

In the commercial process developed by Isler, the starting material ionone is condensed in a Darzens reaction with methyl or ethyl chloroacetate. The resulting glycidic ester is simultaneously hydrolyzed, decarboxylated and rearranged to the C_{14} aldehyde by stirring the crude Darzens reaction mixture with methanolic alkali at 5^0. Next, methyl vinyl ketone is condensed in liquid ammonia with lithium acetylide to yield 3-methylpent-1-en-4-yn-3-ol. This is allylically rearranged in dilute acid to 3-methylpent-2-en-4-yn-1-ol in *cis* and *trans* forms. Conversion of *cis* form to the Grignard reagent by means of ethylmagnesium bromide, followed by condensation with the C_{14} aldehyde gives the carbon skeleton of vitamin A. The acetylenic bond is then selectively semihydrogenated by means of a specially poisoned palladium catalyst and the primary hydroxyl group of the glycol is acetylated to give vitamin A acetate.

11.0 STANDARDS AND SPECIFICATIONS

11.1 STANDARDS

The requirements for lemongrass oil are given below.

Cymbopogon citratus

	ISO : 3217	BS : 2999/36	E.O.A.	I.P.C.
Specific gravity	0.872 – 0.897 (at 20°C)		0.869-0.894 (at 25°C)	0.880-0.905 (at 15.5°C)
Apparent density		0.870-0.895		
Refractive Index (at 20°C)	1.4830-1.4890	1.4830-1.4890	1.4830-1.4890	1.4821.488
Optical rotation	-3° to + 1°	-3° to +1°	-3°to+1°	-3°to+3°
Carbonyl compounds(as citral)	Not less than 75%		Not less than 75%	Not less than 70%
Carbonyl value (Hydroxylamine method)		Not less than 276.0		
Residue			7% maximum	
Solubility	Fresh oil soluble in 70%(v/v) alcohol at 20°C Insoluble in 90% (v/v) alcohol		Yields cloudy solutions in 70, 80,90 & 95% alcohols at 25°C.	Soluble in 3 parts of 70% alcohol

C.S. – Ceylon Standard; B.S. – British Standard; E.O.A. – Essential Oil Association Standards
I.S. – Indian Standard : I.P.C. – Indian Pharmaceutical Codex

Cymbopogon flexuosus

	IS: 327	B.S.:2999/35	C.S. 192	E.O.A.	I.P.C.
Specific gravity	0.888-0.898 (at 30°C)		0.888-0.898	0.894-0.904 (at 25°C)	0.880-0.905 (at 15.5°C)
Apparent density		0.893-0.903			
Optical rotation	-3° to +1°	-30°-+1.0°	-3° to +1°	-3° to +1°	-3° to +3°
Refractive index	1.4786-1.4846 at 30°C	1.4830 - 1.4890 at 20°C	1.4786 - 1.4846	1.4830 - 1.4890 at 25°C	1.482 - 1.488
Citral content % by vol	75%		Not less than 75%	Not less than 75%	Not less than 70%
Carbonyl value		Not less than 265.0			
Residue				8% maximum	
Solubility	1vol in 3vols 70% alcohol	1vol in 3vols 70% ethanol	1vol in 3vols 70% ethanol at 30°C	Soluble in 2-3 vols 70% alcohol with slight turbidity at 25°C	3 parts of 70% alcohol

C.S. – Ceylon Standard; B.S. – British Standard; E.O.A. – Essential Oil Association Standards
I.S. – Indian Standard : I.P.C. – Indian Pharmaceutical Codex

11.2 Adulteration

Kerosene, vegetable oils (e.g. coconut oil), methylated spirits, oil from the white variety of lemongrass and citronella oil, have been detected as adulterants in lemongrass oil. The presence of these can be detected by noting the changes in the physical constants and solubility in 70% alcohol.

On steam distillation of the oil, coconut oil if present, remains in the flask. Vegetable oils can also be detected by heating the adulterated sample with alcoholic potash and diluting the product. On acidifying the non-oily layer, fatty acids separate.

Methyl and ethyl alcohols can be washed out with water and identified by common tests and paraffins can be detected by treatment with concentrated sulphuric acid.

Citronella oil is more difficult to detect. The oils adulterated with citronella oil has a remarkably low citral content and after the citral has been removed the odour of citronella oil is distinctly perceptible.

12.0 TRADE [146,199]

Lemongrass oil is one of the 10 major essential oils. The main exporters of the oil are India and Guatemala. Guatemala is traditionally the main source of the so-called 'West Indian' type of lemongrass oil, where as Indian oil has traditionally been known as `East Indian' or `Cochin' lemon grass oil.

Guatemalan lemongrass oil has traditionally been available in a range of citral contents from 75% to 95% although, as with East Indian' type oil, 75-80% is the most common range. China as a supplier of lemongrass oil has increased steadily over the years. The citral content is typically 80%. The most important buyer of Chinese oil is the USA, with Japan in second place.

Exports of lemongrass oil from Sri Lanka never appear to have been large, although the level of production may be rather higher as there is likely to be some local consumption of the oil. Among the other known producers are Brazil, Argentina, Haiti, Indonesia, Thailand.

The bulk of consumption of internationally traded lemongrass oil takes place in three main areas, namely Western Europe, North America and the Soviet Union. In no country is consumption increasing. On the other hand, in most countries, it is on a slow decline.

The current price for lemongrass oil in the world market is around $ 10.20 per pound. On the Northwest spot market, Guatemalan is going for $ 9.90 per pound. Chinese lemongrass oil hasn't been available since late 1995 when its cheaper prices, then at $ 6.50 per pound caused a buying spree soon after production.

Price for lemongrass oil in US market: (US $/lb)

	1996	1997	1998
Cochin lemongrass	9.30	10.20	9.50-10.20
Guatemalan lemongrass	6.50	9.90	9.90

Chemical Market Reporter

13.0 USES

Lemongrass oil can be used either as an oil in its own right or as a route to the isolation of its derivative citral. Citral can be further processed to isolate a group of chemicals known as the ionones, which possess a violet like fragrance and are important components in many articles of perfumery. A further processing of these ionones makes possible the manufacture of vitamins, notably vitamin A.

13.1 PERFUMERY [118,132]

The oil is currently used more as an oil in its own right in cheap fragrance work. Its many applications include aerosol deodorants, floor polishes, household detergents and other domestic and industrial products requiring a fresh, pleasant fragrance or a mask for the unpleasant odours of certain active ingredients. The odour of the oil resembles that of Verbena oil. 98-100% citral gives a lemon odour to soap after one month, but the odour fades within 6 months. The soap is also liable to yellow slightly. Ionones are a group of very important synthetic aromatics possessing a strong and lasting violet odour.

Opdyke gives the following values for the concentration of lemongrass oil in products, when used as a perfume.

	Soap	Detergents	Creams Lotions	Perfume
Usual	0.02%	0.002%	0.003%	0.08%
Maximum	0.25%	0.025%	0.02%	0.7%

13.2 INSECT REPELLENT PROPERTIES

As an insect repellent it shows great promise and can be combined with the synthetic organic insecticides DDT and BHC.

13.3 GERMICIDAL AND BACTERICIDAL [118,119,131,133]

Lemongrass oil has good antibacterial properties. In preparing a disinfectant solution with lemongrass oil, the least amount of solvent must be used.
It gives a clean smell to hospital rooms and closets. It is a constituent of dermo-cosmetics.
See also Bio-characteristics.

13.4 THERAPEUTIC USAGE [29,30,56,91,93,109,118]

Lemongrass is said to be a stimulant, diaphoretic and anti-spasmodic and its oil is carminative and tonic. Externally it is rubefacient.

According to the Indian Materia Medica, lemon grass oil is useful as a carminative in flatulent and spasmodic affections of the bowels, colic, gastric irritability, and is of great value in cholera with obstinate vomiting. The dose is from 3 to 6 drops on a piece of loaf sugar or in emulsion.

An infusion or decoction of 4 ozs. of the grass to 1 pint of boiling water is an excellent stomachic to children; with ginger, sugar, cinnamon, it is given as disphoretic in fevers, and given with black pepper it is useful in dropsical conditions caused by chronic malaria.
Mixed with equal quantity of pure coconut oil it makes an excellent embrocation or liniment for lumbago, chronic rheumatism, neuralgia, sprains and other painful affections; it is also a good application for ringworm.

A tea of lemongrass leaves is used in Brazil and other Third World countries as a popular remedy for various nervous and gastrointestinal disturbances.

West Indian lemongrass leaves are used in Cuba, as an anti-hypertensive and anti-inflammatory folk medicine. A 10% or 20% decoction of leaves showed some dose-related hypertension effects when given intravenously and some weak diuretic and anti-inflammatory effect when given orally.

In Guatemala, a decoction of *Cymbopogon citratus* leaves are used for flatulence, fever and gripe and low blood pressure by the Carib population.

Herbal tea prepared from *Cymbopogon citratus* leaves showed alleged CNS – depressant effects, is not toxic but also lacks hypnotic or anxiolytic properties.

13.5 OTHER USES [60,118]

Lemongrass oil has been reported for several other minor uses. It is said that the oil can be used to improve the flavour of some fish and can be used to flavour wines, sauces, confectionery, spices and tea leaves.

The safe usage level in food products is:

Non-alcoholic Beverages	4.4 ppm.
Ice cream, ices etc.	9.2 ppm.
Candy and baked goods	38 ppm.
Gelatine and puddings	290 ppm.
Chewing gum	220 ppm.

It can also be used for headache and toothaches, bath crystals and particularly in female complaints.

The oil has been used in insect repellent creams and anti-fungal cream. It has been found that the 2.5% lemongrass oil concentration was demonstrated to be the minimum concentration for preparation of an anti-fungal cream for subsequent

clinical studies for *Trichophyton mentogrophytes. Trichophyton rubrum, Epidermophyton floccosum* and *Microsporum gypseum*.

Deodorising composition

A biocidal – deodorizing composition containing 2.0 parts by weight of a mixture of lemongrass, cedarwood, fir oils, amylacetate and phenyl acetaldehyde, has been patented by Airwick Industries.

A Depilatory wax composition consists of :

		Parts			Parts
Beeswax	-	200	Benzoin	-	10
Resin	-	1700	Lemongrass oil	-	5
Vegetable oil	-	900	Butyl p-amino benzoate	-	10
Triethanolamine	-	100	Jaborandi- alcohol	-	5
Balsam of Tolu	-	10			

The wax is spread on a strip of thin kraft paper siliconized on the smooth outside to prevent migration of oil.

In the extraction of celloidin from impregnated tissues, oil of *Cymbopogon citratus* can replace cajput oil and clove oil.

p-Cymene derived from lemongrass oil has been used for determining the increase in C^{14} in the atmosphere.

Grass [57,60,118,162]

Used for woven articles, as a constituent of dentrifices and sedatives and as a condiment in food.

Spent grass

The residue thrown out after extracting the oil is termed as 'spent grass'. This is used in the preparation of a cattle feed. It is also an excellent source of manure and used in the preparation of compost. Spent grass is also used as fuel for the distillation of oil.

Experiments have shown that spent grass because of its high cellulose content can be converted to wrapping paper. For conversion to paper, *Cymbopogon citratus* spent grass has been digested with 14% chemicals (soda process) for 3 hr. at 135°C., 34% unbleached pulp was obtained. After bleaching 32% pulp, standard sheets prepared from spent grass had the following strength properties

Breaking length	3670m.	fibre length	1-3.08 mm
Burst factor	21.5	fibre width	0.013-0.026
Tear factor	64.1		

Reports from India, state that when spent grass is mixed with wheat stalks and rice bran, writing and printing paper can be produced.

BIBLIOGRAPHY

1. Abegaz, B. and Yohannes, P.G.
   Constituents of the Essential oil of Ethiopian *Cymbopogon citratus* Stapf. *J. Natural Products* **46**(3)p.424-426 (1983)
2. Absar, Ahmad ; Janardhanan, K.K. and Verma H.N.
   In vitro growth of *Balansia sclerotica* (Pat.)Hohn., an endophyte causing grassy-shoot disease of lemongrass. *Kavaka* **19**(1-2)p.48-52 (1994)
3. Adebayo, T. and Gbolade, A.A.
   Protection of stored cowpea from *Callosobruchus maculatus* using plant products. *Insect Science and its Application* **15**(2)p.185-189 (1994)
4. Afridi, M.M.R.K.; Khan, M.A.; Afaq, S.H. and Raychaudhuri, S.P.
   On determing the optimum spacing for transplanted lemongrass-a potential source of vitamin A. *Recent Advances in Med,Aromat.& Spice Crops* **2** p.389-395 (1992)
5. Ahmed, Imtiaz
   Multielemental analysis of lemongrass by inductively coupled plasma spectrometry. *J. Chem. Soc. Pak.* **11**(3)p.251-5 (1989)
6. Alam, K.; Agua, T.; Maven, H.; Taie, R.; Rao, K.S.; Burrows, I.; Huber, M.E.and Rali, T.
   Preliminary screening of seaweeds, seagrass and lemongrass oil from Papua New Guinea for antimicrobial & antifungal activity. *J. of Pharmacognosy* **32**(4)p.396-399 (1994)
7. Ansari, S.H.; Bhatnagar, J.K. and Qadry, J.S.
   Thin layer and gas chromatographic analysis of lemongrass oil. *Indian J. Nat. Prod.* **2**(2)p.3-7 (1986)
8. Ansari, S.H. and Qadry, J.S.
   Cymbopogon citratus utility and prospects in India. Proc. Nat. Sem. on *History of Unani Med. in India* (April 16-17) p.53 (1993)
9. Ansari, S.H. and Qadry, J.S.
   Effects of plants hormones on the growth and chemical composition of volatile oil of *Cymbopogon citratus* (DC) Stapf. *Indian J. Forestry* **13**(1)p.73-75 (1990)
10. Areekul, S. ;Sinchaisri, P. and Tigvatan, Anon. S.
    Effects of Thai plants extracts on the Oriental fruit fly. II Repellency test. *Kasetsart J. Natural Sci.* **22**(1)p.56-61 (1988)
11. Atal, C.K. and Bradu, B.L.
    Search for aroma chemicals of industrial value from genus *Cymbopogon*. Part IV. Chandi and Kolar grasses as source of methyleugenol. *Indian J. Pharm.* **38**(2)p.6304 (1976)
12. Atal, C.K. (Ed.) and Kapur, B.M. (Ed.)
    Cultivation and utilization of aromatic plants. *Council of Sci. & Indust. Res.*, India. 1982
13. Awuah, R.T.
    Fungitoxic effects of extracts from some West African plants. *Annals of Appl. Biology* **115**(3)p.451-454 (1989)
14. Ayoub, S.M.H. and Yankov, L.
    On the composition of the oil from the Sudanese lemongrass. *Fitoterapia* **55**(6)p.368-369 (1984)

15.Balboa, Judith G. and Lim-Sylianco, Clara Y.
Effect of some medicinal plants on skin tumour promotion. *Philipp. J. Sci.* **124**(2)p.203-7 (1995)
16.Barthakur, M.P. and Bordoloi, D.N.
Occurrence of vesiculararbuscular mycorrhizal fungi in some *Cymbopogon* species of North-East India. *Current Science* **59**(9)p.470-471 (1990)
17.Barua, A. and Bordoloi, D.N.
Dynamics of certain plant metabolites in relation to essential oil of lemongrass (*Cymbopogon flexuosus* Stapf). *Herba Hung.* **26**(1)p.41-47 (1987)
18.Barua, A. and Bordoloi, D.N.
Record of a new disease of lemongrass (*Cymbopogon flexuosus* Stapf) caused by *Curvularia verruciformis* Agarwal and Sahni. *Curr.Sci.* **52**(13)p.640-641 (1983)
19.Barua, Anjan and Bordoloi, D.N.
Physiological activities of N on nitrate reductase activity, effect on herb yield, dry matter, N, chlorophyll a & b and essential oil in lemongrass. *Indian Perfumer* **36**(1)p.20-3 (1992)
20.Bauer, Kurt; Garbe, Dorothea and Surburg, Horst
Common fragrance and flavor material. 2nd revised Ed., VCH Publishes, New York, USA. 1990
21.Bavappa, K.V.A.; Ruttimann, R.A. and Gunaratne, W.D.L.
Manuring of export agricultural crops-*Technical Bull.*, Dept. of Export Agriculture. 1996
22.Beech, D.F.
Growth and oil production of *Cymbopogon citratus* in the Ord irrigation area, Western Australia. *Aust. J. Expt. Agric. Anim. Husb.* 17(85)p.301-7 (1977)
23.Beech, D.F.
The effect of carrier and rate of nitrogen application on the growth and oil production of lemongrass in the Ord irrigation area, Western Australia *Aust. J. Exp. Agriculture* **30**(2)p.243-250 (1990)
24.Behura, S.; Sahoo, S. and Pradhan, N.K.
Performance of lemongrass in amended chromite overburden. *Indian Perfumer* **39**(3)p.124-126 (1995)
25.Blake, O.; Booth, R. and Corrigan, D.
The tannin content of herbal teas *British J. Phytotherapy* **3**(3)p.124-27 (1993/94)
26.Boruah, Paran Misra; Bhabani, P.; Pathak, Madan G. and Ghosh, Anil C.
Dynamics of essential oil of *Cymbopogon citratus* (DC) Stapf. Under rust disease indices. *J. Essent. Oil Res.* 7(3)p.337-8 (1995)
27.Brandares, M.F.T.; Vuelban, A.M.; Darfuan, B.B.; Ricalde, M.R. and Anzaldo, E.
Stability studies of essential oils from some Philippine plants II. *Cymbopogon citratus* (DC). *Philippine J. Sci.* **116**(4)p.391-402 (1987)
28.Carbajal, D.; Casaco, A.; Arruzazabala, L.; Gonzalez, R. and Fuentes, V.
Pharmacological screening of plants decoctions commonly used in Cuban folk medicine. *J. Ethnopharmacology* **33**(1-2)p.21-24 (1991)
29.Carbajal, D.; Casaco, A.; Arruzazabala, L.; Gonzalez, R. and Tolon, Z.
Pharmacological study of *Cymbopogon citratus* leaves. *J. Ethnopharmocology* **25**(1)p.103-107 (1989)

30.Carlini, E.A. ;Contar, J.; de D.P. Silva; Filho A.R.; Silveira, Filho N.G. and da Bueno, O.F.A.
Pharmacology of *Cymbopogon citratus* Stapf.I.Effects of teas prepared from the leaves on laboratory animals.J.Ethnopharmocology-1986 17(1)p.37-64

31.Chauhan, L.S. and Singh, J.
Rhizoctonia leaf blight of lemongrass (*Cymbopogon flexuosus*). *Indian J. Mycol. Plant Pathol.* **11**(2)p.245 (1981)

32.Chinnamma, N.P. and Menon, P.K.G.
Effect of harvest at different intervals on the grass and oil yield and citral content in lemongrass (*Cymbopogon flexuosus* Stapf). *Agric. Res. J. of Kerala* **11**(2)p.119-121 (1973)

33.Choudhary, D.K. and Kaul, B.L.
Radiation-induced methyl-eugenol oleficient mutant of *Cymbopogon flexuosus* (Nees ex Steud) Wats. *Proc.-Indian Acad.Sci.*, Sect.B **88**B(Pt.2 No.3)p.225-8 (1979)

34.Choudhury, S.N.
Effect of clipping height on herb and essential oil yeild of *Cymbopogon flexuosus*. *Indian J. Agronomy* **39**(4)p.592-598 (1994)

35.Cicogna Junior, O.; Mancini, B. Jorge and Netom, J.
Influence of distillation time on the quality and composition of the essential oils. *Revista de Ciencias Farmaceuticas* **8/9**p.173-181 (1986/87).

36.Cinnamma, N.P. and Menon, P.K.G.
Effect of pre-treatment of lemongrass (*Cymbopogon flexuosus*, Stapf.) on the yield and citral content of oil. *Agric. Res. J. of Kerala* **11**(1)p.27-31 (1973)

37.De la Torre Melis, R.A.; Capiro Trujillo, N. and Fernandez, I.
Studies on toxic and genotoixc activity of a decoction from lemongrass (*Cymbopogon citratus*) *Revista Biologia Habana* **3**(2)p.131-138 (1989)

38.De Matouschek, B.V. and Stahl-Biskup, E.
Phytochemical studies on non-volatile constitutents of *Cymbopogon citratus* (DC) Stapf *Pharm.Acta Helv.* **66**(9-10)p.242-5 (1991)

39.Deans, S.G.; Svoboda, K.P.; Gundidza, M. and Brechany, E.Y.
Essential oil profiles of several temperate and tropical aromatic plants:their antimicrobial and antioxidant activities. *Acta-Horticulturae* (306)p.229-232 (1992)

40.Demissew, S.
A description of some essential oil bearing plants in Ethiopia and their indigenous uses. *J. Essent. Oil Res.* **5**(5)p.465-479 (1993)

41.Dube, Gita; Rao, T.Siva Sankara and Nigam, S.S.
Anti fungal efficacy of some Indian Essential oils. *Indian Perfumer* **27**(1)p.5-8 (1983)

42.Dutta, D.K.; Misra, B.P.; Borah, U.C. and Bordoloi, D.N.
Distillation of essential oil of *Cymbopogon flexuosus*. *Indian Perfumer* **31**(2)p.128-136 (1987)

43.Dutta, P.K.; Paul, S.C.; Sahoo, S. and Saxena, H.O.
Cultivation of medicinal and aromatic plants in Orissa region. *J. Orissa Bot. Soc.* **1**(1)p.21-22 (1979)

44.Ekundayo, O.
Composition of the leaf volatile oil of *Cymbopogon citratus*. *Fitoterapia* **56**(6)p.339-342 (1985)

45.El-Labban, H.M.; Ashry, M.A. and El-Nawawy, A.S.
The effect of weed control treatments on both weeds and *Cymbopogon citratus*. *Curr.Sci.* **46**(15)p.532-3 (1977)
46.Ellabban, H.M.
Effect of Cycocel and spacing on the growth and volatile oil of *Cymbopogon citratus*. *Scientia Horticulturae* **8**(3)p.237-242 (1978)
47.El-Saeid, H.M.; Hussein, M.S. and El-Sherbeny, S.E.
Effect of some growth regulators on herb, oil yeilds and hormonal content of lemongrass. *Egypt J. Hortic.* **21**(1)p.15-23 (1994)
48.Facknath, S. and Kawol, D.
Antifeedant and insecticidal effects of some plant extracts on the cabbage webworm, *Crocidolomia binotalis*. *Insect Sci. and its Application* **14**(5)p.571-574 (1993)
49.Fonteles, M.C.; Gadelha, M.G.T.; Sousa, N.R.; Alencar, V.H.M. and Matos, F.J.A.
Some pharmacological properties of extracts from plants of North-Eastern Brazil. *Acta Amazonica Suplemento* **18**(1-2)p.113-121 (1988)
50.Formigoni, M.L.O.S.; Lodder, H.M.; Gianotti, Filho; Filho, O.; Ferreira, T.M.S. and Carlini, E.A.
Pharmacology of *Cymbopogon citratus* Stapf. II. Effects of daily two month administration in male and female rats and in offspring exposed "in utero" *J. Ethnopharmacology* **17**(1)p.65-74 (1986)
51.Fuentes, V.; Rodriguez, N.; Rodriguez, C. and Ramos, R.
Screening of 51 medicinal species for salinity tolerance. *Agrotecnia de Cuba* **20**(1)p.1-6 (1988)
52.Ghosh, M. and Chatterjee, S.K.
Effect of N:P:K on growth, development and essential oil content of two species of *Cymbopogon*. *Sci. and Culture* **42**(9)p.490-492 (1976)
53.Ghosh, M.L. and Chatterjee, S.K.
Effect of some hormones and chemicals on seed germination of *Cymbopogon flexuosus* Stapf.in Burdwan *Sci.Cult.* **43**(3)p.128-9 (1977)
54.Ghosh, M.L. and Chatterjee, S.K.
Patterns of essential oil formation in lemongrass in relation to growth and metabolism of the plant under varying nutronal supply. *Recent Advances Med. Aromat. and Spice Crops, Today and Tomorrow'sIndia* **1**p179 (1991)
55.Ghosh, M.L. and Chatterjee, S.K.
Patterns of essential oil formation in two species of *Cymbopogon* in Burdwan, West Bengal. *Indian J. Exp. Biology* **14**(2)p.214-216 (1976)
56.Giron, L.M.; Freire, V.; Alonzo, A. and Caceres, A.
Ethnobotanical survey of the medicinal flora used by the Caribs of Guatemala. *J.Ethnopharmacology* **34**(2-3)p.173-187 (1991)
57.Guha, S.R.D.; Rajesh, Pant and Karira, B.G.
Chemical pulps for writing and printing paper from *Cymbopogon citratus* (DC.) Stapf. *Indian Forester* **99**(2)p.717-720 (1973)
58.Gunasingh, C.; Barnabas Gnanaraj and Nagarajan, S.
Flavonoids of *Cymbopogon citratus*. *Indian J. Pharm. Sci.* **43**(3)p.115 (1981)
59.Gupta, R.S.
Trial cultivation of some medicinal and aromatic plants in Malwa region of M.P. Part II. Analysis of essential oils. *Indian Perfumer* **31**(4)p.370-374 (1987)

60.Gupta, R.K. (Ed.)
Perfumes, flavours and essential oils. Small Business Publications, Delhi
61.Gupta, R.K. and Jain, Naveen
Indian Perfumer **22**(2)p.55-68 (1978)
62.Handique, A.K.; Gupta, R.K. and Borddoi, D.N.
Variation of oil content in lemongrass as influenced by seasonal changes and its genetic aspects. *Indian Perfumer* **28**(1)p.54-63 (1984)
63.Handique, A.K.
Development of a new chemo-mutant of lemongrass. *Indian Perfumer* **29**(3-4)p.139-145 (1985)
64.Hanson, Steven W.; Crawford, Malcolm Koker; Moustapha, E.S. and Menezes, Francis A
Cymbopogonol, a new triterpenoid from *Cymbopogon citratus*. *Phytochemistry* **15**(6)p.1074-5 (1976)
65.Haque, M.Mohibbul and Islam, M.Amirul
Dissolving pulp from lemongrass stem (*Cymbopogon flexuosus* Linn.) by the alkaline-phenazine process. *J. Bangladesh Acad. Sci.* **15**(1)p.39-45 (1991)
66.Hussain, A. and Ali, A.
Endomycorrhizal (vesicular-arbuscular) infection in lemongrass, *Cymbopogon citratus* (DC) Stapf.. *Hamdard Medicus* **38**(1)p.63-70 (1995)
67.Hussain, Akhtar; Viramani, O.P.; Sharma, Ashok; Kumar, Anup and Misra, L.N.
Major Essential oil bearing plants of India. Central Institute of Medicinal and Aromatic Plants, Lucknow, India. 1988
68.Hussain, Akhtar
Essential oil plants and their cultivation. Central Inst. of Medicinal and Aromatic Plants, India. 1994
69.Ibrahim, Darah
Antimicrobial activity of the essential oil of the local serai, *Cymbopogon Citratus*. *J. Biosci.* (Penang Malays.) **3**(1-2)p.87-90 (1992)
70.Il Idrissi, A.; Bellakhdar, J.; Canigueral, S.; Iglesias, J. and Vila, R.
Composition of the essential oil of lemongrass (*Cymbopogon citratus* (DC) Stapf) cultivated in Morocco. *Plantes Medicinales et Phytotherapie* **26**(4)p.274-277 (1993)
71.Janardhanan, K.K.; Ahamd, A.; Gupta, M. and Husain, A.
Grassy-shoot, new disease of lemongrass caused by *Balansia sclerotica* (Pat.) *Hohnel. J. Phytopathology* **133**(2)p.163-168 (1991)
72.Jansz, E.R.; Ratnayake, Damayanthi and Geevaratne, D.V.M.
Distillation of Leaf Essential oils. CISIR. Sri Lanka
73.Joarder, G.J. and Khatun, M.
Inhibitory effects of lemongrass oil on indigenous microflora. Part I. Inhibition of *Aspergillus niger*. *Bangladesh J. Sci. and Indust. Res.* **17**(3-4)p.219-226 (1982)
74.Kasumov, F. and Yu Babaev,R.I.
Components of *Cymbopogon citratus* essential oil. *Khimiya Prirodnykh Soedinenii* (1)p.108-109 (1983)
75.Keiwa, Shoko K.K.
Dog and Cat repellent packing material. Jpn. Kokai Tokkyo Koho JP 82 74,158 (Cl B32B27/10)10May'82, Appl.80/151,968

76.Kharya, M.D. and Varma, K.C.
Cultural studies of some essential oil yielding grasses-influence of plant hormones on *Cymbopogon citratus* (DC) Stapf. *Indian J. Nat. Prod.* **2**(1)p.8-13 (1986)

77.Kinyuy, W.C.; Palevitch, D. and Putievsky, E.
Through integrated biomedical/ethnomedical preparations and ethnotoxonomy, effective malaria and diabetic treatments have evolved. *Acta-Horticulturae* (344)p.205-214 (1993)

78.Kole, C.; Biswas, S. and Sen, S.
Growth and Performance of *Cymbopogon citratus* Stafp. And *Cymbopogon pendulus* (Nees ex Steud) in West Bengal.*Indian Perfumer* **25**(1)p.56-60 (1981)

79.Kulkarni, R.N.; Mallavarapu, G.R. and Ramesh, S.
The oil content and composition of new variants of *Cymbopogon flexuosus*. *J. Essent. Oil Res.* **4**(5)p.511-514 (1992)

80.Kulkarni, R.N.; Rajagopal, K. and Ramesh, S.
Selection for oil content in East Indian lemongrass. *Plant Breeding* **97**(1)p.78-81 (1986)

81.Kulkarni, R.N. and Ramesh, S.
Development of lemongrass clones with high oil content through population improvement. *J. Essent. Oil Res.* **4**(2)p.181-186 (1992)

82.Kulkarni, R.N. and Ramesh, S.
Heritability estimates of citral content in East Indian lemongrass. *Theoretical and Applied Genetics* **73**(3)p.476-477 (1987)

83.Kuriakose, K.P.; Kurian, A. and Rajan, K.C.
Comparative yield trials on induced lemongrass mutants. *Indian Perfumer* **33**(1)p.60-62 (1989)

84.Kuriakose, K.P.; Rajan, K.C. and Kurian, A.
Two promising types of lemongrass (*Cymbopogon flexuosus* Stapf.). *Pafai J.* **9**(4)p.17-18 (1987)

85.Kuriakose, K.P. and Shylaraj, K.S.
Seed germination in lemongrass and palmaros. *Agricultural Res. J. Kerala* **26**(2)p.280-283 (1988)

86.Kuriakose, K.P.
Exploration of wild growing lemongrass types in Kerala. *Indian Perfumer* **34**(1)p.71-74 (1990)

87.Kuriakose, K.P.
Genetic variability in East Indian lemongrass (*Cymbopogon flexuosus* Stapf). *Indian Perfumer* **39**(2)p.76-83 (1995)

88.Kurian, Alice; Nair, E.V.G. and Rajan, K.C.
Effect of antioxidants on the preservation of citral content of lemongrass oil. *Indian Perfumer* **28**(1)p.28-32 (1984)

89.Lalitha, R.; George, R. and Ramasarma, T.
Mevalonate decarboxylation in lemongrass leaves. *Phytochemistry* **24**(11)p.2569-2571 (1985)

90.Lawrence, Brian M.
Essential Oils. *Perfumer & Flavorist* **9**(June/July)p.40-44 (1984)

91.Leite, J.R.; Seabra, M.de L.V.; Maluf, E.; Assolant, K. and Suchecki, D.
Pharmacology of *Cymbopogon citratus* Stapf. III. Assessment of eventual toxic, hypnotic and anxiolytic effects on humans. *J. Ethnopharmocology* **17**(1)p.75-83 (1986)

92.Lim-Sylianco, C.Y.; Jocano, A.P. and Lim, C.M.
Antimutagenicity of twenty Philippine plants using the micronucleus test in mice. *Philippine J. Sci.* **117**(3)p.231-235 (1988)

93.Lorenzetti, Berenice B.; Souza, Gloria E.P.; Sarti, Silvio J. *et.al.*
Myrcene mimics the peripheral analgesic activity of lemongrass tea. *J. Ethnopharmacology* **34**(1)p.43-8 (1991)

94.Mairapetyan, S.K.
Citric sorghum (*Cymbopogon ctratus*) in open air gravel culture in Armenia. *Soilless Culture* **3**(2)p.47-56 (1987)

95.Mairapetyan, S.Kh. and Aleksanyan, D.S.
The water regime and productivity of lemongrass. *Biologicheskii Zhurnal Armenii* 40(6)p.439-442 (1987)

96.Mairapetyan, S.Kh.
Hydroponic culture of essential oil producing plants. *Agrokhimiya* (7)p.107-10 (1982)

97.Mairapetyan, S.Kh.
The effectiveness of cultivating lemongrass hydroponically in the open. *Soobshcheniya In ta Agrokhim.Probl.i Gidroponiki AN ArmSSR.* (18)p.15-21 (1979)

98.Mairapetyan, S.M. and Oganyan, A.S.
Productivity of *Cymbopogon citratus* (D.C. ex Nees) Stapf. grown in open air hydroponics. *Rastitel'nye Resursy* **27**(1)p.108-112 (1991)

99.Mangiarotti, A.M.; Del Frate, G. and Caretta, G.
Note on the action of some essential oils on fungi. *Boletin Micologico* **5**(1-2)p.1-4 (1990)

100.Manzoor-i-Khuda, M.; Rahman, Mujibur; Yusuf, Md. and Chowdhaury, Jasimuddin
Studies on Essential oil bearing plants of Bangladesh. *Bangladesh J. Sci. and Ind. Res.* **21**(1-4)p.70-80 (1986)

101.Matos, F.J.A.; Alencar, J.W.; Carveiro, A.A.; Fonteles, M.C.; Souza, N.R. and Ferreira, M.S.C.
Chemical and pharmacological distinction between clones of *Cymbopogon citratus* Stapf. cultivated in Ceara and Sao Paulo. *Acta Amazonica Suplemento* **18**(1-2)p.345-348 (1988)

102.Matter, M.M.; Marei, S.S.; Moawad, S.M. and El Gengaihi, S.
The reaction of *Aphis gossypii* and its predator, *Coccinella undecimpunctata* to some plant extracts. *Bull. of Faculty of Agric.*, Univ. of Cairo **44**(2)p.417-432 (1993)

103.Mercy, S.T.; Nair, V.G. and Babu, L.C.
Anthesis in Indian lemongrass, *Cymbopogon flexuosus* Stapf. *Agric. Res. J. Kerala* **17**(2)p.200-203 (1979)

104.Mishra, A.K.; Kishore, N.; Dubey, N.K. and Chansouria, J.P.N.
An evaluation of the toxicity of the oils of *Cymbopogon citratus* medica in rats. *Phytotherapy Research* **6**(5)p.279-281 (1992)

105.Misra, A. and Khan, A.
Correction of iron deficiency chlorosis in *Cymbopogon flexuosus* Steud. Watts. *Agrochimica* **36**(4-5)p.349-60 (1992)
106.Misra, A. and Srivastava, N.K.
Effect of the triacontanol formulation 'Miraculan' on photosynthesis, growth, nutrient uptake and essential oil yield of *Cymbopogon flexuosus* Steud. *Plant Growth Regulation* **10**(1)p.57-63 (1991)
107.Mohammad, F.; Nigam, M.C. and Rahman, W.
Detection of new trace constituents in the essential oils of *Cymbopogon flexuosus*. *Perfumer & Flavorist* **6**(2)p.29-31 (1981)
108.Mosquerra, Monica and Munoz, Ricardo
Radiosensitivity of some aromatic herb species. *Politecnica* **17**(1)p.227-74 (1992)
109.Nadkarni, A.K.
Indian Materia Medica (Vol.1), Popular Book Depot, Bombay, India. 1954
110.Nair, E.V.G.; Chinnamma, N.P. and Pushpa Kumari, R.
Investigations on some types of lemongrass (*Cymbopogon flexuosus* Stapf.). *Indian Perfumer* **24**(1)p.20-21 (1980)
111.Nair, E.V.G.; Nair, K. Chandrasekharan and Chinnamma, N.P.
Field experiment with micronutrients on yield of grass and oil and citral content of oil of East Indian lemongrass variety OD-19. *Indian Perfumer* **23**(1)p.55-8 (1979)
112.Nair, E.V.G.; Rajan, K.C.; Chinnamma, N.P. and Kurian, A.
Response of lemongrass varieties to nitrogen application. *Proceedings of National Seminar on Med. and Aromat. Plants* p.153-154 (1982)
113.Nair, K.C. and Nair, E.V.G.
Effects of salt water treatment on the extraction of oil from lemongrass (*Cymbopogon flexuosus*) *Agric. Res. J. of Kerala* **13**(2)p.205-206 (1975)
114.Nair, R.V. ;Misra, H.O.; Lal, R.K. and Naqvi, A.
Development of a new geraniol rich selection from the seed progenies of Lemongrass. *Curr. Sci.* **53**(18)p.986 (1984)
115.Natarajan, N.; Murugesan, M. and Damodaran, N.P.
Studies on Indian essential oils and their isolates-6. *Indian Perfumer* **32**(1)p.90 (1988)
116.Nath, S.C.; Kanjilal, P.B. and Bordoloi, D.N.
Evaluation of germplasm of native *Cymbopogon citratus* (DC) Stapf. *Pafai J.* **14**(1)p.29-30 (1992)
117.Nath, S.C.; Saha, B.N.; Bordoloi, D.N.; Muthur, R.K. and Leclercq, P.A.
The Chemical composition of the essential oil of *Cymbopogon flexuosus* (Steud) Watts. growing in Northeast India. *J. Essent. Oil Res.* **6**(1)p.85-7 (1994)
118.Nethsinghe, Clodagh and Paskaranathan, Uma
Lemongrass-A Literature Survey., CISIR, Sri Lanka and National Science Council
of Sri Lanka. 1976
119.Nigram, S.S.
Antimicrobial activity and essential oil. *Indian Perfumer* **26**(2-4)p.249-254 (1982)

120.Odeyemi, O.
Insecticidal properties of certain indigenous plant oils against *Sitophilus zeamais* Mots. *Applied Entomology and Phytopathology* **60**(1&2)p.19-27 (1993)
121.Ofuya, T.I. and Okuku, I.E.
Insecticidal effect of some plant extracts on the cowpea aphid *Aphis craccivora* Koch (Homoptera:Aphididae). *Anzeiger fur Schadlinskunde, Pflanzenschutz, Umweltschutz* **67**(6)p.127-129 (1994)
122.Olaifa, J.I.; Erhun, W.O. and Akingbohungbe, A.E.
Insecticidal activity of some Nigerian plants. *Insect Sci. and its Application* **8**(2)p.221-224 (1987)
123.Olaniyi, A.A.; Sofowora, E.A. and Oguntimehin, B.O.
Phytochemical investigation of some Nigerian plants used against fevers, *Cymbopogon citratus*. *Planta Med.* **28**(2)p.186-9 (1975)
124.Oliveros, Belardo L. and Aureus, E.
Essential oil from *Cymbopogon citratus* (DC.) Stapf. growing wild in the Philippines. *Perfumer & Flavorist* **2**(5)p.59-60 (1977)
125.Oliveros-Belardo, L. and Aureus, E.
Essential oil from *Cymbopogon citratus* (DC) Stapf. growing wild in the Philippines. *Int.Congr.Essent.oil* [Pap.], 7th 1977(Pub 1979) 7p.166-8
126.Onabanjo, A.O.; Aggbaje, E.O. and Odusote, O.O.
Effects of aqueous extracts of *Cymbopogon citratus* in malaria. *J. Protozoology Res.* **3**(2)p.40-45 (1993)
127.Onawunmi, G.O. and Ogunlana, E.O.
A study of the antibacterial activity of the essential oil of *Cymbopogon citratus* DC) Stapf. *Int. J. Crude Drug Res.* **24**(2)p.64-68 (1986)
128.Onawunmi, G.O. and Ogunlana, E.O.
Effects of lemon-grass oil on the cells and spheroplasts of *Escherichia coli* NCTC 9001. *Microbios Lett.* **28**(110)p.63-8 (1985)
129.Onawunmi, G.O.; Yisak, W.A. and Ogunlana, E.O.
Antibacterial constituents in the essential oil of *Cymbopogon citratus* (DC) Stapf. *J. Ethnopharmacology* **12**(3)p.279-286 (1984)
130.Onawunmi, G.O.
Evaluation of the antifungal activity of lemongrass oil. *Int. J. Crude Drug Res.* **27**(2)p.121-126 (1989)
131.Onawunmi, G.O.
In vitro studies on the antibacterial activity of phenoxyethanol in combination with lemongrass oil. *Pharmazie* **43**(1)p.42-44 (1988)
132.Opdyke, D.L.J. (Ed.)
Monographs on fragrance raw materials. Pergamon Press, Oxford, New York. 1979
133.Orafidya, L.O.
The effect of autoxidation of lemon-grass oil on its antibacterial activity. *Phytotherapy Research* 7(3)p.269-271 (1993)
134.Pal, S. Suresh Chandra; Balyan, S.S.; Singh, A. and Rao, B.L.
Nitrogen requirement of new lemongrass strain-CKP-25. *Indian Perfumer* **36**(2)p.75-80 (1992)
135.Pareak, S.K. and Gupta, Rajendra
On the status of agronomic research in *Cymbopogon* grasses in India with projections on future work. *Indian Perfumer* **29**(3-4)p.215-224 (1985)

136.Patra, N.K.; Srivastava, R.K.; Chauhan, S.P.; Ahmad, A. and Misra, L.N.
Chemical features and productivity of a geraniol-rich variety (GRL-1) of *Cymbopogon flexuosus*. *Planta Medica* **56**(2)p.239-240 (1990)

137.Patra, P. and Dutta, P.K.
Evaluation of improved lemongrass strains for herb and oil yield and citral content under Bhubaneswar condition. *Res. Ind.* **31**(4)p.358-360 (1986)

138.Paul, B.; Singh, K.K.; Jadaun, S.P.S. and Parmar, A.S.
Effect of water salinity on herb and oil yield and composition of some *Cymbopogon* species. *Indian Perfumer* **33**(3)p.196-9 (1989)

139.Prasad, L.K. and Mukherji, S.K.
Effect of nitrogen, phosphorus and potassium on lemongrass. *Indian J. Agron.* **25**(1)p.42-44 (1980)

140.Ragimov, M.A.; Babaev, R.I. and Kasumov, F.Yu
Trials on introducing lemongrass in the Apsheron peninsula. *Introduktsiya i Akklimatizatsiya Rastenii* p.104-107 (1985)

141.Rajan, K.C.; Sadanandan, N. and Nair, E.U.G.
Effect of graded levels of nitrogen on the yield and quality of lemongrass oil. *Agric. Res. J. Kerala* **22**(1)p.37-42 (1984)

142.Rajapakse, R.H.S. and Jayasena, K.W.
Plant resistance and biopesticide from lemongrass oil for suppressing *Spodoptera litura* in peanut. *Agriculture International* **43**(6)p.166-167 (1991)

143.Rao, B.L.; Lala, S.; Dhar, K.L. and Kaul, B.L.
New aroma chemicals in *Cymbopogons* for future. *Indian Perfumer* **36**(4)p.241-245 (1992)

144.Rao, B.R. Rajeswara; Kaul, P.N.; Bhattacharya, A.K.; *et.al.*
Yield and Chemical composition of the essential oils of three *Cymbopogon* species suffering from iron chlorosis. *Flavour & Fragrance J.* **11**p.289-293 (1996)

145.Rao, E.V.S.P.; Singh, Munnu and Rao, R.S.G.
Effect of N, P and K fertilizers on yield and nutrient uptake in lemongrass (*Cymbopogon flexuosus* Stapf). *Inter. J. Tropical Agriculture* **3**(2)p.123-127 (1985)

146.Robbins, S.R.J.
Selected markets for the essential oils of lemongrass, citronella and eucalyptus. Tropical Products Institute, London 1983

147.Samiullah, Varshney A.K.; Afridi, M.M.R.K.; Mohammad, F. and Afaq, S.H.
Nitrogen requirement of lemongrass for optimum performance in western Uttar Pradesh. *Indian Perfumer* **32**(3)p.225-228 (1988)

148.Sanchez, E.; Durand, D. and Llanes, M.
Some pharmacognostic parameters of medicinal plants. I. *Revista Cubana de Farmacia* **19**(3)p.450-453 (1985)

149.Sankar, S.J. and Thomas, J.
Oil yield and quality of lemongrass as influenced by growth regulator under different planting methods. *Inter. J. Tropical Agriculture* **8**(1)p.27-28 (1990)

150.Saradamma, K. and Dale, D.
Clovia bipunctata Kirby (*Cercopidae:Hemiptera*) as a pest of lemongrass. *Agricultural Research J. of Kerala* **21**(1)p.86-87 (1983)

151.Sargenti, Silvia R. Lancas and Fernando M.
Design and constraction of a simple supercritical fluid extraction system with semi-preparative and prep. capabilities for application to natural product. *J. Chromatography* A **667**(1-2)p.213-18 (1994)
152.Sarma, P.C.; Boruah, P.; Pathak, M.G. and Ordoloi, D.N.
Induced mutagenesis for *curvularia* blight resistance in lemongrass (*Cymbopogon flexuosus* Nees ex Steud). *Science & Culture* **58**(5-8)p.157-158 (1992)
153.Sarma, T.C.; Sarma, P.C. and Bordoloi, D.N.
Response of Jor Lab L2-an improved strain of lemongrass to population density and nitrogen levels. *Indian Perfumer* **37**(2)p.171-77 (1993)
154.Secondini, Olindo
Handbook of Perfumer and Flavors. Chemical Publishing Co. Inc. New York. 1990
155.Shadab Qamar, E.; Hanif, M. and Chaudhary, F.M.
Antifungal activity by lemongrass essential oils. *Pakistan J. Scientific & Industrial Res.* **35**(6)p.246-249 (1992)
156.Sharma, J.R.; Naqvi, A.A.; Lal, R.K. and Mishra, H.O.
Genetic variation and stability of oil and citral biosynthesis in lemongrass (*Cymbopogon flexuosus*). *Genet.Agrar* **42**(1)p.13-23 (1988)
157.Shukla, H.S.; Rao, G.P. and Tripathi, S.C.
Reduction in PVX and PVY infectivity by volatile constituents. *An. Edafol. Agrobiol.* **44**(11-12)p.1763-1766 (1985)
158.Shylaraj, K.S.; Kuriakose, K.P. and Thomas, J.
Seed viability and germination on East Indian lemongrass and palmarosa. *Indian Perfumer* **37**(2)p.209-212 (1993)
159.Shylaraj, K.S.; Thomas, J. and Geetha, K.
Productive mutants induced by gamma irradiation in lemongrass (*Cymbopogon flexuosus* Stapf). *Indian Perfumer* **32**(2)p.120-124 (1988)
160.Shylaraj, K.S. and Thomas, J.
Effect of gamma irradiation on growth and oil yield of lemongrass, *Cymbopogon flexuosus* Stapf. *Indian Perfumer* **32**(2)p.116-119 (1988)
161.Shylaraj, K.S.
Comparative performance of clonal and seedling progenies of lemongrass (*Cymbopogon flexuosus*) type OD 440. *Indian Perfumer* **32**(2)p.144-146 (1988)
162.Siddiqueullah, M.; Rahman, C.A.F.M. and Khaleque, M.A.
A microscopic and photomicrographic study of the elementary fibres of different indigenous pulp and paper producing raw materials. *Bangladesh J. Sci. & Indus. Res.* **10**(1-2)(1-6)p.15 (1975)
163.Siddiqui, M.A. and Alam, M.M.
Seasonal fluctuation of plant parasitic nematodes associated with two medicinal plants. *J. the Indian Botanical Society* **67**(1-2)p.231-232 (1988)
164.Siddiqui, Z.A. and Husain, S.I.
Herbal control of root knot and root-rot disease of chickpea.1. Effect of plant extracts. *New Agriculturist* **1**(1)p.1-6 (1990)
165.Singh, N. and Luthra, R.
Sucrose metabolism and essential oil accumulation during lemongrass (*Cymbopogon flexuosus* Stapf.) leaf development. *Plant Sci.* **57**(2)p.127-133 (1988)

166.Singh, Neelam Luthra; Rajesh Sangwan and Rajender, S.
Effect of leaf position and age on the essential oil quantity and quality. in lemongrass. *Planta Med.* **55**(3)p.254-6 (1989)
167.Singh, P.K. and Pal, B.
Effect of salinity and fluorine levels of irrigation water on nutrient uptake in lemongrass. (*Cymbopogon flexuosus*). *Indian Perfumer* **38**(2)p.51-5 (1994)
168.Singh, R.S.; Pathak, M.G. and Bordoloi, D.N.
Citral of lemongrass under different plant population and soil pH. *Pafai J.* **5**(1)p.33-36 (1983)
169.Singh, S.N.; Sangwan, R.S.; Luthra, R. and Thakur, R.S.
Geraniol dehydrogenase: A determinant of essential oil quality in lemongrass. *Planta Medica* **59**(2)p.168-170 (1993)
170.Singh-Sangwan Neelam; Farooqi, A.H. Abad Sangwan and Rajendra Singh
Effect of drought stress on growth and essential oil metabolism in lemongrasses. *New Phytol.* **128**(1)p.173-9 (1994)
171.Srivastava, S.B.
Perfume, Flavour and Essential oil Industries. Small Industry Research Institute, India.
172.Sri Lanka-Development of Essential oil Industry. Commonwealth Secretariat, London SW1. 1987
173.Stein, U. and Klingauf, F.
Insecticidal effect of plant extracts from tropical and subtropical species. *J. Appl. Entomology* **11**(2)p.160-166 (1990)
174.Subrahmanyam, K. and Chattopadhyay, A.
Plant characters and rhizosphere soil properties as influenced by iron chlorosis in *Cymbopogon flexuosus* Linn. Plant *Physiology and Biochemistry*, New Delhi **18**(2)p.68-70 (1991)
175.Sweelam, M.E.
The potential use of some ornamental plants for nematode control in Egypt. *Bulletin of Fac. of Agric.*, Univ. of Cairo **40**(2)p.391-393 (1989)
176.Syed, M.; Khalid, M.R. and Chaudhary, F.M.
Essential oils of Gramineae family having antibacterial activity. Part I. *Pakistan J. Scientific & Industrial Res.* **33**(12)p.529-531 (1990)
177.Tabata, Mamoru; Hiraoka, Noboru and Teranishi, Yoko
Yield trial and tissue culture of Thai lemongrass. *Shoyakugaku Zasshi* **35**(2)p.128-33 (1981)
178.Taskinen, J.; Mathela, D.K. and Mathela, C.S.
Composition of the essential oil of *Cymbobogon flexuosus*. *J.Chromatography* **262**p.364-266 (1983)
179.Thappa, R.K.; Dhar, K.L. and Atal, C.K.
Isointermedeol, a new sesquiterpene alcohol from *Cymbopogon flexuosus*. *Phytochemistry* **18**(4)p.671-672 (1979)
180.Thappa, R.K.; Vashist, V.N. and Atal, C.K.
Arundoin from *Cymbopogon flexuosus* leaves. *Indian J. Chem.* **13**(10)p.1108 (1975)
181.Thomas, J.; Joy, P.P. and Geetha, K.
Optimum method of planting in lemongrass. *Indian Perfumer* **33**(2)p.102-103 (1989)

182.Tiwari, K.P. and Pandey, A.
Effect of some essential oils on lactic acid bacteria. *J. Sci. Res.*(Bhopal) **3**(3)p.161-163 (1981)
183.Tiyagi, S.A.; Siddiqui,M.A. and Alam, M.M.
Toxicity of an insect-repellent plant to plant parasitic nematodes. *Inter. Nematology Network Newsletter* **3**(2)p.16-17 (1986)
184.Torres, R.C.; Estrella, R.R. and Guevarra, B.Q.
Extraction and characterization of the essential oil of Philippine *Cymbopogon citratus* (DC) Stapf. *Philippine J. Sci.* **123**(1)p.51-57 (1994)
185.Torres, R.C. and Ragadio, A.G.
Chemical composition of the essential oil of Philippine *Cymbopogon citratus* (DC) Stapf. 7th Asian Sym. of Med. Plants, Spices & Other Natural Prod. Manila, 2-7Feb.1992
186.Torres, R.C.
Citral from *Cymbopogon citratus* (DC) Stapf (lemongrass) oil. *Philippine J. Sci.* **122**(3)p.269-278 (1993)
187.Valarini, P.J.; Frighetto, R.T.S. and de Melo, I.S.
The effect of medicinal herb *Cymbopogon citratus* on control of phytopathogenic fungi in bean crop. *Revista de Agricultura Piracicaba* **69**(2)p.139-150 (1994)
188.Vatakencherry, P.A.; Pushpakumari, K.N. and Varghese, J.
A new method of separation of citral from lemongrass oil. *Perfumer & Flavorist* **12**(5)p.23-26 (1987)
189.Vimalan, A.K.; Sadanandan, K.; Philip, M.P.; Natrajan, N.; Murugesan, M. *et. al.*
Profiles in Indian essential oils: Essential oil composition as a chemical index of fine classification of selected oleaginous botanical species. *Chemistry-analysis & stucture* **4**p.181-88 (1990)
190.Vinitketkumnuen, Usanee; Puatanachokchai, Rawiwan *et. al.*
Antimutagenicity of *Cymbopogon citratus* to various known mutagens in *Salmonella* mutation assay. *Mutat. Res.* **341**(1)p.71-5 (1994)
191.Viramani, O.P. Srivastava, R. Datta, S.G.
Oil of lemongrass. Part I. East Indian. *World Crops* **31**(2)p.72-74 (1979)
192.Virmani, O.P.; Srivastava, R. and Datta, S.G.
Oil of lemongrass. Part 2: West Indian. *World Crops* **31**(3)p.120-121 (1979)
193.Vitkare, D.G.; Phasate, S.N.; Zade, K.B. and Paulkar, K.S.
Effect of nitrogen and phosphorus fertilization on the oil content and oil quality of lemongrass (*Cymbopogon flexuosus*). *PKV Research J.* **14**(1)p.64-66 (1990)
194.Wijayaratne, Rohini and Pieris, Nirmala
Cultivation of essential oil bearing plants. C.I.S.I.R., Colombo.
195.Wijesekera, R.O.B. (ed.)
Practical manual on : The Essential Oil Industry. UNIDO, Vienna. Austria.
196.Wannmacher, I.; Fuchs, F.D.; Paoli, C.L.; Gianlupi, A.; Fillmann, H.S.; Hassegawa, C.Y. *et.al.*
Plants employed in the treatment of anxiety and insomnia: 1.An ethanopharmacological survey in Porto Alegre, Brazil. *Fitoterapia* **61**(5)p.445-448 (1990)
197.Yadav, P. and Dubey, N.K.
Screening of some essential oils against ringworm fungi. *Indian J. Pharmaceutical Sci.* **56**(6)p.227-230 (1994)

198.Zheng, Guo Qiang; Kenny, Patrick M. and Lam, Luke K.T.
Potential anticarcinogenic natural products isolated from lemon grass oil and galanga root oil. *J. Agric. Food Chem.* 41(2)p.153-6 (1993)
199.Essential oils and oleoresins – A study of selected produces and major markets. International Trade Centre UNCTAD/GATT. Geneva. 1986
200.SBP Board of Consultants and Engineers – Aromatic Chemicals, Perfumes and Flavour Technology – Small Business Publications. New Delhi. India.