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Bio-chemical profiling of black turmeric (*Curcuma caesia* Roxb.) genotypes

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Abstract

Curcuma caesia Roxb. is well known for its social, religious, aesthetic and medicinal purposes. Wide variation in the chemical composition of the leaf and rhizome extract is evident in the GC-MS analysis. GAB-13, GAK-14 and GMI-22 leaf extracts had highest number of phyto- compounds (10 No's), followed by GKM-1, GAB-12, GMK16, GMS-24 and GMR-31 (8 compounds each). However minimum number of biocompounds present in GMA-17 and GNK-25 (5 compounds each). Genotype GMF-21 rhizome extract had maximum number of phyto-compounds (12 No's), followed by GNP-33 (11No's) and GKM-1, GBS-8, GAB-11, GMW-15 and GMS-24 genotypes (10 compounds each). While the least was observed in GNK-25, GNF-27 and GKT- 29 (5 compounds each).

The characterized peaks are unique to the sample extract of Southern Indian genotypes, which differs from the peaks reported for the genotypes originated from Central India and North East India. The uniqueness is due to the presence of tropolone, β -elemene, (-)-, curzerene and alpha santalol. Genotypes collected from central india exhibits unique composition of the retinal, eucalyptol (cineole), 3,7(11)-eudesmadiene, 4 acetylcarene and camphor, similarly north east indian genotypes had γ -elemene, bicyclo (2.2.1) heptan- 2-one, 1,7,7-trimethyl-(1S)-. The study showed less similarity in the composition of both leaf and rhizome extract of different genotypes explained intraspecific diversity with respect to chemical components. Bioactive constituents of black turmeric are dependent on its geographical.

Keywords: *Curcuma caesia* Roxb, Tropolone, β -elemene, (-)-, Curzerene and alpha santalol. retinal, eucalyptol (cineole), 3,7(11)-eudesmadiene, 4 acetylcarene

Introduction

Curcuma caesia Roxb. is an erect, perennial, medicinal rhizomatous herb commonly named as 'black turmeric' due to its bluish - black rhizomes. It is an important, lesser known, non-conventional medicinal plant of Zingiberaceae family. Medicinal potentiality of *Curcuma caesia* Roxb. is varied, entire plant part has been traditionally used for centuries as a folklore remedy. It is widely used in Ayurvedic, Unani and Siddha herbal system of medicines. Rhizomes have a high economical importance owing to its putative medicinal properties. Blood purifying activity (Arulmozhi *et al.*, 2006) [2], bronchodilating activity (Paliwal *et al.*, 2011) [23], anti-oxidant activity (Mangla *et al.*, 2010) [18], anxiolytic and CNS depressant activity, anticonvulsant (Karmakar *et al.*, 2011) [15], anthelmintic activity (Gill *et al.*, 2011) [12], anti-bacterial activity (Rajamma *et al.*, 2012) [25], anti-ulcer activity (Das *et al.*, 2012) [8] were also noticed. The medicinal and nutritive value of a plant is based on the plethora of chemical substances produced in them. A wide range of variation for essential oil content and its chemical components were reported in *Curcuma caesia* Roxb, which may be either because of false taxonomic identification of the specimen or due to environmental effects, maturity variations of the various varieties of rhizome or different analytical techniques used for the extraction of oil (Behar *et al.*, 2013) [3].

Behuria and Srivastava (2004) [5] reported that the volatile oil from *C. caesia* ranged from 1.5% to 1.8%. Essential oil content in the leaves contains α -pinene (1.5%), β -pinene (6.3%), myrcene (0.5%), limonene (2.1%), 1, 8-cineole (27%), camphor (1.68%), linalool (2.8%), β -elemene (2.4%), borneol (8.7%), α -terpenol (5.2%) and eugenol (2%).

This variation in camphor content motivated Pandey and Chowdhary (2003) [24] to conduct a detailed GC-MS investigation of *C. caesia*. They found that volatile constituents of the rhizome from central India has camphor (28.3%), *ar*-turmerone (12.3%), (z)- β -ocimene (8.2%), *ar*-curcumene (6.9%), 1, 8-cineole (5.3%), β -elemene (4.8%), borneol (4.4%), bornyl

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acetate (3.3%) and endo-fenchol (2.3%). The study concluded that essential oil obtained from Indian collections were rather different from that of essential oil produced from Thailand, as it does not contain Curzerene and Curzerenone. Moreover, oil from the Thailand specimens displayed predominance of 1, 8- cineole than camphor. Singh *et al.* (2020)^[27] reported intraspecific variability of *C. caesia* rhizome essential oil associated with two geographical regions, i.e., Odisha and west Bengal. The chemical constituents were analyzed by GC-MS, which detected a total of thirty-four compounds accounting to 90.08-97.94% of the total oil. Oxygenated monoterpenes constituted the major fraction followed by oxygenated sesquiterpenes. West Bengal accessions were dominated by oxygenated monoterpenes (34.8-45.41%) followed by oxygenated sesquiterpenes (26.63-38.06%). However, Odisha accessions were rich in oxygenated monoterpenes (37.6-54.36%) followed by sesquiterpene hydrocarbons (21.9-33.8%). Finally, phyto-chemical variability in *C. caesia* associated with geographical distribution patterns with respect to quality has been successfully identified.

With this background comparative assessment of available genotypes for phyto-constituents present in the leaf and rhizome essential oil will help us to select superior germplasm and it will open a door for new drug discovery.

Material and Methods

The present investigation “Bio-chemical profiling of the black turmeric genotypes” was carried out at ICAR-KVK Chamarajanagar, Karnataka during 2019-20. Thirty three black turmeric genotypes were collected from the provenance of the country (Plate 1) and used for the study. The genotypes were raised in ridges and furrow system in the field in randomized block design with three replications. The crop was raised as per the recommended package of practices of turmeric (Anon, 2016). Rhizomes were planted in each plot (3.2m X 1.8m) at spacing of 45cm X 30cm.

Preparation of rhizome extracts

The matured rhizomes were harvested, cleaned, cut into small pieces was shade dried for twenty days and ground into powder.

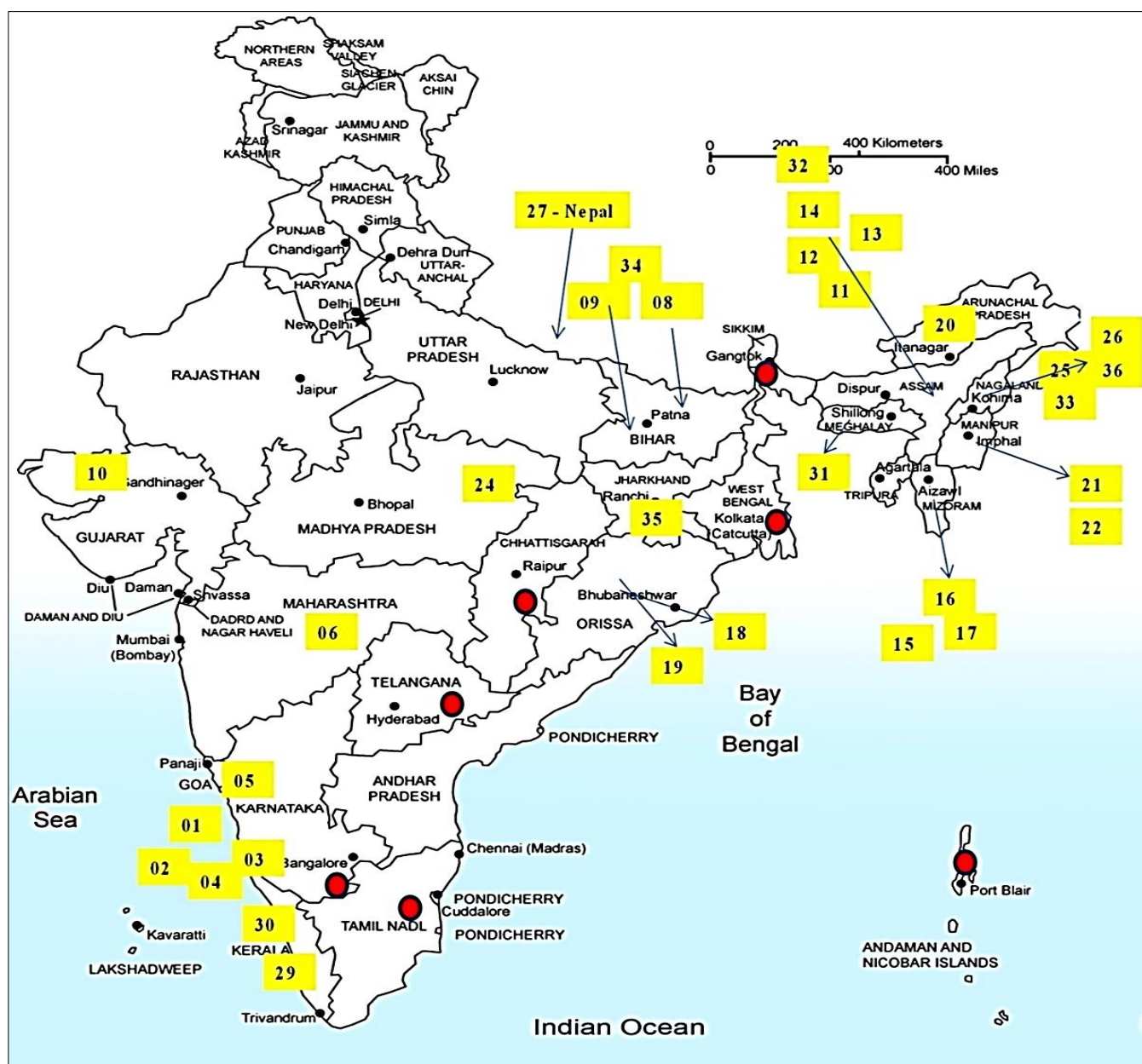


Plate 1: Details of Black turmeric genotypes collected from provenances of India

Crude drug extraction

Known quantities of the ground rhizome material were extracted with methanol using Soxhlet apparatus for 18 hrs at constant temperature of 72 °C (Jyothi and Rajeshwari, 2012; Dutta, 2015) [11]. The finely ground crude drug is placed in a porous bag or "thimble" made of strong filter paper. The extracting solvent is heated and its vapours condense in condenser. The condensed extractant drips into the thimble containing the crude drug and extracts it by contact. When the level of liquid in chamber rises to the top of siphon tube, the liquid contents of siphon drips back into flask. This process is continuous and is carried out until a drop of solvent from the siphon tube does not leave residue when evaporated. The advantage is that large amounts of drug can be extracted with a much smaller quantity of solvent and cost effective in terms of time, energy and consequently financial inputs.

Analysis of volatile compounds by GC-MS method

The GC-MS analysis of the leaf and rhizome extract was done at Laboratory of Sophisticated instrumentation facility (SIF), chemistry division, school of advanced science, VIT University, Vellore-632014.

GC-MS information

- **Make:** Perkin Elmer
- **GC model:** Clarus 680
- **Mass Spectrometer:** Clarus 600 (EI)
- **Software:** Turbo Mass ver 5.4.2
- **Library year:** NIST-2008

Instrument acquisition parameters

- **Oven:** Initial temp 60 °C for 2 min, ramp 10 °C/min to 300 °C, hold 6 min,
- **Total Run Time:** 32.00 min. Inj auto=260 °C, Volume=1 µL, Split=10:1,
- **Flow Rate:** 1 mL/min.
- **Carrier Gas =** He
- **Column =** Elite-5MS (30.0 m, 0.25 mm ID, 250µm df)

The Clarus 680 GC was used in the analysis employed a fused silica column, packed with Elite-5MS (5% biphenyl 95% dimethyl poly siloxane, 30 m × 0.25 mm ID × 250 µm df) and the components were separated using Helium as carrier gas at a constant flow of 1 ml/min.

The injector temperature was set at 260 °C during the chromatographic run. The 1µL of extract sample injected into the instrument the oven temperature was as follows: 60 °C (2 min); followed by 300 °C at the rate of 10 °C min⁻¹ and 300 °C, where it was held for 6 min.

The mass detector conditions were: transfer line temperature 230 °C; ion source temperature 230 °C; and ionization mode electron impact at 70 eV, a scan time 0.2 sec and scan interval of 0.1 sec. the fragments from 40 to 600 Da.

The spectrums of the components were compared with the database of spectrum of known components stored in the GC-MS NIST (2008) library.

Results and discussion

Bioactive compounds present in the plant parts are responsible for varied religious, cosmetic and medicinal values. *Curcuma ceasia* Roxb. is well known for its social, religious, aesthetic and medicinal purposes.

Gas chromatography ("GC") and mass spectrometry ("MS") make a reliable, effective combination for chemical analysis. In the present study an attempt has been made to evaluate the chemical composition of the leaf and rhizome extract of thirty-three black turmeric genotypes through GC-MS analysis. The results are discussed as follows;

Leaf and rhizome extracts of genotype GKM-1 had a complex mixture of mono and sesquiterpenes. Leaf extract had recorded a total of eight components, corresponding to 94.552% of the total volume (Table 1). Leaf extract is composed of 2-isopropylidene-5-methyl hex-4-enal (51.562%) being the major component. (+)-2-bornanone (15.946%), camphor (8.952%), iso-bornyl acetate (4.935%), 1H,4H-3a,8a-methano azulene-1-one, hexahydro- (4.729%), (-)-β- caryophyllene oxide (3.290%), (-)-parthenolide (2.940%) and α-santalol (2.198%) were the other volatile compounds present.

Table 1: GC-MS analysis of leaf and rhizome extract of genotype GKM-1

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	(+)-2-Bornanone	8.376	15.946
2	Camphor	9.066	8.952
3	Isobornyl acetate	10.552	4.935
4	(-)-β- Caryophyllene oxide	13.738	3.290
5	α-Santalol cis	14.608	2.198
6	2-Isopropylidene-5-methylhex-4-enal	15.584	51.562
7	1H,4H-3a,8a-Methanoazulen-1-one, hexahydro-	17.119	4.729
8	(-)- Parthenolide	17.760	2.940
Rhizome extract			
1	Eucalyptol	5.650	12.814
2	(+)-2-Bornanone	7.970	5.969
3	L-Bornyl acetate	10.106	2.800
4	β-Elementene, (-)-	11.132	6.800
5	cis-Caryophyllene	11.322	3.624
6	γ--Selinene	12.537	7.093
7	Tropolone	13.703	36.108
8	3,7-Cyclodecadien-1-one, 10-(1-methylethenyl)-,(E,E)-	14.823	3.386
9	1H-indene 1 ethylidene octa hydro 7 A-methyl cis	15.654	6.495
10	Androsterone	16.234	6.669

Tropolone (36.108%) was found to be highest among ten compounds present in the rhizome extract of genotype GKM-1, followed by eucalyptol (12.814%), γ -selinene (7.093%), β -elemene, (-) (6.800%), (+)-2-bornanone (5.969%), androsterone (6.669%), 1H-indene-1-ethylidene octa hydro-7-a-methyl-cis (6.495%), cis-caryophyllene (3.624%), 3,7-cyclodecadien-1-one, 10-(1-methyl ethenyl)-, (E,E)- (3.386%) and bornyl acetate (2.800%). Compounds comprise 91.758% of the total volume of the extract. Results are in congruence with the findings of Mukunthan *et al.* (2014); Leela and Adheeb (2024) [17, 20].

Genotype GKM-2 leaf extract had six compounds, comprises 94.112% of the total volume of the extract, is mainly composed of cyclohexane, 1-methyl-2,4-bis(1-

methylethenyl)-(63.428%), (+)-2-bornanone (12.133%), 1,3,3-trimethyl-2-hydroxy methyl-3,3-dimethyl-4-(3-methylbut-2-enyl)-cyclohexene (9.884%), (-)- β -caryophyllene oxide (4.121%), α -selinene (2.392%) and α -santalol (2.210%).

Rhizome extract of GKM-2 had eight phyto-compounds of which major components were tropolone (36.919%), β -terpineol (14.171%), β -elemene, (-) (10.597%), longifolene-(V4) (6.184%), (+)-2-bornanone (5.562%), β -elemenone (4.201%), 4,5,6,7-tetra hydroindazole-3-spirocyclohexane (3.532%), and 17 α -methyltestosterone (1.520%). Results are in line with the findings of Pandey and Chowdhari (2003); Behuria & Srivastava (2004) and Mukunthan *et al.* (2014) [5, 20, 24].

Table 2: GC-MS analysis of leaf and rhizome extract of genotype GKM-2

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	(+)-2-Bornanone	9.116	12.133
2	α -Selinene	13.133	2.392
3	(-)- β - Caryophyllene oxide	13.888	4.121
4	α -santalol	14.473	2.210
5	1,3,3-Trimethyl-2-hydroxymethyl-3,3-dimethyl-4-(3-methylbut-2-enyl)-cyclohexene	14.628	9.884
6	Cyclohexane, 1-methyl-2,4-bis(1-methylethenyl)-	15.714	63.428
Rhizome extract			
1	β -terpineol	5.504	14.171
2	(+)-2-Bornanone	7.895	5.562
3	β -Elemene, (-)	10.942	10.597
4	Longifolene-(V4)	12.352	6.184
5	Tropolone	13.753	36.919
6	17 α -Methyltestosterone	14.073	1.520
7	β -Elemenone	14.688	4.201
8	4,5,6,7-tetrahydroindazole-3-spirocyclohexane	16.119	3.532

Total five volatile compounds (amounting 92.522%) were identified in the leaf extract of genotype GKB-3, representing Cyclopentan-1-al, 4-isopropylidene-2-methyl- (55.488%) as a major phyto-compound, followed by isoaromadendrene epoxide (17.902%), (+)-2-bornanone (5.972%), (-)- β -caryophyllene oxide (5.370%) and 4.568%) and (-)- parthenolide (3.222%) (Table 3). Seven peaks of GC-MS analysis comprising 82.646% of the rhizome extract of GKB-3 (Table 3). Bicyclo (2.2.2) octa-2,5-diene 1,2,3,6-

tetramethyl- (45.361%), curzerene (12.296%), β -elemene, (-) (8.017%), p-Menth-2-en-1-ol (5.835%), cyclopropane, 1-bromo-2,2,3,3-tetramethyl-1-prop-1-ynyl (4.163%), (1E,7Z,8aE,13aZ,15Z,19E)3,5,6,9,11,12,13,14,17,18,21,22,23,24,25,26-hexadecahydro-4h-dicyclodeca[c,j]oxacyclopentadecene (4.081%) and tumerone (2.893%) were the components. Similar components confirmed by Pakkirisamy *et al.* (2017); Mahanta *et al.* (2019) [19, 22], Borah *et al.* (2019) [6] in the rhizomes.

Table 3: GC-MS analysis of leaf and rhizome extract of genotype GKB-3

Sl.No.	Compound	RT	Peak area (%)
Leaf extract			
1	(+)-2-Bornanone	8.846	5.972
2	(-)- β - Caryophyllene oxide	13.713	4.568
3	Isoaromadendrene epoxide	14.638	17.902
4	(-)- β - Caryophyllene oxide	15.068	5.370
5	Cyclopentan-1-al, 4-isopropylidene-2-methyl-	15.594	55.488
6	(-) Parthenolide	17.854	3.222
Rhizome extract			
1	p-Menth-2-en-1-ol	5.765	5.835
2	β -Elemene, (-)	10.952	8.017
3	Curzerene	12.312	12.296
4	Tumerone	14.568	2.893
5	Cyclopropane, 1-bromo-2,2,3,3-tetramethyl-1-prop-1-ynyl	14.663	4.163
6	(1E,7Z,8aE,13aZ,15Z,19E)-3,5,6,9,11,12,13,14,17,18,21,22,23,24,25,26-Hexadecahydro-4H-dicyclodeca[c,j]oxacyclopentadecene	15.423	4.081
7	Bicyclo (2.2.2) octa-2,5-diene 1,2,3,6-tetramethyl-	15.954	45.361

GKB-4 leaf and rhizome extract consists six (93.863%) and nine (86.578%) bio-active compounds, respectively (Table 4). Leaf extract had abundant tricyclo [5.1.0.0(3,5)]octane-2,6-dione, 1,3,5,7-tetramethyl-(57.299%), followed by

bornyl formate (16.300%), cis α -santalol(10.029%), (-)- β -caryophyllene oxide (4.136%), iso-bornyl acetate (2.801%) and 2-isopropyl-5 methyl cyclohexyl 3-(1-(4-chlorophenyl)-3-oxobutyl)-coumarin-4-yl carbonate (3.298%) compounds.

Table 4: GC-MS analysis of leaf and rhizome extract of genotype GKB-4

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bornyl formate	9.151	16.300
2	Isobornyl acetate	11.057	2.801
3	(-)- β -Caryophyllene oxide	14.088	4.136
4	cis α -Santalol	14.913	10.029
5	Tricyclo [5.1.0.0(3,5)]octane-2,6-dione, 1,3,5,7-tetramethyl-	15.799	57.299
6	2-Isopropyl-5 methyl cyclohexyl 3-(1-(4-chlorophenyl)-3-oxobutyl)-coumarin-4-yl carbonate	18.095	3.298
Rhizome extract			
1	Cis β -terpineol	5.394	14.330
2	Bornyl acetate	9.651	5.269
3	β -Elemene, (-)-	10.807	15.058
4	β -cubebene	12.082	1.581
5	Aromadendrene	12.262	14.861
6	γ -elemene	13.748	22.904
7	Germacrol	14.678	3.230
8	17 α -Methyltestosterone	15.509	2.864
9	Bicyclo (2.2.2) octa-2,5-diene 1,2,3,6-tetramethyl-	15.959	6.481

Rhizome extract of GKB-4 had higher percentage of γ -elemene (22.904%), β -elemene (-) (15.058%), aromadendrene (14.861%) and cis β -terpineol (14.330%) compounds Bicyclo (2.2.2) octa-2,5-diene 1,2,3,6-tetramethyl- (6.481%), bornyl acetate (5.269), germacrol (3.230%), 17 α -methyltestosterone (2.864%), β -cubebene (1.581%) were other phyto-compounds. Results are in line with Pandey and Chowdhari (2003); Mukunthan *et al.* (2014) & Pakkirisamy *et al.* (2017) [20, 22, 24].

GC-MS peaks revealed six compounds in the leaf extract of genotype GKB-4, which amounting to 90.14% of the total volume of the extract (Table 4). Cyclohexane, 1-methyl-2,4-bis(1-methylethenyl)- (53.237%) was higher compounds. (+)-2-Bornanone (14.128%), kauren-18-ol, acetate, (4 β)- (12.136%), (-)- β -caryophyllene oxide (5.029%), α -cadinol (3.209%) and (-)- parthenolide (2.401%) were other phyto-compounds present.

Table 5: GC-MS analysis of leaf and rhizome extract of genotype GKJ-5

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	(+)-2-Bornanone	8.766	14.128
2	(-)- β -Caryophyllene oxide	13.888	5.029
3	Kauren-18-ol, acetate, (4 β)-	14.793	12.136
4	α -Cadinol	15.043	3.209
5	Cyclohexane, 1-methyl-2,4-bis(1-methylethenyl)-	15.719	53.237
6	(-)- Parthenolide	18.215	2.401
Rhizome extract			
1	(+)-2-Bornanone	11.402	3.001
2	γ -elemene	13.553	4.112
3	Aromadendrene	14.633	2.372
4	4-Ethynyl-4-hydroxy-3,5,5-trimethyl-2-cyclohexen-1-one	15.569	52.704
5	3 α ,7 α -Methano-1H-inden-1-one, 4,5,6,7-tetrahydro	17.494	17.576
6	Diazoprogestosterone	21.376	4.644
7	7-(1,3-Dimethyl buta-1,3-dienyl)-1,6,6-trimethyl-3,8-dioxatricyclo(5.1.0.0(2,4) octane	27.273	9.078

Methanolic rhizome extract of GKJ-5 had seven phytocompounds, amounting 93.487% of the extract (Table 5). 4-Ethynyl-4-hydroxy-3,5,5-trimethyl-2-cyclohexen-1-one (52.704%) was major, followed by 3 α ,7 α -methano-1H-inden-1-one, 4,5,6,7-tetrahydro (17.576%), 7-(1,3-dimethyl buta-1,3-dienyl)-1,6,6-trimethyl-3,8-dioxatricyclo (5.1.0.0(2,4) octane (9.078%), diazo progesterone (4.644%), γ -elemene (4.112%), (+)-2-bornanone (3.001%) and aromadendrene (2.372%). The components are in confirmation with findings of Raina *et al.* (2012); Borah *et*

al. (2019); Pandey and Chowdhary (2003) [6, 24, 26] for γ -elemene.

GMV-6 leaf extract is composed of six bioactive compounds, cis-dihydrocarvone (42.375%) and (+)-2-bornanone (11.077%) were the major compounds. (1S, 4R)-p-mentha-2,8-diene, 1-hydroperoxide (5.188%), (-)- β -caryophyllene oxide (4.112%), ledol (3.603%) and iso bornyl acetate (3.078%) were the other components (Table 6). Rhizome extract had eight peaks, out of which 4,5,6,6a-tetrahydro-1H-pentalen-2-one (26.345%) was the major compound, followed by [2,2-dimethyl-4-(3-methylbut-2-

enyl)-6-methylidenecyclohexyl] methanol (9.226%), 7-(1,3-dimethyl buta-1,3-dienyl)-1,6,6-trimethyl-3,8-dioxatricyclo (5.1.0.0(2.4) octane (9.078%), germacrol (7.845%), megastigma-4,6(E)-triene (7.594%), β -spathulenol (3.466%), 4 acetyl careen (3.013%) and methandrostenolone (1.544%) were the other compounds in the GMV-6 rhizomes. Nayak *et al.* (2014); Mukunthan *et al.* (2014); Pakkirisamy *et al.* (2017) [20, 21, 22] observed similar

compounds in the rhizome and leaf extract of *Curcuma caesia* Roxb.

Abundance of monoterpenoid alcohol cis-dihydrocarvone in the leaf extract, reflects the strong perfumery activity of the leaves. Traces of isobornyl acetate will have a synergetic correlation with major compound and enhances the perfumery efficiency (Borah *et al.*, 2019) [6].

Table 6: GC-MS analysis of leaf and rhizome extract of genotype GMV-6

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	(+)-2-Bornanone	8.546	11.077
2	Isobornyl acetate	10.682	3.078
3	(-)- β - Caryophyllene oxide	13.808	4.112
4	(1S,4R)-p-Mentha-2,8-diene, 1-hydroperoxide	14.683	5.188
5	cis-Dihydrocarvone	15.644	42.375
6	Ledol	17.779	3.603
Rhizome extract			
1	4,5,6,6a-tetrahydro-1H-pentalen-2-one	13.823	26.345
2	Germacrol	14.863	7.845
3	[2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl] methanol	15.739	9.226
4	Megastigma-4,6(E)-triene	16.349	7.594
5	Spathulenol	18.190	3.466
6	Methandrostenolone	19.190	1.544
7	4 Acetyl careen	20.241	3.013
8	7-(1,3-Dimethyl buta-1,3-dienyl)-1,6,6-trimethyl-3,8-dioxatricyclo(5.1.0.0(2.4) octane	20.946	9.078

GBS-8 had six and ten compounds, amounting 94.361% and 85.484% of the leaf and rhizome extract, respectively (Table 7). Leaf extract had abundant sesquiterpenes and trace amount of monoterpenes. Sesquiterpene β -elemene, (-)- (61.809%) was the major compound, followed by 1-

cycloheptene, 1,4-dimethyl-3-(2-methyl-1-propene-1-yl)-4-vinyl-(11.479%), ledol (11.000%), camphor (4.413%), (-)-parthenolide (3.172%) and (-)- β - caryophyllene oxide (2.488%). Mukunthan *et al.* (2014) [20] and Borah *et al.* (2019) [6] confirmed β -elemene and camphor in the leaves.

Table 7: GC-MS analysis of leaf and rhizome extract of genotype GBS-8

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Camphor	10.076	4.413
2	(-)- β - Caryophyllene oxide	14.643	2.488
3	1-Cycloheptene, 1,4-dimethyl-3-(2-methyl-1-propene-1-yl)-4-vinyl-	15.428	11.479
4	Ledol	15.669	11.000
5	β -Elemene, (-)-	16.364	61.809
6	(-)- Parthenolide	18.885	3.172
Rhizome extract			
1	Isobornyl acetate	12.367	1.829
2	3,7(11)-Eudesmadiene	13.428	1.221
3	3,7(11)-Eudesmadiene	14.453	0.849
4	4-Ethynyl-4-hydroxy-3,5,5-trimethyl-2-cyclohexen-1-one	15.388	17.982
5	Cyclopentan-1-al, 4-isopropylidene-2-methyl	17.039	14.717
6	Retinal	20.726	12.330
7	4 Acetyl careen	22.196	11.381
8	6 β , 6 β -dibromo-6-7-methylene testosterone	23.562	5.927
9	7 α -methylthiotestosterone acetate	24.757	4.677
10	Retinal	26.823	14.571

Out of ten peaks retinal identified at two hits (20.726 min. & 26.823 min.) shows abundance of retinal in the rhizomes (12.330% and 14.571% respectively). Followed by 4-ethynyl-4-hydroxy-3,5,5-trimethyl-2-cyclohexen-1- (17.982%), cyclopentan-1-al, 4-isopropylidene-2-methyl (14.717%) and 4-acetyl careen (11.381%& 3.334%) were other compounds. However, 6 β , 6 β -dibromo-6-7-methylene testosterone (5.927%), 7 α -methylthiotestosterone acetate

(4.677%), 3,7(11)-eudesmadiene (1.221% & 0.849%) and iso-bornyl acetate (1.829%) were the other minor compounds in the rhizome extract of GBS-8.

The result clearly shows the abundance of polyene and ketones, traces of monoterpenoid alcohol and steroids in the rhizomes. Findings were supported by Pakkirisamy *et al.* (2017); Zhou *et al.* (2007); Borah *et al.* (2019) [6, 22, 28] for camphor in *C. caesia* leaf oil.

Table 8: GC-MS analysis of leaf and rhizome extract of genotype GBH-9

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Camphor	8.791	7.121
2	Bornyl acetate	10.717	2.727
3	(-)- β - Caryophyllene oxide	13.788	3.166
4	Santalol, E-cis, epi- β -	14.513	4.080
5	Z-3-Hexadecen-7-yne	15.634	50.362
6	1H,4H-3a,8a-Methanoazulen-1-one, hexahydro-	17.034	7.026
7	cis-Z- α -Bisabolene epoxide	17.754	3.909
Rhizome extract			
1	Eucalyptol	8.830	4.639
2	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.426	6.218
3	3,7(11)-Eudesmadiene	10.807	5.565
4	[2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl]methanol	12.007	4.549
5	Propanedinitrile, (Ethoxymethylene)-	14.198	41.238
6	Cyclopentan-1-al, 4-isopropylidene-2-methyl	17.039	4.217
	[2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl]methanol	16.144	2.485
7	4 Acetyl careen	22.196	9.611
8	Retinal	26.823	11.571

Leaf extract of GBH-9 has detected seven peaks, Hydrocarbons- alkene (Z-3-Hexadecen-7-yne - (50.362%) was the major constituent of the leaf. Other components were camphor (7.121%), 1H,4H-3a,8a-methanoazulen-1-one, hexahydro- (7.026%), santalol, e-cis, epi- β - (4.080%), cis-Z- α -bisabolene epoxide (3.909%), (-)- β -caryophyllene oxide (3.166%) and bornyl acetate (2.727%).

GBH-9 rhizome is characterized with propanedinitrile, (ethoxymethylene)- (41.238%). Other components were retinal (11.571%), 4 acetyl careen (9.611%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (6.218%), 3,7(11)-eudesmadiene (5.565%), [2,2-dimethyl-4-(3-methylbut-2-

enyl)-6-methylidenecyclohexyl]methanol (4.549%) and cyclopentan-1-al,4-isopropylidene-2-methyl (4.217%) (Table 8).

1,E-8,Z-10-tridecatriene (48.917%) was the highest observed compound in the leaf extract of genotype GGR-10, followed by bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (11.896%), 5,8-decadien-2-one, 5,9-dimethyl-, (E)- (5.744%), bornyl acetate (4.329%), (-)- β - caryophyllene oxide (3.268%) and 2-methyl-3-(3-methyl-but-2-enyl)-2-(4-methyl-pent-3-enyl)-oxetane (3.065%). Six peaks comprise 77.219 % of the total volume of the leaf extract (Table 9).

Table 9: GC-MS analysis of leaf and rhizome extract of genotype GGR-10

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.451	11.896
2	Bornyl acetate	10.562	4.329
3	(-)- β - Caryophyllene oxide	13.793	3.268
4	5,8-Decadien-2-one, 5,9-dimethyl-, (E)-	14.643	5.744
5	1,E-8,Z-10-Tridecatriene	15.574	48.917
6	2-Methyl-3-(3-methyl-but-2-enyl)-2-(4-methyl-pent-3-enyl)-oxetane	17.824	3.065
Rhizome extract			
1	Eucalyptol	6.000	8.407
2	Bornyl acetate	10.076	4.529
3	β -Elemene, (-)-	11.147	7.537
4	Cis-Caryophyllene	11.337	4.185
5	Curzerene	12.522	10.929
6	4,5,6,6A-Tetrahydro-2(1H)-Pentalenone	13.708	43.929
7	Santalol cis alpha	14.143	2.874
8	Germacrol	14.843	2.768
9	3,4-Nonadien-6-yne, 5-ethyl-3-methyl-	15.979	15.082

Nine compounds were identified in the rhizome extract of GGR-10, includes bicyclic ketone 4,5,6,6A-tetrahydro-2(1H)-pentalenone (43.929%), 3,4-nonadien-6-yne, 5-ethyl-3-methyl- (15.082%), curzerene (10.929%), eucalyptol (8.407%), β -elemene, (-)- (7.537%), bornyl acetate (4.529%), cis-caryophyllene (4.185%), santalol cis alpha (2.874%) and germacrol (2.768%). Above findings are matched well with the previous study of Mahanta *et al.* (2019); Dosoky *et al.* (2019); Jyotirmayee Lenka *et al.*, (2025) [10, 13, 19].

1,E-8,Z-10-dodecatriene and ent-16-kauren-19-ol acetate were the major components of the leaf extract of GAB-11, comprises 40.853% and 34.034% of the total volume of the extract respectively (Table 10). 1,4-Cyclohexanedimethanol (10.719%), iso bornyl acetate (4.218%), alpha-selinene (2.584%) and 2,6,10-dodecatrien-1-ol, 3,7,11-trimethyl- (2.097%) were the other volatile compounds found.

The rhizome of genotype GAB-11 had highest percentage of propanedinitrile, (ethoxymethylene) (35.640%). Total ten volatile components were identified, constitute 87.994% of

the extract. Other compounds were elemene (9.988%), (-)- α -helmiscapene (7.764%), bornyl acetate (7.388%), androstan-17-one, 3-ethyl-3hydroxy-, (5.alpha)- (6.770%), eucalyptol (6.308%), 1,E-8z-10-dodecatiene (5.569%), bicyclo [2.2.1]

heptan-2-one, 1,7,7-trimethyl-, (1S)- (5.347%), 1R,3Z,9s-4,11,11-trimethyl-8-methylenebicyclo[7.2.0]undec-3-ene (1.923%) and methandrostenolone (1.297%). The findings are in line with Dessy *et al.* (2019) [9].

Table 10: GC-MS analysis of leaf and rhizome extract of genotype GAB-11

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	1,4-Cyclohexanedimethanol	10.922	10.719
2	Iso bornyl acetate	12.537	4.218
3	α -Selinene	14.958	2.584
4	Ent-16-Kauren-19-ol acetate	16.674	34.034
5	1,E-8,Z-10-Dodecatiene	17.384	40.853
6	2,6,10-Dodecatien-1-ol, 3,7,11-trimethyl-	21.056	2.097
Rhizome extract			
1	Eucalyptol	6.260	6.308
2	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.451	5.347
3	Bornyl acetate	10.011	7.388
4	Elemene	11.112	9.988
5	1R,3Z,9s-4,11,11-Trimethyl-8-methylenebicyclo[7.2.0]undec-3-ene	12.442	1.923
6	(-)- α -helmiscapene	12.567	7.764
7	Propanedinitrile, (ethoxymethylene)	13.743	35.640
8	Methandrostenolone	14.498	1.297
9	1,E-8z-10-dodecatiene	15.744	5.569
10	Androstan-17-one, 3-ethyl-3hydroxy-, (5.alpha)-	16.284	6.770

Total eight phyto-compounds found in the leaf extract of genotype GAB-12, amounting to 93.673% of the total volume (Table 11). About 50.676% of leaf extract was constituted by 1-silacyclohexa diene -2,5-. Followed by 1-cycloheptene, 1,4-dimethyl-3-(2-methyl-1-propene-1-yl)-4-vinyl- (11.102%), 3,7-cyclodecadien-1-one, 10-(1-methylethenyl)-, (E,E)- (10.430%), (-)- β -caryophyllene oxide (7.874%), santalol, e-cis, epi- β - (5.243%), bicycle [2.2.1]heptan-2-ol, 1,7,7-trimethyl-, formate, endo- (3.938%), iso bornyl acetate (2.280%) and 4-methoxy-6-methyl-6,7-dihydro(4H) furo [3,2-c]pyran (2.130%) were other volatile compounds.

Table 11: GC-MS analysis of leaf and rhizome extract of genotype GAB-12

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo[2.2.1]heptan-2-ol, 1,7,7-trimethyl-, formate, endo-	9.226	3.938
2	Iso bornyl acetate	10.907	2.280
3	(-)- β - Caryophyllene oxide	13.823	7.874
4	Santalol, E-cis, epi- β -	14.558	5.243
5	1-Cycloheptene, 1,4-dimethyl-3-(2-methyl-1-propene-1-yl)-4-vinyl-	14.853	11.102
6	3,7-Cyclodecadien-1-one, 10-(1-methylethenyl)-, (E,E)-	15.133	10.430
7	1-Silacyclohexa diene -2,5-	15.829	50.676
8	4-Methoxy-6-methyl-6,7-dihydro(4H)furo[3,2-c]pyran	18.400	2.130
Rhizome extract			
1	Elemene	11.147	6.653
2	Humulen-(v1)	11.347	3.780
3	1,4-Methano-1H-indene, octahydro-4-methyl-8-methylene-7-(1-methylethyl)-, [1S-(1 α ,3 α ,4 α ,7 α ,7 α)]-	12.517	11.339
4	Methandrostenolone	13.703	41.950
5	Tetracyclo[5.2.1.0(2,6).0(3,5)]decane, 4,4-dimethyl-	14.163	2.886
6	3,7-Cyclodecadien-1-one, 10-(1-methylethenyl)-, (E,E)-	14.838	2.273
7	5,6-decadien-3-yne, 5,7-diethyl	16.019	19.703

Genotype GAB-13 leaves characterized by ten phyto-compounds, amounting to 85.246% of the total volume of the extract (Table 12). 1H,4H-3a,8a-methanoazulen-1-one, hexahydro- (18.638%), iso-steviol (16.890%) and γ -elemene (12.804%) were the largest compounds, followed by parthenolide (7.495%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (6.930%), (-)- β - caryophyllene oxide

(6.358%), 2,6,10,14-hexadecatetraen-1-ol, 3,7,11,15-tetramethyl-, acetate, (E,E,E)- (6.026%), santalol cis alpha (4.719%), bicycle [5.2.0] nonane, 4-methylene-2,8,8-trimethyl-2-vinyl- (4.084%) and bicyclo germacrene (1.302%) were other volatile components present in the leaf extract.

Table 12: GC-MS analysis of leaf and rhizome extract of genotype GAB-13

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.671	6.930
2	Bicyclo[5.2.0]nonane, 4-methylene-2,8,8-trimethyl-2-vinyl-	12.262	4.084
3	Bicyclogermacrene	12.837	1.302
4	(-)- β - Caryophyllene oxide	14.098	6.358
5	Santalol cis alpha	14.668	4.719
6	γ -Elemene	15.323	12.804
7	Isosteviol	16.164	16.890
8	1H,4H-3a,8a-Methanoazulen-1-one, hexahydro-	17.229	18.638
9	Parthenolide	18.285	7.495
10	2,6,10,14-Hexadecatetraen-1-ol, 3,7,11,15-tetramethyl-, acetate, (E,E,E)-	19.590	6.026
Rhizome extract			
1	Elemene	11.017	4.848
2	Curzerene	12.272	12.177
3	γ -Elemene	12.977	2.254
4	Tricycle (5.2.1.0(2,6))dec-3ene,4-ethyl-	13.823	66.254
5	3,7-Cyclodecadien-1-one, 3,7-dimethyl-10-(1-methylethylidene)-, (E,E)-	14.738	4.646
6	Ibuprofen	15.604	3.678

Six volatile compounds constitute 93.857% of the rhizome extract of genotype GAB-13. Tricycle (5.2.1.0 (2,6) dec-3ene,4-ethyl- (66.254%) being the single largest compound, followed by curzerene (12.177%), elemene (4.848%), 3,7-cyclodecadien-1-one, 3,7-dimethyl-10-(1-methylethylidene)-, (E,E)- (4.646%), ibuprofen (3.678%) and γ -elemene (2.254%) (Table 12) (Leela and Adheeb (2024); Jyotirmayee Lenka *et al.*, (2025))^[13, 17].

GC-MS analysis of genotype GAK-14 leaf extract had ten compounds comprise 92.558% of the total volume of the

extract (Table 13). 1,E-8,Z-10-dodecatriene (41.630%) was the major compound, followed by 1H,4H-3a,8a-methanoazulen-1-one, hexahydro- (10.287%), (1S,4R)-p-mentha-2,8-diene, 1-hydroperoxide (9.384%), bicyclo [2.2.1] heptan-2-one,1,7,7-trimethyl-, (1S)- (7.994%), santalol, e-cis, epi- β - (6.185%), (-)- β -caryophyllene oxide (4.800%), 3-methyl-4-(phenylthio)-2-prop-2-enyl-2,5-dihydrothiophene 1,1-dioxide (4.782%), bornyl acetate (2.451%) and 5,9,13-pentadecatrien-2-one, 6,10,14-trimethyl-, (E,E)- (1.431%) were other volatile compounds present.

Table 13: GC-MS analysis of leaf and rhizome extract of genotype GAK-14

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.806	7.994
2	Camphor	9.356	3.615
3	Bornyl acetate	10.817	2.451
4	(-)- β - Caryophyllene oxide	13.918	4.800
5	Santalol, E-cis, epi- β -	14.503	6.185
6	(1S,4R)-p-Mentha-2,8-diene, 1-hydroperoxide	14.803	9.384
7	1,E-8,Z-10-Dodecatriene	15.774	41.630
8	1H,4H-3a,8a-Methanoazulen-1-one, hexahydro-	17.229	10.287
9	3-Methyl-4-(phenylthio)-2-prop-2-enyl-2,5-dihydrothiophene 1,1-dioxide	18.029	4.782
10	5,9,13-Pentadecatrien-2-one, 6,10,14-trimethyl-, (E,E)-	19.275	1.431
Rhizome extract			
1	Elemene	10.997	5.905
2	cis- Caryophyllene	11.202	3.306
3	1,4-Methano-1H-indene, octahydro-4-methyl-8-methylene-7-(1-methylethyl)-, [1S-(1 α ,3 $\alpha\beta$,4 α ,7 α ,7 $\alpha\beta$)]-	12.262	14.228
4	γ -Elemene	12.958	3.076
5	Thio carbonic acid, di-P-tolyl ester	13.808	60.656
6	1-Oxaspiro[2.5]oct-5-ene, 8,8-dimethyl-4-methylene-	14.713	6.833

Six volatile compounds constituted 94.004% of the GAK-14 rhizome extract, thio-carbonic acid, di-P-tolyl ester (60.656%) being the single largest compound identified, followed by 4-methano-1H-indene, octahydro-4-methyl-8-methylene-7-(1-methylethyl)-, [1S-(1 α ,3 $\alpha\beta$,4 α ,7 α ,7 $\alpha\beta$)] (14.228%), 1-oxaspiro[2.5]oct-5-ene, 8,8-dimethyl-4-methylene- (6.833%), elemene (5.905%), cis-caryophyllene (3.306%) and γ -elemene (3.076%) were other volatile compounds present (Table 13).

Genotype GMW-15 leaf had abundant bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (25.895%), tricycle [5.1.0.0(3,5)]octane-2,6-dione, 1,3,5,7-tetramethyl- (23.736%) and santalol cis alpha (23.495%) compounds. Borneol formate (10.221%), iso-aromadendrene epoxide

(5.851%), iso bornyl acetate (5.580%) and 5-pentadecen-7-yne, (Z)- (0.793%) were other components. Seven compounds comprise 95.571% of the total volume of the leaf extract (Table 14).

Norethynodrel (24.004%) and 5,6-decadien-3-yne, 5,7-diethyl (23.298%) were found to be the highest observed compounds in the rhizome extract of genotype GMW-15 (Table 14). Ten compounds constitute 87.528% of the extract. Other volatile compounds were cyperene (9.896%), eucalyptol (9.743%), elemene (9.549%), bornyl acetate (3.076%), azulene, 1,2,3,4,5,6,7,8-octahydro-1,4-dimethyl-7-(1-methylethenyl)-, (1S,4S,7R)- (2.890%), germacrol (2.323%), camphene (1.427%) and γ -elemene (1.322%).

Table 14: GC-MS analysis of leaf and rhizome extract of genotype GMW-15

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Borneol formate	9.356	10.221
2	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.676	25.895
3	Iso bornyl acetate	11.622	5.580
4	5-Pentadecen-7yne,(Z)-	12.973	0.793
5	Iso-aromadendrene epoxide	14.723	5.851
6	Santalol cis alpha	15.824	23.495
7	Tricyclo[5.1.0.0(3,5)]octane-2,6-dione, 1,3,5,7-tetramethyl-	16.974	23.736
Rhizome extract			
1	Camphene	4.024	1.427
2	Eucalyptol	5.399	9.743
3	Bornyl acetate	9.641	3.076
4	Elemene	10.762	9.549
5	Cyperene	12.237	9.896
6	γ -Elemene	12.947	1.322
7	Norethynodrel	13.823	24.004
8	Germacrol	14.668	2.323
9	Azulene, 1,2,3,4,5,6,7,8-octahydro-1,4-dimethyl-7-(1-methylethenyl)-, (1S,4S,7R)-	15.293	2.890
10	5,6-decadien-3-yne,5,7-diethyl	15.949	23.298

GC-MS analysis had eight peaks represents presence of eight phyto-compounds in the leaf extract of genotype GMK-16, amounting 76.806% of the total volume (Table 15). Bicyclo[10.1.0]tridec-1-ene (47.792%) was found to be the highest observed compound, followed by 1,4 cyclohexane dimethanol (8.773%), santalol, e-cis, epi- β -

(4.353%), norbornane, 2-methyl-3-methylene-2-(4-methyl-3-pentenyl)- (4.047%), cis-caryophyllene (3.664%), bornyl acetate (3.312%), aromadendrene (3.213%) and 5,9,13-pentadecatrien-2-one, 6,10,14-trimethyl-, (E,E)- (1.652%) were other components.

Table 15: GC-MS analysis of leaf and rhizome extract of genotype GMK-16

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	1,4 Cyclohexanedimethanol	8.581	8.773
2	Bornyl acetate	10.682	3.312
3	cis- Caryophyllene	13.823	3.664
4	Santalol, E-cis, epi- β -	14.673	4.353
5	Aromadendrene	15.153	3.213
6	Bicyclo[10.1.0]tridec-1-ene	15.598	47.792
7	Norbornane, 2-methyl-3-methylene-2-(4-methyl-3-pentenyl)-	17.154	4.047
8	5,9,13-Pentadecatrien-2-one, 6,10,14-trimethyl-, (E,E)-	19.010	1.652
Rhizome extract			
1	Bornyl acetate	10.041	5.112
2	Elemene	11.087	8.883
3	1,4-Methano-1H-indene, octahydro-4-methyl-8-methylene-7-(1-methylethyl)-, [1S-(1 α ,3 α ,4 α ,7 α ,7 α)]-	12.467	11.347
4	4,5,6,6a-tetrahydro-1H-pentalen-2-one	13.678	40.718
5	1,4-Methanophthalazine, 1,4,4a,5,6,7,8,8a-octahydro-9,9-dimethyl-, (1.alpha.,4.alpha.,4a.alpha.,8a.alpha.)-	14.778	2.047
6	Bicyclo[5.1.0]octan-2-one, 4,6-diisopropylidene-8,8-dimethyl-	15.458	8.077
7	Cyperene	15.894	17.649

A bi-cycle ketone, 4,5,6,6a-tetrahydro-1H-pentalen-2-one (40.718%) was highest observed compound in the rhizome extract of GMK-16. Other compounds were cyperene (17.649%), 1,4-methano-1H-indene, octahydro-4-methyl-8-methylene-7-(1-methylethyl)-, [1S-(1 α ,3 α ,4 α ,7 α ,7 α)]- (11.347%), elemene (8.883%), bicyclo[5.1.0]octan-2-one, 4,6-diisopropylidene-8,8-dimethyl- (8.077%), bornyl acetate (5.112%) and 1,4-methanophthalazine, 1,4,4a,5,6,7,8,8a

octahydro-9,9-dimethyl (1.alpha., 4.alpha.,4a.alpha., 8a.alpha.)-(2.047%).

Five peaks comprise 91.691% of the total volume of the leaf extract of genotype GMA-17 (Table 16). 1,E-8,Z-10-dodecatriene (65.190%) being the single largest compound present, followed by bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (12.541%), santalol cis alpha (9.522%), 2,15-hexadecanedione (2.769%) and (-)- β -caryophyllene oxide (1.669%) were other components.

Table 16: GC-MS analysis of leaf and rhizome extract of genotype GMA-17

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	10.021	12.541
2	(-)- β - Caryophyllene oxide	14.958	1.669
3	Santalol cis alpha	15.694	9.522
4	1,E-8,Z-10-Dodecatriene	16.554	65.190
5	2,15-Hexadecanediol	19.215	2.769
Rhizome extract			
1	Bornyl acetate	12.112	3.682
2	γ -Elemene	13.203	2.919
3	Azulene, 1,2,3,4,5,6,7,8-octahydro-1,4-dimethyl-7-(1-methylethenyl)-, (1S,4S,7R)-	14.358	2.344
4	α santalol	15.484	17.878
5	Santalol cis α	17.169	12.098
6	(-)- β - Caryophyllene oxide	18.675	38.466
7	Cedarn-diol,8S,14	26.693	12.258

The rhizome extract of genotype GMA-17 had highest percentage of (-)- β -caryophyllene oxide (38.466%), followed by α santalol (17.878%), cedarn-diol,8S,14 (12.258%), santalol cis α (12.098%), bornyl acetate (3.682%), γ -elemene (2.919%) and azulene, 1,2,3,4,5,6,7,8-octahydro-1,4-dimethyl-7-(1-methylethenyl)-, (1S,4S,7R)- (2.344%). Seven peaks were identified in the GC-MS analysis of GMA-17 rhizome extract (Table 16). Results confirmed by the findings of Pandey and Chowdhari (2003); Mukunthan *et al.* (2014); Zhou *et al.* (2007) and Dessy *et al.* (2019) [19, 20, 24, 28].

Genotype GOK-18 leaf had highest 1,E-8,Z-10-dodecatriene (46.040%), followed by 3,5-nonadien-7yn-2-01 (E,E)- (21.095%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (16.139%), (-)- β -caryophyllene oxide (5.208%), cis-Z- α -bisabolene epoxide (3.297%), 1-(2'-

nitro-2'-propenyl) cyclooctene (3.104%) and iso bornyl acetate (3.090%) compounds (Table 17). Total seven compounds amounting 97.793% of volume of the leaf extract.

Nine compounds amounting 80.027% of the GOK-18 rhizome extract. 40.749% of the rhizome extract was constitute with 2-cyclohexen-1-one, 4-ethynyl-4-hydroxy-3,5,5-trimethyl-phyto-compound. Other volatile components were megastigma-4,6(E),8(E)-triene (11.950%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (6.095%), cyclohexane, 1-ethenyl-1-methyl-2,4-bis (1-methylethenyl)-, (5.402%), bornyl acetate (4.886%), elemene (4.384%), germacrol (2.686%), γ -elemene (2.182%) and retinal (1.693%). The results are in congruence with the findings of Pakkirisamy *et al.* (2017); Pandey and chowdhary (2003); Mukunthan *et al.* (2014 in *Curcuma caesia* Roxb. [20, 22, 24]

Table 17: GC-MS analysis of leaf and rhizome extract of genotype GOK-18

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.311	16.139
2	Iso bornyl acetate	11.267	3.090
3	(-)- β - Caryophyllene oxide	14.363	5.208
4	3,5-Nonadien-7yn-2-01 (E,E)-	15.278	21.095
5	1,E-8,Z-10-Dodecatriene	16.214	46.040
6	1-(2'-Nitro-2'-propenyl)cyclooctene	18.130	3.104
7	cis-Z- α -Bisabolene epoxide	18.820	3.297
Rhizome extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.006	6.095
2	Bornyl acetate	10.471	4.886
3	Elemene	11.597	4.384
4	γ -Elemene	12.837	2.182
5	2-Cyclohexen-1-one, 4-ethynyl-4-hydroxy-3,5,5-trimethyl-	13.858	40.749
6	Germacrol	14.988	2.686
7	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis (1-methylethenyl)-,	15.779	5.402
8	Megastigma-4,6(E),8(E)-triene	16.349	11.950
9	Retinal	17.714	1.693

The GC-MS analysis of leaf extract had seven peaks (Table 18), GOK-19 had cyclohexane, 1-methyl-2,4-bis (1-methylethenyl)- (45.158%), 1-cycloheptene, 1,4-dimethyl-3-(2-methyl-1-propene-1-yl)-4-vinyl (20.116%), 2-undecanone,6,10-dimethyl (6.708%), 5,9,13-Pentadecatrien-2-one, 6,10,14-trimethyl-, (E,E)- (6.336%), aromandendrene (3.912%), (-)- β -caryophyllene oxide (3.656%) and bornyl acetate (3.424%). The results denote abundance of

sesquiterpenes and cyclo alkene (20.116%) in the leaves of genotype GOK-19. A Sesquiterpene tropolone (49.703%) was found to be the major bioactive compound of genotype GOK-19 rhizome extract (Table 18), followed by patchulane (10.661%), bicyclo [2.2.1] heptan-2-one,1,7,7-trimethyl-, (1S)- (6.095%), bornyl acetate (4.886%), retinal (4.757%), anobin (3.338%), selina-4(15),7(11)-diene (3.138%) and γ -elemene (2.454%).

Table 18: GC-MS analysis of leaf and rhizome extract of genotype GOK-19

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bornyl acetate	11.977	3.424
2	(-)- β -Caryophyllene oxide	13.118	3.656
3	Aromadendrene	14.153	3.912
4	1-cycloheptene, 1,4-dimethyl-3-(2-methyl-1-propene-1-yl)-4-vinyl	15.769	20.116
5	Cyclohexane, 1-methyl-2,4-bis (1-methylethenyl)-	16.464	45.158
6	2-undecanone,6,10-dimethyl	18.970	6.708
7	5,9,13-Pentadecatrien-2-one, 6,10,14-trimethyl-, (E,E)-	20.140	6.336
Rhizome extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.881	6.095
2	Bornyl acetate	11.172	4.886
3	γ -Elemene	12.272	2.454
4	Selina-4(15),7(11)-diene	13.443	3.138
5	Tropolone	14.413	49.703
6	Patchulane	16.349	10.661
7	Retinal	18.540	4.757
8	Anobin	20.245	3.338

The highest percentage of 1-silacyclohexa-2-5-diene (56.579%) was found in the leaf extract of GAP-20. Other compounds were iso-aromadendrene-(V) (18.782%), camphor (5.206%), 2-methyl-3-(3-methyl-but-2-enyl)-2-(4-

methyl-pent-3-enyl)-oxetane (4.807%), (-)- β -caryophyllene oxide (3.777%) and isobornyl acetate (2.029%). These six compounds comprise 91.18% of the total volume of the extract (Table 19).

Table 19: GC-MS analysis of leaf and rhizome extract of genotype GAP-20

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Camphor	9.286	5.206
2	Isobornyl acetate	11.182	2.029
3	(-)- β -Caryophyllene oxide	14.133	3.777
4	Iso-aromadendrene-(V)	15.053	18.782
5	1-Silacyclohexa-2-5-diene	15.909	56.579
6	2-Methyl-3-(3-methyl-but-2-enyl)-2-(4-methyl-pent-3-enyl)-oxetane	18.275	4.807
Rhizome extract			
1	Eucalyptol	7.936	5.262
2	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.096	5.255
3	Isobornyl acetate	10.497	5.965
4	Elemene	11.717	7.672
5	γ -Elemene	13.043	4.097
6	2(3H)-Naphthalenone, 4,4a,5,6,7,8-hexahydro-4a-phenyl-, (R)-	14.028	48.473
7	γ -Elemene	16.209	11.494
8	Tricyclo(3.2.1.0 ^{2,4})octane, 3,3-dimethyl-8-methylene-, (1 α ,2 α ,4 α ,5 α)-	16.739	4.692

2(3H)-naphthalenone, 4, 4a, 5, 6, 7, 8-hexahydro-4a-phenyl-, (R)- (48.473%) was found to be the major bioactive compound in the rhizome of genotype GAP-20. γ -elemene (11.494%), elemene (7.672%), isobornyl acetate (5.965%), eucalyptol (5.262%), bicyclo [2.2.1] heptan-2-one, 1,7,7-

trimethyl-, (1S)- (5.255%), tricyclo (3.2.1.0^{2,4})octane, 3,3-dimethyl-8-methylene-, (1 α ,2 α ,4 α ,5 α)- (4.692%) and γ -elemene (4.097%) were other volatile compounds present (Table 19).

Table 20: GC-MS analysis of leaf and rhizome extract of genotype GMF 21

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo[3.1.0]hexan-3-ol, 4-methyl-1-(1-methylethyl)-	9.356	3.286
2	Isobornyl acetate	11.012	1.929
3	α -farnesene	13.938	4.571
4	(+)-Ingenol	14.838	12.576
5	1-Formyl-2,2,6-trimethyl-3-cis-(3-methylbut-2-enyl)-5-cyclohexene	15.769	51.421
6	Estran-3-one, 17-(acetyloxy)-2-methyl-, (2 α ,5 α ,17 β)-	18.069	4.799
7	Nerolidyl acetate	19.400	1.824
Rhizome extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.751	5.697
2	Isobornyl acetate	10.236	11.258
3	Elemene	11.517	8.750
4	γ -Elemene	12.827	2.336
5	[2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl]methanol	13.803	4.613
6	Propanedinitrile, (ethoxymethylene)	14.183	27.012
7	(-)-Isosativene	14.828	4.325
8	[2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl]methanol	15.238	5.662
9	6-(3-Methyl-3-cyclohexenyl)-2-methyl-2,6-heptadienol	16.169	8.653
10	Lanceol cis	16.689	3.447
11	Isoaromadendrene epoxide	17.724	2.137
12	Dihydro-isosteviol methyl ester	18.125	2.746

Unique peaks represents presence of 1-formyl-2,2,6-trimethyl-3-cis-(3-methylbut-2-enyl)-5-cyclohexene (51.421%), (+)-Ingenol (12.576%), estran-3-one, 17-(acetyloxy)-2-methyl-, (2 α , 5 α , 17 β)- (4.799%), α -farnesene (4.571%), bicyclo[3.1.0]hexan-3-ol, 4-methyl-1-(1-methylethyl)- (3.286%), isobornyl acetate (1.929%) and nerolidyl acetate (1.824%) in the leaf extract of genotype GMF-21 (Table 20).

GMF-21 rhizome extract had twelve peaks, amounting 86.636% of the total volume. Out of twelve peaks, propanedinitrile, (ethoxymethylene) (27.012%) was the major bioactive compound present, followed by isobornyl acetate (11.258%), elemene (8.750%), 6-(3-Methyl-3-cyclohexenyl)-2-methyl-2,6-heptadienol (8.653%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (5.697%), [2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl] methanol (4.613%), (-)-iso-sativene (4.325%), lanceol cis (3.447%), dihydro-isosteviol methyl ester (2.746%), γ -

elemene (2.336%) and iso-aromadendrene epoxide (2.137%).

GMI-22 leaf extract had highest Curdione (27.436%), followed by eucalyptol (14.888%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (13.598%), α -himachalene (8.614%), cyclohexane, 3,4-bis(1-methylethenyl)-1,1-dimethyl- (8.183%), patchouli alcohol (6.879%), 2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidene cyclo hexyl methanol (5.634%), isobornyl acetate (2.266%), and bicyclo[5.2.0]nonane, 4-methylene-2,8,8-trimethyl-2-vinyl- (0.941%) (Table 21).

Rhizome extract of GMI-22 also abundant in Curdione compound (49.392% and 17.122%) observed at two different retention times (13.938 min. and 15.604 min) (Table 21). Other components were 3,7-cyclodecadien-1-one, 10-(1-methylethenyl)-, (E,E)- (15.490%), elemene (7.205%), α -caryophyllene (4.541%), curzerene (3.141%) and γ -elemene (3.111%) (Jyotirmayee Lenka *et al.*, (2025) [13]).

Table 21: GC-MS analysis of leaf and rhizome extract of genotype GMI-22

Sl.No.	Compound	RT	Peak area (%)
Leaf extract			
1	Eucalyptol	6.160	14.888
2	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.551	13.598
3	Isobornyl acetate	10.512	2.266
4	Bicyclo[5.2.0]nonane, 4-methylene-2,8,8-trimethyl-2-vinyl-	11.692	0.941
5	2,2-Dimethyl-4-(3-methylbut-2-enyl)-6-methylidene cyclo hexyl methanol	13.563	5.634
6	α -Himachalene	14.083	8.614
7	Patchouli alcohol	14.373	6.879
8	Neocuridione	14.703	1.876
9	Curdione	15.123	27.436
10	Cyclohexane, 3,4-bis(1-methylethenyl)-1,1-dimethyl-	15.809	8.183
Rhizome extract			
1	γ -Elemene	11.407	3.111
2	Elemene	11.502	7.205
3	α caryophyllene	12.072	4.541
4	Curzerene	12.917	3.141
5	Curdione	13.938	49.392
6	3,7-Cyclodecadien-1-one, 10-(1-methylethenyl)-, (E,E)-	14.998	15.490
7	Curdione	15.604	17.122

Out of eight compounds Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)- (40.22%), was found to be the highest compound in the leaf extract of GMS-24 (Table 22). Alpha santalol (13.008%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (11.819%), eucalyptol (11.066%), bicycle (5.2.0) non-1-ene (5.958%), (-)- β -caryophyllene oxide (3.502%), bornyl acetate (2.703%) and estran-3-one, 17-(acetyloxy)-2-methyl-, (2 α ,5 α ,17 β)- (2.619%) were other compounds present.

4-Ethynyl-4-hydroxy-3,5,5-trimethyl-2-cyclohexen-1-one (22.894%), 3-keto-isosteviol (12.179%), methandrostenolone (11.813%), 7-(1,3-dimethylbuta-1,3-dienyl)-1,6,6-trimethyl-3,8-dioxatricyclo[5.1.0.0(2,4)]octane (10.686%), verrucarol (6.523%), 5,6-decadien-3-yne,5,7-diethyl- (5.828%), γ -elemene (0.956%) and cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)- (0.878%) were the phyto compounds present in the rhizome extract of GMS-24. (Table 22).

Table 22: GC-MS analysis of leaf and rhizome extract of genotype GMS-24

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Eucalyptol	6.100	11.066
2	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.606	11.819
3	Bornyl acetate	10.842	2.703
4	(-)- β - Caryophyllene oxide	14.003	3.502
5	Alpha santalol	14.868	13.008
6	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)-	15.844	40.202
7	Bicycle (5.2.0) non-1-ene	17.429	5.958
8	Estran-3-one, 17-(acetyloxy)-2-methyl-, (2 α ,5 α ,17 β)-	18.305	2.619
Rhizome extract			
1	Isobornyl acetate	12.402	1.002
2	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)-	13.338	0.878
3	γ -Elemene	14.293	0.956
4	4-Ethynyl-4-hydroxy-3,5,5-trimethyl-2-cyclohexen-1-one	15.178	22.894
5	Z-3-hexadecen-7-yne	16.859	5.302
6	3-keto-isosteviol	17.109	12.179
7	Verrucarol	19.035	6.523
8	Methandrostenolone	20.580	11.813
9	7-(1,3-Dimethylbuta-1,3-dienyl)-1,6,6-trimethyl-3,8-dioxatricyclo[5.1.0.0(2,4)]octane	22.081	10.686
10	5,6-decadien-3-yne,5,7-diethyl-	23.377	5.828

GC-MS analysis revealed five and four bioactive symmetrical peaks for leaf and rhizome extract of GNK-25 respectively (Table 23). 1,E-8Z-10-tridecatriene (47.802%)

and 4,5,6,6a-tetrahydro-1H-pentalen-2-one (42.648%) were found to be highest observed compounds in leaf and rhizome respectively.

Table 23: GC-MS analysis of leaf and rhizome extract of genotype GNK-25

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.056	6.873
2	Bicyclo[5.2.0]nonane, 4-methylene-2,8,8-trimethyl-2-vinyl-	12.162	1.166
3	2,2-Dimethyl-4-(3-methylbut-2-enyl)-6-methylidene cyclo hexyl methanol	14.033	7.157
4	18-Oxokauran-17-yl acetate	14.563	1.208
5	1,E-8Z-10-Tridecatriene	15.984	47.802
Rhizome extract			
1	4,5,6,6a-tetrahydro-1H-pentalen-2-one	16.759	42.648
2	Alpha santalol	18.300	5.057
3	Patchulane	21.600	10.532
4	Patchulane	23.080	9.748
5	7-(1,3-Dimethylbuta-1,3-dienyl)-1,6,6-trimethyl-3,8-dioxatricyclo[5.1.0.0(2,4)]octane	27.159	3.172

Other components of the leaf were 2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidene cyclo hexyl methanol (7.157%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (6.873%), 18-oxokauran-17-yl acetate (1.208%) and bicyclo[5.2.0]nonane, 4-methylene-2,8,8-trimethyl-2-vinyl- (1.166%).

Patchulane (18.135 min and 23.08 min. at 10.532% and 9.748% respectively), alpha santalol (5.057%) and 7-(1,3-dimethylbuta-1,3-dienyl)-1,6,6-trimethyl-3,8-dioxatricyclo

[5.1.0.0(2,4)]octane (3.172%) were other bioactive compounds present in the rhizome extract of GNK-25.

The highest percentage of 2,6,10,14-hexadecatetraen-1-ol, 3,7,11,15-tetramethyl-, acetate, (E,E,E)- (44.521%) was identified in the leaf extract GNU-26 (Table 24). Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (8.410%), cis-Z-alpha-bisabolene epoxide (6.157%), iso-bornyl acetate (5.624%), santalol cis alpha (4.715%) and +-aromadendrene (1.041%) were other compounds present.

Table 24: GC-MS analysis of leaf and rhizome extract of genotype GNU-26

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	12.032	8.410
2	Iso-Bornyl acetate	13.803	5.624
3	+-Aromadendrene	16.039	1.041
4	Santalol cis alpha	17.544	4.715
5	2,6,10,14-Hexadecatetraen-1-ol, 3,7,11,15-tetramethyl-, acetate, (E,E,E)-	18.190	44.521
6	Cis-Z-alpha-bisabolene epoxide	20.405	6.157
Rhizome extract			
1	Eucalyptol	5.830	9.256
2	Isobornyl acetate	10.051	4.409
3	γ -Elemene	11.122	5.929
4	Benzofuran, 6-ethenyl-4,5,6,7-tetrahydro-3,6-dimethyl-5-isopropenyl-, trans-	12.487	10.265
5	Norbornane, 2-methyl-3-methylene-2-(4-methyl-3-pentenyl)-	13.673	40.031
6	Verrucarol	15.514	4.304
7	Cyclohexene,1,5,5-trimethyl-6-(2-propenylidene)-	15.919	15.929

Norbornane, 2-methyl-3-methylene -2-(4-methyl-3-pentenyl)- (40.031%) was found to be the highest phyto-compound in the GNU-26 rhizome extract, followed by cyclohexene,1,5,5-trimethyl-6-(2-propenylidene)- (15.929%), benzofuran, 6-ethenyl-4,5,6,7-tetrahydro-3,6-dimethyl-5-isopropenyl-, trans-(10.265%), eucalyptol (9.256%), γ -elemene (5.929%), isobornyl acetate (4.409%) and verrucarol (4.304%).

Genotype GNF-27 leaf characterized by seven peaks (Table 25). 4-Isopropenyl-4,7-dimethyl-1-oxaspiro [2.5] octane (41.034%), 4,5,6,6a-tetrahydro- 1H-pentalen-2-one

(15.422%), eucalyptol (11.653%), 18-oxokauran-17-yl acetate (3.193%), 4-methoxy-6-methyl-6,7-dihydro(4H) furo[3,2-c] pyran (2.780%) and iso-bornyl acetate (2.743%) were the other phyto-compounds present. Rhizome extract had five symmetric peaks, 4-ethynyl-4-hydroxy-3,5,5-trimethyl-2-cyclohexen-1-one (26.639%) was found to be the major compound, followed by 1H indene, 1ethylidene-octahydro-7a-methyl-cis (15.306%), androstan -17-one,3-ethyl-3-hydroxy-, (5alpha) (12.222%), cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)- (1.865%) and iso bornyl acetate (1.762%) (Table 25).

Table 25: GC-MS analysis of leaf and rhizome extract of genotype GNF-27

Sl.No.	Compound	RT	Peak area (%)
Leaf extract			
1	Eucalyptol	6.500	11.653
2	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.776	16.907
3	Iso-Bornyl acetate	11.267	2.743
4	18-Oxokauran-17-yl acetate	14.493	3.193
5	4,5,6,6a-tetrahydro-1H-pentalen-2-one	15.358	15.422
6	4-Isopropenyl-4,7-dimethyl-1-oxaspiro[2.5]octane	16.324	41.034
7	4-Methoxy-6-methyl-6,7-dihydro(4H) furo[3,2-c] pyran	19.050	2.780
Rhizome extract			
1	Iso bornyl acetate	10.707	1.762
2	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)-	11.792	1.865
3	4-Ethynyl-4-hydroxy-3,5,5-trimethyl-2-cyclohexen-1-one	13.898	26.639
4	1H indene, 1ethylidene-octahydro-7a-methyl-cis	15.814	15.306
5	Androstan -17-one,3-ethyl-3-hydroxy-, (5 α)	16.434	12.222

Genotype GKT-29 leaf extract had seven symmetric peaks, Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)- (30.811%) and cis-beta-terpineol (24.167%) were the major peaks. Besides bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (14.184%), santalol cis alpha

(6.924%), iso aromadendrene epoxide (2.471%) and trace amount of acetic acid, 1,7,7-trimethyl-bicyclo[2.2.1]hept-2-yl ester (0.987%) were the other compounds observed (Table 26).

Table 26: GC-MS analysis of leaf and rhizome extract of genotype GKT-29

Sl.No.	Compound	RT	Peak area (%)
Leaf extract			
1	cis-Beta-terpineol	6.200	24.167
2	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.766	14.184
3	Acetic acid, 1,7,7-trimethyl-bicyclo[2.2.1]hept-2-yl ester	11.442	0.987
4	Iso Aromadendrene epoxide	14.568	2.471
5	Santalol cis alpha	15.334	6.924
6	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)-	16.529	30.811
Rhizome extract			
1	Acetic acid, 1,7,7-trimethyl-bicyclo[2.2.1]hept-2-yl ester	10.221	3.042
2	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)-	11.247	3.619
3	Benzene, ethoxy-	13.678	46.962
4	3,7-Cyclodecadien-1-one, 10-(1-methylethenyl)-, (E,E)-	14.768	2.485
5	5,10-penta decadiene,1-chloro	15.408	14.931

Rhizome extract had five bioactive compounds (Table 26). Benzene, ethoxy- (46.962%) being the major compound, besides 5,10-penta decadiene,1-chloro (14.931%), cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)- (3.619%), acetic acid, 1,7,7-trimethyl-bicyclo[2.2.1]hept-2-yl ester (3.042%) and 3,7-cyclodecadien-1-one, 10-(1-methylethenyl)-, (E,E)- (2.485%) were the other volatile compounds present in the GKT-29 rhizome extract.

1-Methyl-2-(1-methylethylidene) cyclo butane aceto nitrile (49.063%) being the major compound of GKK-30 leaf (Table 27). Followed by bicyclo [2.2.1] heptan-2-one, 1,7,7-

trimethyl-, (1S)- (23.653%), 4,5,6,6a-tetrahydro-1H-pentalen-2-one (12.427%), (-)- β - caryophyllene oxide (3.520%), iso bornyl acetate (2.867%) and 6-10,14-Trimethyl pentadecan-2-one (2.762%). Similarly, rhizome had benzene, ethoxy- (42.703%) followed by [2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl] methanol (15.342%), cyclohexene, 1,5,5-trimethyl-6-(2-propenylidene)- (12.725%), γ -elemene (5.368%) and bornyl acetate (2.886%). These phytochemicals comprise of 94.292% and 82.968% of the total volume of the leaf and rhizome extracts respectively (Table 27).

Table 27: GC-MS analysis of leaf and rhizome extract of genotype GKK-30

Sl.No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.946	23.653
2	Iso bornyl acetate	11.082	2.867
3	(-)- β - Caryophyllene oxide	14.148	3.520
4	4,5,6,6a-tetrahydro-1H-pentalen-2-one	15.028	12.427
5	1-Methyl-2-(1-methylethylidene) cyclo butane aceto nitrile	15.994	49.063
6	6-10,14-Trimethyl pentadecan-2-one	18.490	2.762
Rhizome extract			
1	Bornyl acetate	10.392	2.886
2	γ -Elemene	11.402	2.565
3	γ -Elemene	12.672	5.368
4	Benzene, ethoxy-	13.728	42.703
5	7-epi- α -Cadinene	14.443	1.379
6	Cyclohexene, 1,5,5-trimethyl-6-(2-propenylidene)-	15.529	12.725
7	[2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl] methanol	16.079	15.342

Eight peaks were observed for GMR-31 leaf extract (Table 28), comprises 77.277% of the total volume. 1-ethenyl-1-methyl-2, 4-bis (prop-1-en-2-yl) cyclohexane (38.254%) was the highest observed peak. Other peaks were 1H-3A,7-methanoazulene, octahydro-1,4,9,9-tetra methyl (11.721%), nerolidyl acetate (9.415%), cis-z-alpha-bisabolene epoxide (6.514%), caryophyllene oxide (4.124%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (3.421%) and acetic acid, 1,7,7-trimethyl-bicyclo [2.2.1] hept-2-yl ester (1.178). Similarly rhizome extract also had seven peaks, 2-cyclohexen-1-one, 4-ethynyl-4-hydroxy-3, 5, 5-trimethyl-

(29.557%) and 1,7,7 trimethyl-2-vinyl-bicyclo (2.2.1) hept-2-ene (24.974%) were the two major compounds identified. Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (8.049%), 1,2,3-trimethyl-cyclopent-2-ene carboxaldehyde (7.370%), cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)- (6.279%), 3,7-cyclodecadien-1-one, 10-(1-methylethenyl)-, (E,E)- (2.880%) and cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)- (2.797%) were other volatile compounds present in the rhizome extract of GMR-31.

Table 28: GC-MS analysis of leaf and rhizome extract of genotype GMR-31

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.486	3.421
2	Acetic acid, 1,7,7-trimethyl-bicyclo [2.2.1] hept-2-yl ester	11.252	1.178
3	Bicyclo[5.2.0]nonane, 4-methylene-2,8,8-trimethyl-2-vinyl-	12.232	2.650
4	Caryophyllene oxide	14.008	4.124
5	1H-3A,7-methanoazulene, octahydro-1,4,9,9-tetra methyl	14.803	11.721
6	1-ethenyl-1-methyl-2,4-bis(prop-1-en-2-yl) cyclohexane	15.944	38.254
7	Cis-Z-alpha-bisabolene epoxide	18.300	6.514
8	Nerolidyl acetate	19.480	9.415
Rhizome extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.746	8.049
2	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)-	11.377	2.797
3	2-Cyclohexen-1-one, 4-ethynyl-4-hydroxy-3,5,5-trimethyl-	13.808	29.557
4	3,7-Cyclodecadien-1-one, 10-(1-methylethenyl)-, (E,E)-	14.848	2.880
5	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)-	15.513	6.279
6	1,7,7 trimethyl-2-vinyl-bicyclo (2.2.1)hept-2-ene	15.974	24.974
7	1,2,3-trimethyl-cyclopent-2-ene carboxaldehyde	20.766	7.370

Cyclohexane, 1-methyl-2,4-bis(1-methylethenyl)- (43.988%), globulol (25.420%), camphor (13.151%), bicyclo [2.2.1] heptan-2-ol, 1,7,7-trimethyl-, formate, endo- (8.815%), [2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl] methanol (3.913%) and acetic acid, 1,7,7-trimethyl-bicyclo [2.2.1] hept-2-yl ester (1.336%) were the bioactive compounds present in the leaf extract of GAD-32 (Table 29). (2R,6S,7S,10Z)-beta-santala 3(15),10-

dien-12-01(17.593%), 7-(1,3-dimethyl buta-1,3-dienyl)-1,6,6-trimethyl-3,8-dioxatricyclo [5.1.0.0(2,4)] octane (16.170%) and [2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl] methanol (12.608%) were the major compounds present in the GAD-32 rhizome extract. Acetic acid, 1,7,7-trimethyl-bicyclo [2.2.1] hept-2-yl ester (8.701%), γ -elemene (4.777%) and endo borneol (3.282%) were the other components.

Table 29: GC-MS analysis of leaf and rhizome extract of genotypeGAD-32

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Camphor	9.706	13.151
2	Acetic acid, 1,7,7-trimethyl-bicyclo [2.2.1] hept-2-yl ester	11.467	1.336
3	[2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl]methanol	14.453	3.913
4	Globulol	15.133	25.420
5	Cyclohexane, 1-methyl-2,4-bis(1-methylethenyl)-	16.359	43.988
6	Bicyclo [2.2.1] heptan-2-ol, 1,7,7-trimethyl-, formate, endo-	18.014	8.815
Rhizome extract			
1	Endo borneol	10.897	3.282
2	Acetic acid, 1,7,7-trimethyl-bicyclo [2.2.1] hept-2-yl ester	11.692	8.701
3	γ -Elemene	12.843	4.777
4	(2R,6S,7S,10Z)-beta-santala 3(15),10-dien-12-01	15.339	17.593
5	[2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl]methanol	16.999	12.608
6	7-(1,3-Dimethylbuta-1,3-dienyl)-1,6,6-trimethyl-3,8-dioxatricyclo[5.1.0.0(2,4)]octane	26.873	16.170

Leaf extract of GNP-33 had 1,3,3-trimethyl cyclohex-ene-4-carboxaldehyde (+)- (37.965%), -iso aromadendrene -(V) (8.697%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (7.620%), [2,2-dimethyl-4-(3-methylbut-2-enyl)-6-

methylidenecyclohexyl]methanol (5.086%), bornyl acetate (2.710%), parthenolide (2.367%), and trace amount of bicyclo[5.2.0]nonane, 4-methylene-2,8,8-trimethyl-2-vinyl- (0.847%) volatile compounds in the leaf extract (Table 30).

Table 30: GC-MS analysis of leaf and rhizome extract of genotype GNP-33

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	8.786	7.620
2	Bornyl acetate	10.762	2.710
3	Bicyclo[5.2.0]nonane, 4-methylene-2,8,8-trimethyl-2-vinyl-	11.967	0.847
4	[2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl]methanol	13.838	5.086
5	-iso aromadendrene -(V)	14.738	8.697
6	1,3,3-Trimethyl cyclohex-ene-4-carboxaldehyde (+-)-	15.739	37.965
7	Parthenolide	17.899	2.367
Rhizome extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	11.172	1.141
2	Acetic acid, 1,7,7-trimethyl-bicyclo [2.2.1] hept-2-yl ester	12.112	1.627
3	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)-	13.098	1.383
4	γ -Elemene	14.093	1.559
5	2-Cyclohexen-1-one, 4-ethynyl-4-hydroxy-3,5,5-trimethyl-	14.968	20.154
6	1,3,2-dioxaphosphorinane-2-oxide	16.644	15.973
7	(3E,5E,7E)-6-Methyl-8-(2,3,3-trimethyl-1-cyclohexenyl)-3,5,7-octatriene-2-one	18.775	7.188
8	Anobin	20.391	6.040
9	3-carene, 2-acetyl methyl	21.091	13.223
10	Verrucarol	23.112	7.128
11	Chloranthalactone A	24.187	13.460

GNP-33 rhizomes had 2-cyclohexen-1-one, 4-ethynyl-4-hydroxy-3,5,5-trimethyl- (20.154%) as major compound, followed by 1,3,2-dioxaphosphorinane-2-oxide (15.973%), chloranthalactone A (13.460%), 3-carene, 2-acetyl methyl (13.223%), (3E,5E,7E)-6-Methyl-8-(2,3,3-trimethyl-1-cyclohexenyl)-3,5,7-octatriene-2-one (7.188%), verrucarol (7.128%), anobin (6.040%), acetic acid, 1,7,7-trimethyl-bicyclo [2.2.1] hept-2-yl ester (1.627%), γ -elemene (1.559%), cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)- (1.383%) and bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (1.141%) (Table 30). GBC-34 had seven and nine sharp peaks for leaf and rhizome extracts respectively (Table 31). 1 E-8, Z-10-

dodecatene (53.640%) and propanedinitrile, (ethoxymethylene)- (50.389%) were found to be highest recorded phyto-compounds in the leaf and rhizome extract respectively.

Other components of leaf were bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (18.136%), 2,4,4-trimethyl-3-hydroxymethyl-5a-(3-methyl-but-2-enyl)-cyclohexene (10.077%), 3,6-octadien-1-ol,3,7-dimethyl-, (Z)- (2.307%), [2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl] methanol (2.062%), 5,9,13-pentadecatrien-2-one, 6,10,14-trimethyl-, (E,E)- (1.526%) and bornyl acetate (1.384%).

Table 31: GC-MS analysis of leaf and rhizome extract of genotype GBC-34

Sl.No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	10.176	18.136
2	Bornyl acetate	12.182	1.384
3	[2,2-dimethyl-4-(3-methylbut-2-enyl)-6-methylidenecyclohexyl]methanol	15.123	2.062
4	2,4,4-Trimethyl-3-hydroxymethyl-5a-(3-methyl-but-2-enyl)-cyclohexene	16.229	10.077
5	1 E-8, Z-10-Dodecatene	16.874	53.640
6	3,6-octadien-1-ol,3,7-dimethyl-, (Z)-	19.665	2.307
7	5,9,13-pentadecatrien-2-one, 6,10,14-trimethyl-, (E,E)-	20.616	1.526
Rhizome extract			
1	Eucalyptol	7.830	4.439
2	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.326	6.849
3	Bornyl acetate	10.807	5.565
4	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)-	12.007	4.549
5	Propanedinitrile, (Ethoxymethylene)-	14.198	50.389
6	1,3 bis-(2-cyclopropyl, 2-methylcyclopropyl)-but-2-en-1-one	16.254	6.390
7	Cyclohexene, 1,5,5-trimethyl-6-(2-propenylidene)-	16.739	7.394
8	Azulene, 1,2,3,3a,4,5,6,7-octahydro-1,4-dimethyl-7-(1-methylethenyl)-, [1R-(1 α ,3 α ,4 α ,7 β)]-	18.445	1.676
9	Parthenolide	21.786	4.266

GBC-34 rhizome had cyclohexene, 1,5,5-trimethyl-6-(2-propenylidene)- (7.394%), bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (6.849%), 1,3 bis-(2-cyclopropyl, 2-methylcyclopropyl)-but-2-en-1-one (6.390%), bornyl acetate (5.565%), cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, (1 α ,2 β ,4 β)- (4.549%), eucalyptol

(4.439%), parthenolide (4.266%) and azulene, 1,2,3,3a,4,5,6,7-octahydro-1,4-dimethyl-7-(1-methylethenyl)-, [1R-(1 α ,3 α ,4 α ,7 β)]- (1.676%) as other volatile components.

3-decyne (39.421%) and propanedinitrile, (ethoxymethylene) (45.749%) were the highest bioactive

compounds of genotype GJG-35 leaf and rhizome extract respectively (Table 32). Other components of the leaf were bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (18.917%), santalol, e-cis, epi- β - (11.437%), himbaccol (5.482%), cis-z-.alpha.-bisabolene epoxide (2.016%) and bornyl acetate (1.857%). Retinal

(12.577%), 4 acetyl careen (11.381%), bornyl acetate (7.561%), cyclohexene, 1,5,5-trimethyl-6-(2-propenylidene)-(7.394%), parthenolide (7.214%), 1,3 bis-(2-cyclopropyl, 2-methylcyclopropyl)-but-2-en-1-one (6.390%) and eucalyptol (5.249%) are other volatile compounds present in the rhizome extract of GJG-35 (Table 32).

Table 32: GC-MS analysis of leaf and rhizome extract of genotype GJG-35

Sl.No.	Compound	RT	Peak area (%)
Leaf extract			
1	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.551	18.917
2	Bornyl acetate	11.467	1.857
3	Himbaccol	15.253	5.482
4	Santalol, E-cis, epi- β -	15.719	11.437
5	3-decyne	16.514	39.421
6	Cis-z-.alpha.-bisabolene epoxide	19.095	2.016
Rhizome extract			
1	Eucalyptol	7.542	5.249
2	Bornyl acetate	9.607	7.561
3	Propanedinitrile, (Ethoxymethylene)-	15.398	45.749
4	Cyclohexene, 1,5,5-trimethyl-6-(2-propenylidene)-	16.173	7.394
5	Retinal	19.220	12.577
6	Parthenolide	21.786	7.214
7	4 Acetyl careen	22.316	11.381
8	1,3 bis-(2-cyclopropyl, 2-methylcyclopropyl)-but-2-en-1-one	16.254	6.390

Genotype GNP-36 leaf had Z-3-hexadecen-7-yne (23.659%) and 1-cycloheptene, 1,4-dimethyl-3-(2-methyl-1-propene-1-yl)-4-vinyl (22.818%) as major compounds. Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)- (14.729%),

caryophyllene oxide (6.733%), cis-Z-. alpha. -bisabolene epoxide (3.953%), eucalyptol (1.815%) and traces of acetic acid, 1,7,7-trimethyl-bicyclo [2.2.1] hept-2-yl ester (0.833%) were the other minor compounds ((Table 32).

Table 33: GC-MS analysis of leaf and rhizome extract of genotype GNP-36

Sl. No.	Compound	RT	Peak area (%)
Leaf extract			
1	Eucalyptol	8.586	1.815
2	Bicyclo [2.2.1] heptan-2-one, 1,7,7-trimethyl-, (1S)-	9.481	14.729
3	Acetic acid, 1,7,7-trimethyl-bicyclo[2.2.1]hept-2-yl ester	11.662	0.833
4	Caryophyllene oxide	14.538	6.733
5	1-cycloheptene, 1,4-dimethyl-3-(2-methyl-1-propene-1-yl)-4-vinyl	15.759	22.818
6	Z-3-Hexadecen-7-yne	16.664	23.659
7	Cis-z-alpha-bisabolene epoxide	18.855	3.953
Rhizome extract			
1	Eucalyptol	7.321	10.256
2	γ -Elemene	10.232	6.121
3	Curzerene	13.487	12.526
4	Verrucarol	15.214	4.304
5	Alpha santalol	16.289	6.057
6	4,5,6,6a-tetrahydro-1H-pentalen-2-one	16.759	40.448
7	Patchulane	18.735	10.532

Similarly, rhizome had 4,5,6,6a-tetrahydro-1H-pentalen-2-one (40.448%) being the major compound identified, followed by curzerene (12.526%), patchulane (10.532%), γ -elemene (6.121%), alpha santalol (6.057%) and verrucarol (4.304%) are other volatile compounds identified in the genotype GNP-36.

Overall GC-MS analysis of leaf and rhizome extract of thirty three black turmeric genotypes revealed wide variation in the chemotypes and chemical composition of individual genotypes. The results are in accordance with the findings of Mukunthan *et al.* (2014) [20], Singh *et al.* (2020) and Borah *et al.* (2020) [7, 27]. Besides, work carried out by Behura and Srivastava (2004) and Borah *et al.* (2019) [6] provides a strong base to further explore and repurpose leaf and rhizome extracts based on geographical collection (Leela and Adheeb (2024)) [17]. The results on identification

of new compounds from leaf and rhizome extract of *Curcuma caesia* Roxb. Genotypes are in congruence with the reports Kumar *et al.* (2020) [16] and Borah *et al.* (2020) [7].

Conclusion

The study showed less similarity in the composition of both leaf and rhizome extract of different genotypes explained intraspecific diversity with respect to chemical components. Bioactive constituents of black turmeric are dependent on its geographical distribution also gave an insight of diverse pharmacological potentiality of each genotype. GC-MS analysis of leaf and rhizome extract revealed that a wide variation was observed in the chemotypes and chemical composition of the genotypes.

GAB-13, GAK-14 and GMI-22 genotypes leaf extract had highest number of phyto- compounds (10 No's), followed

by GKM-1, GAB-12, GMK16, GMS-24 and GMR-31 with eight compounds each. However minimum number of biocompounds present in GMA-17 and GNK-25 with five compounds each.

The GMF-21 rhizome extract had maximum number of phyto-compounds (12 No's), followed by GNP-33(11No's) and GKM-1, GBS-8, GAB-11,GMW-15 and GMS-24 genotypes had ten compounds each. While the least was observed in the genotypes GNK-25, GNF-27and GKT- 29 with five compounds each.

The characterized peaks are unique to the sample extract of Southern Indian genotypes, which differs from the peaks reported for the genotypes originated from Central India and North East India. The uniqueness is due to the presence of tropolone, β -elemene, (-)-, curzerene and alpha santalol. Genotypes collected from central india exhibits unique composition of the retinal, eucalyptol (cineole), 3,7(11)-eu desmadiene, 4 acetylcarene and camphor, similarly north east indian genotypes had γ -elemene, bicyclo (2.2.1) heptan-2-one,1,7,7-trimethyl-(1S)-.

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