VARIABILITY IN GINGER (*Zingiber officinale* Rosc.) FOR YIELD AND RESISTANCE TO RHIZOME ROT

by

ANARGHA T.

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THESIS

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VELLAYANI, THIRUVANANTHAPURAM- 695 522

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DECLARATION

I, hereby declare that this thesis entitled **"VARIABILITY IN GINGER (*Zingiber officinale* Rosc.) FOR YIELD AND RESISTANCE TO RHIZOME ROT"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship or other similar title, of any other University or Society.

18/10/19

Place : Vellayani
Date :18 /10/2019

ANARGHA.T
(2017-12-010)

CERTIFICATE

Certified that this thesis entitled **"VARIABILITY IN GINGER (*Zingiber officinale* Rosc.) FOR YIELD AND RESISTANCE TO RHIZOME ROT"** is a record of research work done independently by Ms. ANARGHA T. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

18/10/19

Place : Vellayani
Date : 18/10/2019

Dr. G. S. Sreekala
(Major Advisor, Advisory Committee)
Assistant Professor
Department of Plantation Crops and Spices
College of Agriculture, Vellayani

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Anargha, T., a candidate for the degree of **Master of Science in Horticulture** with major in Plantation Crops and Spices, agree that the thesis entitled **"Variability in ginger (*Zingiber officinale* Rosc) for yield and resistance to rhizome rot"** may be submitted by Ms. Anargha, T., in partial fulfilment of the requirement for the degree.

18/10/19

Dr. G. S. Sreekala
(Chairperson, Advisory Committee)
Assistant Professor
Dept. of Plantation Crops and Spices
College of Agriculture, Vellayani.

18/10/19

Dr. Deepa S. Nair
(Member, Advisory Committee)
Assistant Professor and Head
Dept. of Plantation Crops and Spices
College of Agriculture, Vellayani.

18/10/2019

Dr. Mareen Abraham
(Member, Advisory Committee)
Professor
Dept. of Plant Breeding and Genetics
College of Agriculture, Vellayani.

18/10/2019

Dr. Joy M.
(Member, Advisory Committee)
Associate Professor and Head
Dept. of Plant Pathology
College of Agriculture, Vellayani.

DEPARTMENT OF PLANTATION CROPS & SPICES
VELLAYANI
695 522
COLLEGE OF AGRICULTURE

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LIST OF ABBREVIATIONS

CD (0.05)	:	Critical difference at 5 % level
DUS	:	Distinctiveness, Uniformity and Stability
et al.	:	Co-workers/ Co-authors
Fig.	:	Figure
FYM	:	Farm yard manure
GA	:	Genetic advance
GCV	:	Genotypic coefficient of variation
HCl	:	Hydrochloric acid
KAU	:	Kerala Agricultural University
kg	:	Kilogram
LOX	:	Lipoxygenase
m^2	:	Square metre
MAP	:	Months after planting
mg	:	Milligram
min	:	Minute
nm	:	Nanometer
No.	:	Number
NS	:	Not significant
OD	:	Optical Density
PCV	:	Phenotypic coefficient of variation
PO	:	Peroxidase
PAL	:	Phenyl alanine ammonia lyase
PPO	:	Polyphenyl oxidase
RHS	:	Royal Horticultural Society
SEm	:	Standard error of mean
viz.,	:	Namely

LIST OF SYMBOLS

%	:	Per cent
@	:	at the rate of
µ	:	Micro

Introduction

1. INTRODUCTION

Ginger (*Zingiber officinale* Rosc.) herbaceous perennial of Zingiberaceae family is one of the earliest oriental spice and medicinal plant valued in India and China from ancient times. In Ayurveda, ginger is known as 'Mahaoushadhi' meaning great medicine (Purseglove *et al.*, 1981).

Ginger is the third most important spice originated in South East Asia. In India, it is confined to the Himalayas, North Eastern parts, and also in the Western Ghats (Bailey, 1949). Ginger is cultivated in India, China, Nepal, Indonesia, Thailand, Bangladesh and West Indies islands. In India, ginger occupies an area of 160,000 ha with a production of 11,18,000 tonnes (NHB, 2018). In India, it is cultivated mostly in states of Karnataka, Assam, Orissa, West Bengal, Meghalaya, Mizoram and Kerala. Kerala contributes 22,190 tonnes of ginger from an area of 4,970 ha (Spices Board, 2018).

Ginger is used in fresh, dried and preserved form. Fresh ginger is consumed as vegetable whereas, dried and preserved forms are traded internationally. Cochin ginger (NUGC) and Calicut ginger (NUBK) are the popular Indian ginger varieties in the world market. Ginger contains volatile oil, fixed oil, pungent compounds, resins, starch, protein, and minerals. Starch, crude fibre and protein contribute to the dry matter in ginger. Aroma and flavor are imparted by essential oils, the main constituents of which are zingiberene and phellandrene.

Ginger is one of the species that is prone to sexual reproduction constraints, and is vegetatively propagated (Jatoi and Watanabe, 2013). Since ginger is vegetatively propagated, the genetic variability is very narrow (Babu *et al.*, 2013). The available germplasm serves as most valuable natural reservoir for providing donor parent to improve a particular trait.

Cultivation of ginger is mostly based on developed varieties and land races selected by farmers over time, which are well adapted to environmental conditions. In India, more than 75 named varieties and more than 500 local cultivars are under cultivation (Rattan, 1994). Most of these ginger cultivars are grown by farmers over small and marginal areas generally for local or self-consumption (Ravindran and Nirmal, 2005). In the Indian subcontinent, the North East and Western Ghats form the area for ginger diversity. The richness of diversity of ginger plants grown in the Western Ghat region of Kerala is not fully inventoried and documented. Moreover, wherever ginger is grown, rhizome rot is a problem that limits the yield and cultivation of ginger. The disease leads to a loss of 30 to 100 per cent. Thus, an initial attempt has to be made to find out variability in ginger and to screen whether any resistant / tolerant genotypes are available in these regions. Keeping in view of these two aspects, germplasm need to be collected from different regions for high yield, quality and resistance / tolerance to rhizome rot disease. Hence, a study was formulated with the objective to collect the ginger genotypes from different regions of Kerala and to evaluate for yield and resistance / tolerance to rhizome rot.

Review of Literature

2.REVIEW OF LITERATURE

The study on "Variability in ginger (*Zingiber officinale* Rosc.) for yield and resistance to rhizome rot" was carried out at College of Agriculture, Vellayani with the objective to characterize the ginger genotypes collected from different regions of Kerala and to evaluate different ginger genotypes for yield and resistance or tolerance to rhizome rot. The relevant literature on the evaluation of ginger genotypes on morphological, yield and quality attributes, genetic analysis and screening of ginger genotypes for resistance/tolerance to rhizome rot, biochemical changes after artificial inoculation of *Pythium aphanidermatum* and the environmental factors leading to disease development were reviewed. Literature on other crops were also reviewed wherever pertinent literature in ginger was lacking.

2.1 COLLECTION OF GINGER GENOTYPES AND ANALYSIS FOR GENETIC VARIABILITY AND YIELD

2.1.1 Variability in ginger genotypes

The cultivar diversity of ginger is the highest in China. Many of the cultivars have unique morphological markers for identification. In India, more diversity was noticed in Kerala and in North Eastern states. Variability in ginger is less in other ginger growing countries (Ravindran and Nirmal, 2005).

Ridley (1915) reported three different types of ginger from Malaysia which include Halyia betel, Haliya bara and Halyia udang. A red variety of ginger known as *Zingiber officinale* var *rubra* has also been reported from Malaysia. Five kinds of ginger were reported from Jamaica which include St Mary, Red eye, Blue Tumeric, Bull Blue and China Blue (Graham, 1936). In Philippines two types- one a native and other Hawaiian had been reported (Rosales, 1938). However, Lawrence (1984) reported only one widely grown cultivar in Jamaica.

Tindall (1968) reported two types of ginger in West Africa differing in colour of rhizome, purplish red or bluish tissue below the outer scaly skin and yellowish white flesh.

In Japan ginger cultivars were of small sized, medium and large sized plants. The common cultivars of these groups include Kintoki, Sanshu and Oshoga. The autotetraploid cultivar reported for cultivation from ginger is 4x Sanshu (Adaniya, 2001). More over Japanese ginger (*Zingiber mioga*) is also cultivated in Japan. Varieties of ginger grown in Australia are Queensland local and Buderim local. Buderim Gold is the tetraploid derived from Buderim local by Buderim Co Ltd (2002).

According to Holttum (1950) Indo Malayan region is very rich in Zingeberaceous flora. Geographic spread together with genetic differentiation into locally adapted populations due to mutations could be the main factor responsible for variations in cultivated ginger. Selection for fresh ginger yield, good dry recovery, and less fibre content over the years might have resulted in the evolution of landraces in ginger (Ravindran *et al.*, 1994).

2.1.2 Evaluation of ginger genotypes for morphological, yield and quality attributes

A thorough knowledge about the variability in ginger is essential for an effective breeding strategy. In the case of vegetatively propagated plants, germplasm should be collected from wide agroecological areas otherwise the extent of variability will be less. Ravindran *et al.* (1994) characterized 100 accessions of ginger based on morphological, yield and quality parameters and found moderate variability for yield and quality. Tiller number per plant had the highest variability followed by rhizome yield per plant. The shogaol content showed highest variability followed by crude fibre and oleoresin among the quality traits.

Nybe, (1978) evaluated twenty five ginger genotypes for morphological parameters. Plant height, number of leaves per tiller, number of roots were the highest in Valluvanad.

Guidelines for the conduct of Distinctiveness, Uniformity and Stability (DUS) were published by UPOV in 1966. Guidelines for DUS testing in ginger were prepared by PPVFRA (Protection of Plant Varieties and Farmer's Rights

Authority), New Delhi, in collaboration with IISR (Indian Institute of Spices Research) (Singh, 2001).

Characteristics like plant height, number of shoots, rhizome thickness, rhizome shape and crop duration were used for grouping ginger genotypes (PPVFRA, 2007).

Muralidharan (1973) studied the varietal performance of ginger in Wayanad and found that the cultivar 'Rio de Janeiro' gave the highest fresh ginger yield, whereas the dry ginger yield was lowest in this cultivar. Dry ginger yield was highest in cultivar 'Tura'. Cultivars Maran, Nadia, and Thingpuri were the other high yielders.

Assessment of yield and quality components of 28 ginger cultivars was carried out by Nybe *et al.* (1982). Cultivar Rio de Janeiro had the highest oleoresin content of 10.53%, followed by Maran (10.05%). 'Karakkal' cultivar scored the highest essential oil (2.4%) and Kuruppumpadi had the highest crude fibre content (6.47%).

Eight ginger cultivars were evaluated over two years, at five different locations of Himachal Pradesh for yield. Himachal Local (109.6 q/ha), Kerala Local (96.2 q/ha) and Maran (92.3 q/ha) recorded high yield (Arya and Rana,1990).

Mohanty *et al.* (1990) analysed seven ginger varieties and found that Suprabha gave the highest yield (16.3 t/ha) followed by SG – 666 (13.9 t/ha). Rio de Janeiro gave lowest yield (10.62t/ha).

Pandey and Dhobal (1993) evaluated 29 ginger accessions collected from Assam, Meghalaya, Tripura and Nagaland. The collection H-85 was high yielder with a per plant yield of 202.2g, followed by NH 6/4 (175.6 g).

Korla *et al.* (1999) evaluated twenty four ginger genotypes for quality attributes at Solan. SG-692 had the highest dry matter content (18.06%) and least dry matter content was recorded for SG-61(12.90%). The highest yield was obtained for Himgiri (9 kg per plot).

Govind and Chandra (1999) observed that number of leaves per clump, weight of mother rhizome and internodal distance were the most variable characters.

Pandravada and Sivaraj (1999) found that variability in ginger was mainly observed for days to maturity, rhizome shape, rhizome size (small/medium/big), number of fingers/branches (primary/secondary/tertiary), surface colour (brownish-orange/shining brownish yellow/brownish-saffron/light brownish-red/dull brown), inside colour (light greenish yellow, dark greenish yellow, different shades of saffron-red, dark orange-red), aroma, yield and resistance/tolerance to different biotic/abiotic stresses.

Das *et al.* (1999) found that all the genotypes differed significantly for tiller number, leaf number and yield.

Datta *et al.* (2003) evaluated quality of 12 ginger cultivars in West Bengal and reported the highest dry recovery percentage in Tura (26.77%) followed by Suravi (23.45%), Suprabha (20.60%), Uttar Pradesh (20.48%) and Gorubathan (20.30%). The lowest dry recovery was in Bhoinse (15.84%).

Sasikumar *et al.* (2003) evaluated 14 ginger genotypes at three locations in Kerala and selected two accessions 107 and 35 based on superiority in dry yield, oil and oleoresin content. It was then multiplied and released for cultivation as IISR Mahima and IISR Rejatha.

Nayak *et al.* (2005) assessed genetic variability of 16 promising cultivars and found that rhizome yield per plant varied significantly from 181.9g in Singhaghara to 477.3g in Gorubathaney.

Twenty one ginger genotypes were evaluated for yield and quality attributes in Himachal Pradesh. The genotype PLS 4 recorded maximum yield. Three genotypes (SG 705, SG 1133 and SG 857) had high essential oil and oleoresin content (Bala *et al.*, 2007).

Kizhakkayil and Sasikumar (2009) evaluated forty six ginger accessions collected from India, Pakistan, China, Brazil, Oman, Nigeria, Nepal and

Queensland for quality traits and found that primitive landraces have more oleoresin and essential oil and low crude fibre content than improved varieties. Kozhikkalan variety recorded the highest oleoresin content (8.2%). Pink ginger had an essential oil content of 4%. Primitive landraces like 'Kintoki' and 'Nadia' had low crude fibre content of 1.3% and 1.8% respectively whereas improved varieties like Suruchi had a higher crude fibre content of 6.8%.

Roy and Wamanan (1990) evaluated fifteen ginger genotypes in North East India and observed higher yield in Nadia (24.8 kg/ha) and China (22.7 kg/ha).

Eighteen ginger genotypes of Nagaland were evaluated for growth, yield and quality and found that Thinglaidum, Nadia and Khasi local were tallest and had maximum number of tillers. Rio de Janeiro, Nadia and Thinglaidum had more fibre and oil contents (Singh *et al.*, 1999).

Prasad *et al.* (1997) evaluated 15 ginger genotypes for growth, yield and quality parameters and reported significant differences among the cultivars in all the parameters studied.

Five hundred and ninety five accessions of ginger were maintained in the germplasm repository of IISR besides 64 accessions received from NBPGR. Among five shortlisted nematode tolerant accessions evaluated for morphological and yield characters, Acc. 219 was found to be promising with high yield and nematode tolerant (IISR, 2011).

Chongtham *et al.* (2013) evaluated ten ginger varieties in West Bengal and recorded highest rhizome yield in Gorubathan (18.25 t/ha). The genotype was superior in yield attributes like length of primary fingers (2.28 cm), diameter of secondary fingers (1.95 cm).

Six hundred and sixty eight ginger accessions were maintained in the field gene bank of Indian Institute of Spices Research, Calicut. Germplasm conservatory was enriched with extra bold local accession from Arunachal Pradesh. Evaluation of extra bold and low fibre accession led to the identification of three accessions

(Accession 723, Accession 247, Accession 248) with high yield and bold rhizomes (IISR, 2014).

Rajyalakshmi and Umajyothi (2014) evaluated eight ginger genotypes at Srikakulam district of Andhra Pradesh and reported taller (50.60cm) and the highest fresh rhizome yield from Suprabha variety (21.71t/ha).

Evaluation of extra bold ginger accessions resulted in short listing of accessions Acc.723, Acc. 247 and Acc. 713 for high yield and bold rhizomes. Chromosome indexing of bold rhizome type ginger accessions confirmed that all the accessions had 2n=22, indicating that boldness was not due to polyploidy but genotypic in nature. Two bold accessions showed aneu somatic variation with 2n=21 and 2n=23 (IISR, 2015).

Twenty seven turmeric genotypes were characterized using DUS guidelines in West Bengal. Among these, only one genotype was of short type with a plant height of less than 85 cm, one of medium type (58-100cm) and rest 25 belonged to tall type (> 100cm). In the case of petiole length, fifteen genotypes were found under long, ten were of intermediate category and two were of short type. Among 27 genotypes, only one had medium leaf length all others were of long type (Deb and Chakraborty, 2017).

Morphological characterization of 18 ginger cultivars in Terai region of West Bengal for two consecutive years was done based on DUS guidelines. Plant height varied from 50.52cm to 70.63 cm in the genotypes and all were of short type (plant height less than 100cm). Maximum plant height was observed for GCP- 30. Shoot height varied from 33.18cm to 53.72cm and all genotypes were of short type with a shoot height less than 75cm. Leaf length varied from 17.64cm to 23.79cm, while leaf width varied from 1.99cm to 2.61 cm. In all genotypes, leaf length and leaf width were short (<25cm) and narrow (<2.5cm) respectively. Rhizome shapes like straight, curved and zig-zagged were observed in the genotypes. Thin and medium rhizome thickness were found among genotypes (Basak *et al.*, 2019).

2.1.3 Character association in ginger

Pandey and Dhobal (1993) evaluated 29 ginger accessions collected from Assam, Meghalaya, Tripura and Nagaland. The correlation studies revealed that plant height, number of fingers, weight of fingers were significantly and positively correlated with yield.

According to Singh (2001) rhizome yield per plant was positively correlated with plant height, number of tillers, leaf length and width.

Abraham and Latha (2003) analysed correlation of 40 ginger genotypes for twelve morphological parameters. They found that yield had high positive correlation with number of leaflets, followed by height of tiller, rhizome length and thickness of secondary rhizome.Leaflet number showed the highest positive effect and thus could be taken for direct selection.

Tiwari (2003) evaluated 24 ginger genotypes and found that rhizome yield per plant had significant and positive correlation with number of leaves per shoot, number of tillers, leaf length, leaf breadth, rhizome length and breadth.

Bala *et al.* (2007) evaluated 20 ginger genotypes in Himachal Pradesh and found that yield per plot was positively correlated with essential oil while negatively correlated with dry matter, oleoresin content and crude fibre content.

According to Islam *et al.* (2008) rhizome yield per plant was positively correlated with plant height, leaf length, number of leaves per tiller, number of primary fingers per rhizome, number of secondary fingers per rhizome and number of tertiary fingers per rhizome.

Chandra and Govind (1999) observed negative correlation between fibre content and rhizome yield.

Parmar (2011) evaluated genetic variability in 30 ginger genotypes in Himachal Pradesh. Ten morphological characters like plant height, number of tillers

per plant, leaf length, number of leaves per plant, leaf breadth, fresh rhizome weight with aerial parts, fresh rhizome weight without aerial parts, rhizome length, rhizome breadth and dry weight of rhizome were subjected to correlation and revealed positive correlation of dry weight with all other characters.

Jatoi and Watanabe (2013) evaluated diversity analysis and relationships among 19 ginger landraces and found that plant height had positive correlation with rhizome weight, rhizome thickness, sheath length and number of leaves per tiller.

Ravisankar *et al.* (2013) assessed the genetic variability for yield and quality traits in 25 ginger genotypes and found that rhizome yield was significantly and positively correlated with plant height, length of primary rhizome and rhizome thickness.

Ravi *et al.* (2017) studied correlation in sixteen ginger genotypes and found that fresh rhizome yield was highly correlated with plant height, number of tillers, leaf area index, number and length of primary rhizome, number and length of secondary rhizome, oleoresin content and crude fibre content.

According to Blanco and Pinheiro (2017), yield per plant was positively and significantly correlated with plant height, number of tillers and rhizome thickness.

Akshitha *et al.* (2018) evaluated correlation coefficients of different plant characters in 28 ginger genotypes for two consecutive years. The study revealed that yield per plant was significantly and positively correlated with plant height (0.201), number of leaves (0.293), shoot diameter (0.221), rhizome thickness (0.297) and dry recovery (0.201). Essential oil showed high positive correlation with oleoresin and crude fibre content.

2.1.4 Genetic parameters *viz*, Phenotypic variation, genotypic variation, coefficient of variation, heritability, genetic advance and path analysis

Phenotypic variation can be produced by genetic differences, environmental influences and stochastic developmental events. Whilst the genetic and environmental components are rather well investigated, developmental

variation (DV), also called `intangible variation' or `developmental noise', remained a largely untouched field of research (Astauroff, 1930; Falconer and Mackay, 1996; Gartner, 1990; Whitelaw, 2006; Veitia, 2005).

Pandey and Dobhal (1993) conducted character association and path analysis in twenty nine ginger accessions. High PCV and GCV was found for plant height, number of suckers and fingers, weight of primary rhizome and yield. High heritability coupled with genetic advance was found for number of suckers, weight of fingers, primary rhizome and yield. Path analysis revealed that weight of fingers had the largest direct effect on yield (0.989) which was followed by number of fingers, weight of finger and leaf width.

Ali *et al.* (1994) analysed genotypic coefficient of variation in ginger genotypes and found that high GCV was for rhizome yield, primary and secondary rhizome length and weight.

Yadav (1999) evaluated coefficient of variation, genetic advance and heritability of 26 ginger accessions of Raigarh district. GCV was high for length and width of secondary rhizome, primary rhizome weight, rhizome yield per plant. High heritability and genetic advance was found for plant height, suckers per plant, number of primary and secondary rhizomes.

Nandkangre *et al.* (2016) did the morphometric and agronomic characterization of 56 ginger landraces in Burkina Faso. Coefficient of variation was high for rhizome weight per plant (54.34%) and rhizome yield (55.45%) whereas, low values of coefficient of variation were recorded for leaf width (12.17%) and leaf length (12.19%).

Twenty five ginger genotypes were evaluated for variability, heritability, and genetic advance by Ravisankar *et al.* (2013). Plant height and yield showed wide genetic variation. Oleoresin content, ascorbic acid content, acidity showed high genetic advance and heritability.

Genetic variability, character association and path analysis in nineteen genotypes were evaluated by Islam *et al.* (2008). Genetic advance and heritability

was high for plant height, number of tillers, leaf length and breadth. Number of leaves per tiller showed highest positive effect on rhizome yield and it can be considered for direct selection.

Aragaw *et al.* (2011) analysed the variability of thirty six ginger accessions for morphological and yield traits in ethiopia. Genetic advance and heritability was found high for fresh rhizome yield, dry rhizome yield, fibre content, oleoresin content, oil content.

Blanco and Pinheiro (2017) analysed the genetic diversity of 61 ginger accessions based on agronomic traits. High heritability was found for rhizome thickness (93.05%), yield per plot (90.69%) and plant height (81.41%).

Path coefficient analysis is the standardized partial regression coefficient which split correlation coefficient into direct and indirect effects. Path analysis measures the direct and indirect contribution of various independent characters on dependent character. The partitioning of phenotypic correlation between yield and morphological characters into direct and indirect effect by path analysis revealed that plant height exhibited a high direct effect as well as indirect effect (Nair *et al.*, 1982, Ratnambal 1984).

According to Rattan *et al.* (1988) the number of leaves per plant had maximum direct effect on yield per plant followed by rhizome breadth. High positive direct effect was reported for stomatal number, leaf area, leaf number and plant height on rhizome yield (Das *et al.*, 1999).

Sasikumar *et al.* (1992) conducted path analysis of 100 ginger accessions and found that plant height exhibited the highest direct effect on yield followed by leaf length. Dry recovery had negative direct effect on yield.

Singh (2001) analysed 16 ginger genotypes in Himachal Pradesh and observed that number of leaves hadmaximum indirect effect on yield followed by leaf length.

Rai *et al.* (2008) conducted path coefficient analysis in 26 ginger genotypes. The study revealed direct effect of leaf area, plant height and number of leaves on

rhizome yield. Relative humidity and leaf temperature showed negligible and relative direct effect on rhizome yield per plant.

Number of tillers per plant showed high positive effect on fresh rhizome yield followed by leaf area index, thickness of secondary rhizome. Plant height had positive indirect effect on fresh rhizome yield through number of tillers (Ravi *et al.*, 2017).

2.2 SCREENING OF GINGER GENOTYPES AGAINST RHIZOME ROT UNDER NATURAL CONDITION.

Indrasenan and Paily (1974) reported that Maran cultivar was resistant against rhizome rot caused by *Pythium aphanidermatum*. It scored a mean infection percentage of 12.6% whereas others had higher infection percentage of 20 to 75%.

Setty *et al.* (1995) evaluated susceptibility of 18 ginger genotypes to rhizome rot and found that cultivars Suprabha and Himachal Pradesh have less than 3% disease incidence.

Panyanthatta (1997) tested 148 accessions of ginger and 7 related taxa for assessing their reaction to rhizome rot caused by *Pythium aphanidermatum*. All the accessions were susceptible and the incidence was less in five accessions: namely IISR-73, 79, 215 and 250.

Nybe and Nair (1979) evaluated 25 ginger cultivars for rhizome rot incidence. Among the 25 cultivars, Rio de Jeneiro showed maximum susceptibility (27.50%) to soft rot disease followed by Tafingiya (26.40%) and Himachal Pradesh (16.30%). The infection was very mild in Maran (3.20%), Vengara (3.40%), Wayanad Local (3.50%), Mananthody (3.60%) and Kuruppampady (3.60%). The incidence was medium in Bajpai (5.32%) and Nadia (7.50%).

Shankar (2003) screened seven variants along with three check varieties and found that Himachal Pradesh showed the least susceptibility to soft rot (20.28%).

Paul *et al.* (2006) also found that during field evaluation of somaclones of cultivar Maran and Rio de Janeiro for a period of three years (2002-2004), rhizome rot incidence was noticed in 14 per cent clones each of Maran and Rio de Janeiro.

Shylaja *et al.* (2010) reported of two new ginger varieties; Athira and Karthika, developed at Kerala Agricultural University, from cv. Maran, exploiting somaclonal variation. Athira and Karthika are more resistant to soft rot (*Pythium* sp.).

2.2.1 Screening by artificial inoculation of pathogen

Karmarkar *et al.* (2003) assessed susceptibility of 6 ginger cultivars (Pulpally, Kunduli, Himachal, Maran, Varada and Suprabha) to *Pythium aphanidermatum*. Among the cultivars, Kunduli was the least susceptible while Varada was the most susceptible followed by Suprabha and Maran.

One thirty four ginger cultivars were evaluated for three years in Orissa against rhizome rot (Senapati and Sugata, 2005). Only one variety 'ZO- 16' was found to be resistant with percentage disease incidence of 0% and eight varieties were moderately resistant.

Four thousand one hundred and twenty buds were subjected to gamma irradiation at 0.8, 0.9 and 1 Kr. The M1V1 mutants established in the green house was screened against *Pythium* species. Screening of three hundred M1V2 and one twenty M1V7 mutants against soft rot caused by *Pythium myriotylum* resulted in three mutants without infection. Four mutants escaped three rounds of bacterial wilt infection were clonally multiplied for further yield evaluation (IISR, 2014).

Pattnaik *et al.* (2015) screened 25 ginger varieties against *Pythium aphanidermatum* for two consecutive years in Orissa. 'Sargiguda' variety showed resistance and varieties 'China' and 'Varada' showed partial resistance. Varieties like Suravi, Suruchi, Wayanad local were susceptible to rhizome rot.

2.2.2 Peroxidase (PO), polyphenyl oxidase (PPO), lipoxygenase (LOX) and phenylalanine ammonia lyase (PAL) activity

Chen *et al.* (2000) reported that high levels of phenylalanine ammonia lyase, polyphenyl oxidase and peroxidase were induced in cucumber roots when inoculated with *Pythium aphanidermatum*. The peak level of PAL and PPO was observed on fourth day of inoculation whereas, six days for PO.

Ghosh evaluated enzymatic responses of ginger plants to *Pythium* infection after SAR induction in West Bengal (2015). Peroxidase activity increased in leaves of untreated inoculated plants upto 21 days of inoculation and then declined. Similarly, polyphenyl oxidase activity increased upto 14 days following inoculation and then gradually declined. Lipoxygenase and phenylalanine ammonia lyase activity also increased upto 14 days of inoculation and then declined.

Materials and Methods

3. MATERIALS AND METHODS

The investigation on "Variability in ginger (*Zingiber officinale* Rosc.) for yield and resistance to rhizome rot" was undertaken in the Department of Plantation Crops and Spices, College of Agriculture, Vellayani, Thiruvananthapuram during the period from 2017 to 2019. The experiment was conducted to evaluate ginger genotypes for yield and resistance/tolerance to rhizome rot.

3.1 COLLECTION OF GINGER GENOTYPES AND ANALYSIS FOR GENETIC VARIABILITY AND YIELD.

Twenty different genotypes of ginger were collected from farmer's field from different parts of Kerala. The details of ginger genotypes collected are given in table 1.

3.1.1 Experimental site

3.1.1.1 Location

The field experiment was carried out at the Instructional Farm, College of Agriculture, Vellayani, Kerala located at a latitude of 8^0 30'North and 76^0 54'East longitude at an altitude of 29m above MSL.

3.1.1.2 Soil

Soil of the experimental site was red loam belonging to the Vellayani series and texturally classed as sandy clay loam.

3.1.1.3 Season

The field experiment was conducted from May 2018 to January 2019.

3.1.2 Materials

3.1.2.1 Seed material

Twenty different genotypes of ginger collected from farmer's field from different parts of Kerala. Control variety (T_{21}), Aswathy was collected from College of Horticulture, Vellanikkara. These varieties were planted in beds in the Instructional Farm, Vellayani.

Table 1: Details of ginger genotypes collected from farmer's field of Kerala

Sl. No.	Treatment	Location	District	Altitude
1	T_1	Mananthavady	Wayanad	760m
2	T_2	Kanchiar	Idukki	850m
3	T_3	Thalayolaparambu	Kottayam	24m
4	T_4	Haripad	Alappuzha	10m
5	T_5	Kottarakkara	Kollam	41m
6	T_6	Ambalavayal	Wayanad	974m
7	T_7	Kothamangalam	Ernakulam	34m
8	T_8	Karunagapally	Kollam	14m
9	T_9	Mannarkkad	Palakkad	76m
10	T_{10}	Kattapana	Idukki	900m
11	T_{11}	Kazhakootam	Trivandrum	11m
12	T_{12}	Irinjalakkuda	Thrissur	39m
13	T_{13}	Sulthan Bathery	Wayanad	901m
14	T_{14}	Murickassery	Idukki	28m
15	T_{15}	Nedumkandam	Idukki	975m
16	T_{16}	Pozhuthana	Wayanad	700m
17	T_{17}	Kalliyur	Trivandrum	28m
18	T_{18}	Kottiyoor	Kannur	11m
19	T_{19}	Thariode	Wayanad	52m
20	T_{20}	Thalavur	Kollam	41m

3.1.3 Methods

3.1.3.1Design of the experiment

Design	:	Randomised block design
Treatments	:	21
Replication	:	4
Bed size	:	$1.5m^2$ (1.5m x 1.0 m)
Spacing	:	20 cm x 20 cm

3.1.3.2 Layout of the experiment

Layout of the experiment is shown in Fig. 1.

R_1T_3	R_2T_{13}	R_3T_{19}	R_4T_4
R_1T_8	R_2T_1	R_3T_{21}	R_4T_2
R_1T_6	R_2T_{17}	R_3T_7	R_4T_{20}
R_1T_{18}	R_2T_{14}	R_3T_2	Coconut
R_1T_4	R_2T_{20}	R_3T_5	R_4T_{19}
R_1T_2	R_2T_{10}	R_3T_{16}	R_4T_{15}
R_1T_5	R_2T_{12}	R_3T_9	R_4T_{12}
R_1T_{14}	R_2T_{18}	R_3T_{15}	R_4T_7
R_1T_{17}	R_2T_6	R_3T_{11}	R_4T_{10}
R_1T_{10}	R_2T_3	R_3T_{13}	Coconut

R_1T_{15}	R_2T_{19}	R_3T_8	R_4T_{16}
R_1T_9	R_2T_4	R_3T_{20}	R_4T_9
R_1T_{21}	R_2T_{16}	R_3T_1	R_4T_{14}
R_1T_{11}	R_2T_2	R_3T_{12}	Coconut
R_1T_{16}	Coconut	R_3T_{10}	R_4T_{18}
R_1T_{20}	R_2T_9	R_3T_{17}	R_4T_6
R_1T_7	R_2T_5	R_3T_3	R_4T_{13}
R_1T_{12}	R_2T_{15}	R_3T_4	R_4T_{11}
R_1T_{19}	R_2T_8	R_3T_6	R_4T_{21}
R_1T_1	R_2T_2	R_3T_{14}	R_4T_1
R_1T_{13}	R_2T_{11}	R_3T_8	R_4T_8
	R_2T_7		R_4T_3
			R_4T_5
			R_4T_{17}

3.1.3.3 Seed treatment

Selected rhizomes were cut into pieces of 10-15 g containing at least two buds. These rhizome bits were treated with pseudomonas (20 g/L) for 20 min and shade dried.

3.1.3.4 Raising of ginger seedlings in portrays

Treated rhizome bits were planted in portrays containing potting medium of coir pith and farm yard manure (FYM) in 3:1 ratio and were kept in polyhouse for 40 days (Plate 1). These seedlings were planted in beds (Plate 1).

3.1.3.5 Land preparation and planting

The experimental plot was prepared by ploughing followed by bed preparation with a plot size of 1.5 m x 1 m in the interspaces of coconut garden (Plate 2). A drainage channel of 40 cm was given between each bed. Eighty four beds were taken for planting with four replications of twenty genotypes and one control variety. Trichoderma enriched FYM was applied in the bed @ 30 t/ha. Six kilograms of Trichoderma was mass-multiplied in 540 kg FYM and 60 kg neem cake and was applied to each bed at the rate of 6 kg. Forty day-old seedlings were transplanted at a spacing of 20 cm x 20 cm.

3.1.3.6 Fertilizer application

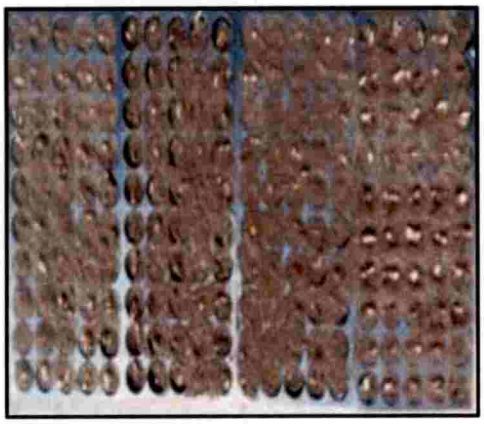
Fertilizers were applied as per package of practices recommendation of Kerala Agricultural University (KAU, 2016). 52 g Rajphos and 8.5 g Muriate of Potash were applied as basal in each bed. 16.5g Urea was applied 2 months after planting. Remaining dose of 16.5 g Urea and 8.5 g Muriate of Potash were applied 4 month after planting in each bed.

3.1.4 After Cultivation

Beds were mulched with glyricidia leaves @ 3 kg per bed at the time of transplanting. Mulching was repeated twice at the rate of 1.5 kg per bed at two month

(a) Rhizome bits

(b) Dipping in *Pseudomonas*



(c) Protray planting

(d) Ginger plantlets ready for transplanting

Plate 1. Raising of ginger plantlets in protrays

Plate 2. Main field planting of the ginger genotypes

Plate 3. Mulched beds of the ginger genotype

and four month after planting (Plate 3). Hand weeding was done 45 days after transplanting and repeated before next mulching and fertilizer application. Earthing up was carried out after each mulching.

3.1.5 Qualitative characterization of selected ginger genotypes

Qualitative characterization of twenty selected genotypes and one control variety Aswathy (Plate 4) were undertaken based on DUS guidelines formed for ginger (PPVFRA, 2007). For the assessment of distinctiveness, uniformity and stability, observations were made on 40 plants which were equally divided among four replications (10 plants per replication).

Selected ginger genotypes were characterized as per DUS (Distinctiveness, uniformity and stability) guidelines. The recorded characters include plant characters like growth habit, height, shoot characters like number of shoots (few, medium, many) height of shoot (short, medium, tall), shoot diameter (narrow, medium, broad), shoot intensity of green colour (light green, green, dark green), leaf characters like leaf length (short, medium, long), leaf width (narrow, medium, broad), leaf intensity of green colour (light green, green, dark green) leaf petiole length (short, medium, long), inflorescence characters like spike length (short, medium, long), colour of the bract tip of fully developed spike (Crimson, yellowish white tip), rhizome characters like rhizome thickness (thin, medium, bold),rhizome shape (straight, curved, zig zagged), rhizome skin colour (yellowish white, greyish yellow, greenish yellow, reddish yellow), rhizome flesh colour (light yellowish grey, grayish yellow, yellow). For the assessment of colour characteristics, the latest Royal Horticultural Society (RHS) colour chart was used. All observation on the plant, the leaf and the stem were made before the end of the growing phase and during the full expression time. All observations on the pseudostem were made on the main shoot (tallest) and all observations on the rhizome were made at the time of harvest.

Plate 4. General view of the experimental site

3.1.5.1 Plant characters

Growth habit was recorded on visual observation at the end of growing phase. Based on height, they were divided into short (height less than 100cm), medium (height between 100 and 120cm) and tall (more than 120cm). Plant characters were recorded for 20 genotypes and one control.

3.1.5.2 Shoot characters

Genotypes were classified into three, based on number of shoots which include few (less than 10), medium (between 10 and 15) and many (more than 15). Based on diameter, shoots were classified as narrow (less than 3cm), medium (between 3 and 5) and broad (more than 5cm). Intensity of green colour of shoot include light green, green and dark green.

3.1.5.3 Leaf characters

Leaf characters include leaf length, leaf width, leaf intensity of green colour and leaf petiole length. Leaf length can be short, medium and long. The leaf having a length of less than 25 cm is classified as short, 25 to 30 cm as medium and more than 30 cm as long. Based on the breadth of leaf it is classified as narrow (<2.5 cm), medium (2.5- 3.5 cm) and broad (>3.5 cm). The intensity of green colour of leaf may vary from light green, green and dark green. Petiole length may vary from short (<0.5 cm) and medium (0.5-0.7 cm) to long (>0.7 cm).

3.1.5.4 Inflorescence characters

Inflorescence characters include spike length, classified into short (<25 cm), medium (25-35 cm) and long (>35cm). Colour of bract of fully developed spike may be of two types, crimson and yellowish white tip (Plate 5).

3.1.5.5 Rhizome characters

Based on rhizome thickness, ginger genotypes were included under three categories such as thin (<2cm), medium (2-3 cm) and bold (> 3cm). Rhizome shape

(A) Crimson coloured bract tip

(B) Yellowish white bract tip

Plate 5. Variability in bract tip of ginger inflorescence

of genotypes was categorized under straight, curved and zig-zagged. Rhizome skin colour (yellowish white, greyish yellow, greenish yellow, reddish yellow) and flesh colour (light yellowish grey, grayish yellow, yellow) were recorded and compared as per RHS colour charts. These characters were recorded after harvest.

3.1.6 Quantitative characterization of selected ginger genotypes

3.1.6.1 Days to sprouting

Days taken to sprout was recorded for each genotype.

3.1.6.2 Plant characters

a. Plant height

Height of the plant was measured from the base of the plant to the tip of the young fully opened leaf of the main shoot and was expressed in centimeter.

b. Number of tillers

The number of aerial shoots produced by each observational plant was counted and mean expressed.

c. Dry matter production

The pseudostem, leaves, petioles, roots and rhizomes of the uprooted plants were separated and dried to a constant weight at 70$\pm$ 5°C in a hot air oven. The sum of dry weights of the component parts gave the total dry matter production of the plant and mean value expressed as g plant^{-1}.

3.1.6.3 Leaf characters

a. Leaf length

Length of upper fourth leaf of the main shoot was measured from base of petiole to highest tip of leaf using a meter scale and expressed in centimeter.

b. Leaf breadth

Width of the upper fourth leaf of the main shoot was measured at widest portion of leaf using a meter scale and expressed in centimeter.

c. Leaf area

Leaf area was estimated using the formula

Leaf Area (Y) = k x Leaf length x Leaf width – 0.7607

where, k= 0.6695and was expressed in cm^2 (Joseph, 1992)

3.1.6.4 Rhizome characters

a. Rhizome spread

The horizontal width of the rhizomes was measured and expressed in centimeter.

b. Rhizome thickness

Rhizome thickness was measured using vernier caliper and expressed in centimeter.

3.1.6.5 Yield characters

a. Fresh yield (kg/plant, kg/plot)

Rhizomes were harvested after yellowing and drying of the plants. Yield per plant and per plot was recorded (Plate 6).

b. Dry yield (kg/plant, kg/plot)

The rhizomes harvested, washed and allowed to dry in hot air oven at $70\pm5^{\circ}C$ until constant weight was obtained.

c. Harvest index

Harvest index was calculated at harvest as the ratio of dry weight of rhizome to the dry weight of whole plant.

$$\text{Harvest index (HI)} = \frac{Y_{eco}}{Y_{bio}} \quad \text{where}$$

Yeco = Total dry weight of rhizome

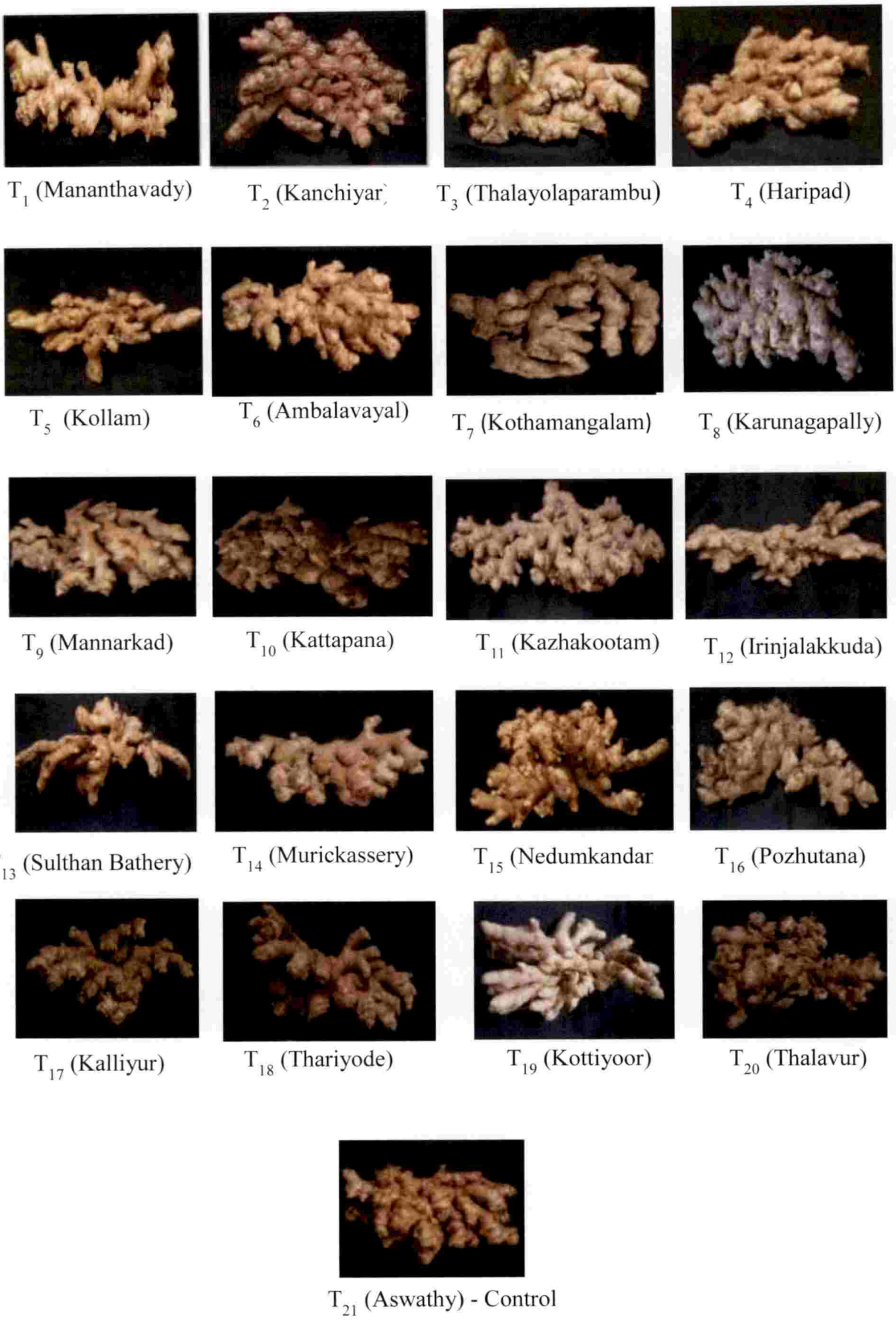


Plate 6. Fresh rhizome yield of ginger genotypes

Y bio = Total dry weight of plant

d. Dry recovery (%)

Dry recovery was calculated at harvest. Fresh rhizomes after washing was weighted and kept in drier at 60-70°C till constant weight was obtained. The dry weight was then noted and the mean dry recovery was expressed as given below.

Dry recovery (%) = B/A X 100 where,

A = Fresh sample weight of rhizome (g)

B = Weight of sample after drying (g)

3.1.7. Quality attributes

Rhizomes were analysed for quality attributes like starch content, volatile oil content, oleoresin, crude fibre content and total phenol content.

3.1.7.1 Starch

Starch was estimated colorimetrically using anthrone reagent as per Sadasivam and Manickam (2008). 0.3 g of sample was taken and extracted using 80 % ethanol. Residue was extracted repeatedly to remove all sugars. Centrifuged and the residue was dried over a water bath. To the residue 5 ml water and 6.5 ml of 52 per cent perchloric acid were added and extracted at 0° C for 20 min. The sample was then centrifuged and the supernatant was saved. The extraction was repeated with fresh perchloric acid. The supernatant was pooled and made up to 100 ml. From this 0.2 ml of the supernatant was pipetted out and made up to one ml with water. Standards were prepared by taking 0.2, 0.4, 0.6, 0.8 and 1 ml of working standard and made up to one ml in each test tube with water. To this 4 ml of anthrone reagent was added and heated for 8 min, cooled and read the OD at 630 nm.

3.1.7.2 Crude fibre

Crude fibre was estimated using Sadasivam and Manickam (2008). Ginger powder of 2 g was boiled with 200 ml sulphuric acid for 30 min. It was then filtered with muslin cloth and washed using boiling water. Subsequently boiled with 200 ml

of sodium hydroxide solution of 30 min and it was again filtered and washed with 25 ml of boiling 1.25 % sulphuric acid, three 50 ml portions of water and 25 ml alcohol. The residue was removed and transferred to ashing dish and residue was dried for two hours at 130± 2°C. The dish is cooled in a desiccator and weighed. This is ignited for 30 min at 600±15°C. This is cooled again in a desiccator and reweighed. It was expressed in percentage.

3.1.7.3 Essential oil

Essential oil was extracted by hydro-distillation method using Clevenger apparatus (Pruthy, 1993). 20 g dried powdered ginger sample were taken in a 1 L round bottom flask. 300 ml distilled water was added. This was distillated for about 3 h. Total volatile content obtained was expressed in percentage.

Percentage of volatile oil (v/w) = (Volume of oil (ml)/ Weight of sample (g)) X 100

3.1.7.4 Oleoresin

Oleoresin was extracted using soxlet apparatus (Braga *et al.*, 1998). A thimble was made out of 20 g of dried powdered sample kept in a filter paper. This was kept in soxlet extracter. 300 ml of acetone was taken in a round bottom flask and heated. When it started boiling, vapour rise up on distillation arm and get condensed through condenser and fell into sample. Thus material got dissolved in solvent. This process was repeated for 3 h until all oleoresin get extracted. Thus round bottom flask contains both solvent and extract. The solvent was removed before it siphon back to flask and extract was collected in a crucible. Total oleoresin content was expressed in percentage.

Percentage of oleoresin (v/w) = (Volume of extract(ml)/ Weight of sample (g)) x 100

3.1.7.5 Total phenol

Total phenol estimation was carried out as per the method suggested by Sadasivam and Manickam (2008). 0.5 to 1 gram of sample was grinded using mortar

and pestle in a 10 time volume of 80% ethanol. Then it was strained and centrifuged at 15,000 rpm for 20 min. Supernatant was taken. Re-extract the residue with 5 time volume of 80% ethanol. It was centrifuged and supernatant taken. Supernatant was evaporated until dryness. Then the residue was dissolved in a known volume of distilled water. Then different aliquots (0.2 to 2 ml) were pipetted out into test tubes. Each test tube was made upto 3 ml with water. Then 0.5 ml of Folin- Ciocalteau reagent was added. After 3 min, 2 ml of 20 % Na_2CO_3 solution were added to each tube. After mixing well, tubes were placed in boiling water for one min and absorbance was measured at 650 nm.

3.1.8 Statistical analysis

3.1.8.1 Analysis of Variance

Per replication mean value of each treatment is used for analysis of variance (Panse and Sukhatme, 1967).

Sources of variation	Degree of freedom	Sum of squares	Mean squares	F ratio
Replications	t-1	SSR	MSR	MSR/MSE
Treatment	r-1	SST	MST	MST/MSE
Error	(t-1)(r-1)	SSE	MSE	
Total	rt-1			

Where r = number of replications

t = number of treatments

SSR= sum of squares for replication

SST= sum of squares for treatments

SSE= sum of squares for error

Critical Difference, $CD = t_{\alpha}\sqrt{\frac{2MSE}{r}}$

Where t_{α} students't table value distribution at error degrees of freedom with level of significance α (5% or 1%).

3.1.8.2 Estimation of genetic parameters

a. Genetic components of variance

The phenotypic and genotypic variances were calculated using the respective mean square values (Johnson *et al.*, 1955).

i. Genotypic variance, $V_G = \frac{MST - MSE}{r}$

ii. Environmental variance, $V_E = MSE$

iii. Phenotypic variance, $V_P = V_G + V_E$

b. Coefficient of variation

Genotypic, Phenotypic and Environmental Coefficient of Variation were estimated from V_P, V_G and V_E, expressed in percentage for each trait.

i. Genotypic coefficient of variation, $GCV = \frac{\sqrt{VG}}{X} \times 100$

ii. Phenotypic coefficient of variation, $PCV = \frac{\sqrt{VP}}{X} \times 100$

iii. Environmental coefficient of variation, $GCV = \frac{\sqrt{VE}}{X} \times 100$

Where, X= Grand mean

Sivasubrahmanian and Menon (1973) reported following categories for the range of variation.

High: >20 percent

Medium: 10-20 percent

Low: <10 percent

d. Broad sense heritability

Heritability is the ratio of genotypic variance to the total observed variance in the population and expressed in percentage.

$$H^2=\frac{VG}{VP}\times 100$$

Range of Heritability estimation (Johnson *et al.*, 1955)

High: >60 percent

Medium: 30-60 percent

Low: <30 percent

e. Genetic advance

Genetic advance is estimated using Burton formula (1952).

$$GA= KH^2\sqrt{VP}$$

Where K= selection differential

e. Genetic Advance as Percent of Mean

$$GAM =\frac{GA}{X}\times 100$$

GA= Genetic Advance

X= Grand Mean

Ranges of genetic advance by Johnson *et al.* (1955).

High= >20 percent

Medium= 10-20 percent

Low= 10 percent

f. Path analysis

It is a standardized partial regression coefficient which separates the correlation coefficients into direct and indirect effects (Dewey and Lu, 1959).

$$r_{1y} = P_{1y}r_{11}+P_{2y}r_{12}+P_{3y}r_{13}.....+P_{ny}r_{1n}$$

$r_{2y} = P_{2y}r_{21}+P_{2y}r_{22}+P_{3y}r_{23}.....+P_{ny}r_{2n}$

$r_{ny} = P_{1y}r_{n1}+P_{2y}r_{n2}+P_{3y}r_{n3}.....+P_{ny}r_{nn}$

Where,

1,2.....n =independent variables

y = dependent variable

$r_{1y}, r_{2y}.....r_{ny}$ =coefficient of correlation between independent variables 1 to n on dependent variable y.

$P_{1y}, P_{2y}.....P_{ny}$ =direct effect of character 1 to n on character y.

The above equation can be written in matrix form

$$\begin{bmatrix} r_{1y} \\ r_{2y} \\ . \\ . \\ . \\ r_{ny} \end{bmatrix} \quad \begin{bmatrix} 1 & r_{12} & r_{13} & . & . & r_{1n} \\ r_{21} & 1 & r_{23} & . & . & r_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ r_{n1} & r_{n2} & r_{n3} & . & . & 1 \end{bmatrix} \quad \begin{bmatrix} P_{1y} \\ P_{2y} \\ . \\ . \\ . \\ P_{ny} \end{bmatrix}$$

Then $B=C^{-1}A$ where $C^{-1}=\begin{bmatrix} C_{11} & C_{12} & C_{13} & . & . & C_{1n} \\ C_{21} & C_{22} & C_{23} & . & . & C_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ C_{n1} & C_{n2} & C_{n3} & . & . & C_{nn} \end{bmatrix}$

Direct effects:

$P_{1y}= \sum_{i=1}^{k} c_{1i}\, r_{iy}$

$P_{2y} = \sum_{i=1}^{k} c_{2i} r_{iy}$

$P_{ny} = \sum_{i=1}^{k} c_{ni} r_{iy}$

Residual effect $PR_y= \sqrt{1-r^2}$

Where, $r^2 = (P_{1y}r_{1y} + P_{2y}r_{2y} + P_{3y}r_{3y} \dots\dots\dots\dots\dots\dots\dots\dots + P_{ny}r_{ny})$

P_{iy} = direct effect of X_i on y

r_{iy} = correlation coefficient of X_i on y

i = 1,2,3.....n

3.2 SCREENING OF GINGER GENOTYPES AGAINST RHIZOME ROT UNDER NATURAL CONDITION

3.2.1 Source of ginger and *Pythium* culture

Rhizomes of genotypes were treated with mancozeb (0.3%) and malathion (0.1%) and shade dried. *Pythium aphanidermatum* culture was grown in potato dextrose broth.

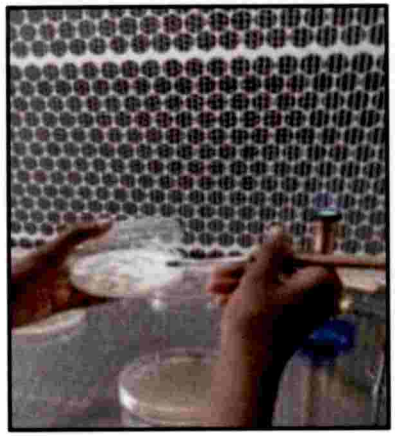
3.2.2 Pathogenicity test

Healthy rhizomes were planted in plastic pots containing sterilized potting media (coirpith and FYM in the ratio 3:1). The plants were maintained at ordinary temperature and day length. The plants were inoculated with 20 ml of inoculum and irrigated daily (Plate 7).

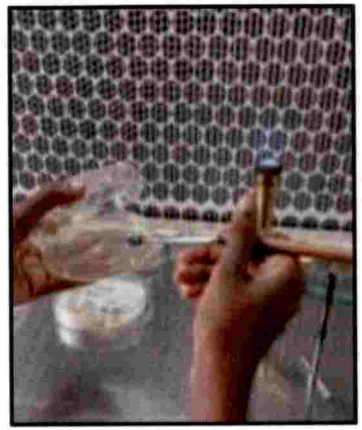
3.2.2.1 Biochemical

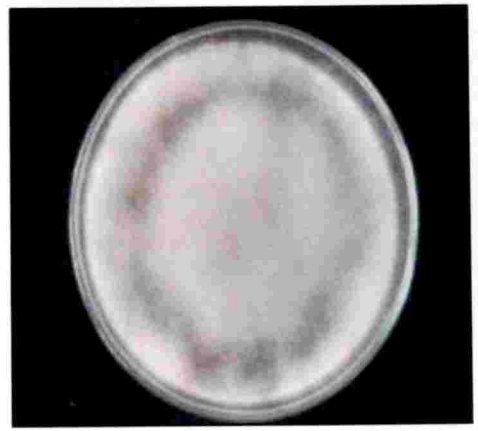
a. Total phenol

Total phenol estimation was carried out as per Sadasivam and Manickam (2008). 0.5 to 1 gram of sample was grinded using mortar and pestle in a 10 time volume of 80% ethanol. Then it was strained and centrifuged at 15,000 rpm for 20minutes. Supernatant was taken. Re-extract the residue with 5 time volume of 80% ethanol. It was centrifuged and supernatant taken. Supernatant was evaporated until dryness. Then the residue was dissolved in a known volume of distilled water. Then different aliquots (0.2 to 2 ml) were pipetted out into test tubes. Each test tubes were made upto 3 ml with water. Then 0.5 ml of Folin- Ciocalteau reagent was added. After 3 min, 2 ml of 20 % Na_2CO_3 solution were added to each tube. After mixing well, tubes were placed in boiling water for one min and absorbance was measured at 650 nm.



a. Sub culturing of *Pythium aphanidermatum* culture





b. Full grown *Pythium aphanidermatum* culture

c. Subculturing in PD broth

d. Pythium aphanidermatum culture grown in PD broth

e. Inoculation

Plate 7. Preparation of broth for inoculation of *Pythium aphanidermatum*

b. Peroxidase

Extraction of peroxidase was carried out as per spectrophotometric method (Srivasthava, 1987). At first, ginger leaves were homogenized in 5 ml of 0.1 M sodium phosphate buffer (PH 6.5). Then it was strained using a muslin cloth and centrifuged at 5,000 rpm for 15 min at 4^0C. Supernatant was taken as the enzyme source.

The reaction mixture consists of 1 ml of 0.05 M pyrogallol and 50 µl of enzyme extract. Then the reaction was started after addition of 1 ml of 1% H_2O_2 solution. The initial optical density was noted at 420 nm and then readings were taken at an interval of 30 seconds for 3 min. The enzyme activity was expressed as change in absorbance/minute/gram of fresh weight of tissue.

c. Polyphenol oxidase

Extraction of polyphenyl oxidase was done as per Sadasivam and Manickam (2008). Leaf tissue of ginger was homogenized in 50 mM of tris-HCL buffer, 7.2 pH (2 ml g^{-1} tissue). Then homogenate was strained using muslin cloth and centrifuged at 15,000 rpm for 10 min at 4^0C. Supernatant was used as enzyme extract.

One ml of enzyme extract was added to a mixture containing 0.6 ml of catechol solution (0.01 M) and 5 ml phosphate buffer (0.1 M, pH 6.5). change in the optical density was noted at 490 nm for 30 seconds for 4 min. Enzyme activity was expressed as change in OD at 490 nm per unit time per unit mg protein.

d. Lipoxygenase

Method of Vick and Zimmerman (1976) was used for the extraction of LOX. LOX was extracted from leaf tissues using potassium phosphate buffer (0.05 M, pH 6). The homogenate was centrifuged at 15,000 rpm for 15 min at 4^0C and supernatant was taken for estimation. LOX activity was measured spectrophotometrically using linoleic acid as substrate.100 µl of enzyme extract was added to 2.9 ml of potassium

phosphate buffer. The reaction was initiated by 20 µl of linoleic acid at room temperature. The enzyme activity was measured by conjugated diene absorption of hydroperoxide at 234 nm. It is expressed as mol conjugated diene produced per unit time per mg protein.

e. Phenylalanine ammonia lyase

Method of Dixon *et al.* (1986) was followed for estimation. Ginger leaf tissue were homogenized in 5 ml of 0.1 M sodium borate buffer (pH – 8.8) with a mortar and pestle. The homogenate was filtered and centrifuged at 10,000 rpm for 10 min at 4^0C and the supernatant was used for assay. Reaction mixture consist of 3 ml of 0.1 M sodium borate buffer, 0.2 ml of enzyme extract and 0.1 ml of 12 mM L-phenylalanine. Reaction was stopped by adding 0.2 ml of 5 N HCL. Absorbance was measured at 290 nm. The activity was expressed as amount of cinnamic acid produced per unit time per mg protein.

3.2.2.2 Disease incidence and disease severity

The disease incidence (DI) was calculated using the formula developed by Singh (2001) as follows,

$$\text{Disease incidence (DI)} = \frac{\text{Number of infected plants}}{\text{Total number of plants}} \times 100$$

The disease severity was assessed by determining the percent disease index (PDI) using standard score chart for rhizome rot of ginger (Plate 8). The disease scoring was done based on the method proposed by Kavitha and Thomas (2008).

Score chart to assess the disease severity of Rhizome rot of ginger caused by *Pythium aphanidermatum*

T_1 (Mananthavady) T_2 (Kanchiyar) T_3 (Thalayolaparambu) T_4 (Haripad)

T_5 (Kollam) T_6 (Ambalavayal) T_7 (Kothamangalam) T_8 (Karunagapally)

T_9 (Mannarkad) T_{10} (Kattapana) T_{11} (Kazhakootam) T_{12} (Irinjalakkuda)

T_{13} (Sulthan Bathery) T_{14} (Murickassery) T_{15} (Nedumkandam) T_{16} (Pozhutana)

Plate 8. Inoculated plants expressing symptom

T_{17} (Kalliyur)

T_{18} (Thariyode)

T_{19} (Kottiyoor)

T_{20} (Thalavur)

T_{21} (Karthika)

T_{22} (Rio de Janeiro)

Plate 8. Inoculated plants expressing symptom (Cont.)

Scale	Description
0	No symptom
1	Up to 25% tiller death
3	26-50% tiller death
5	51-75% tiller death
7	> 75% tiller death after 25 days post infection
9	> 75% tiller death within 25 days post infection

Based on the above score chart, disease severity was calculated using the formula,

$$\text{Percent disease index (PDI)} = \frac{\text{Sum of scores}}{\text{N x Maximum score}} \times 100$$

with N being the number of plants inoculated per genotype. (Sousa *et al.*, 1997).

Results

4. RESULTS

The results of the experiment entitled "Variability in ginger (*Zingiber officinale* Rosc.) for yield and resistance to rhizome rot" conducted during 2017-2019 are presented in this chapter.

4.1 OF GINGER GENOTYPES AND ANALYSIS FOR GENETIC VARIABILITY AND YIELD

4.1.1 Germplasm collection and preparation of passport data sheet.

Twenty ginger genotypes were collected locally from different regions of Kerala. The collection was based on information obtained from Krishi Bhavan regarding best farmers cultivating ginger. Details of the selected genotypes like location, village, taluk, district, latitude, longitude and habitat, ethnobotanical information, pest and disease (resistance/susceptibility/tolerance) and special characters were recorded and presented in the table 2. The twenty genotypes were designated as T_1 (Mananthavady), T_2 (Kanchiar), T_3(Thalayolaparambu), T_4 (Haripad), T_5 (Kottarakkara), T_6 (Ambalavayal), T_7 (Kothamangalam, T_8 (Karunagapally), T_9 (Mannarkkad), T_{10} (Kattapana), T_{11} (Kazhakootam), T_{12} (Irinjalakkuda), T_{13} (Sulthan Bathery), T_{14} (Murickassery), T_{15} (Nedumkandam), T_{16} (Pozhuthana), T_{17} (Kalliyur), T_{18} (Kottiyoor), T_{19} (Thariyode) and T_{20} (Thalavur). Ginger genotypes were collected from farmer's field both in plains and high altitude areas of Kerala.

4.1.2 Qualitative characterization of selected ginger genotypes

Qualitative characterization of collected ginger genotypes and control variety 'Aswathy' were carried out using distinctiveness, uniformity and stability (DUS) guidelines by protection of plant varieties and farmer's rights authority. The qualitative characters observed in the selected ginger genotypes include plant, shoot, leaf, inflorescence and rhizome characters.

Table 2a. Passport data of the collected ginger genotypes

Genotype	Location	Village, Taluk, District	Latitude	Longitude	Altitude
T_1 (Mananthavady)	Mananthavady	Mananthavady Wayanad	11°48'0''N	76°0'E	760m
T_2 (Kanchiar)	Kanchiar	Kanchiar Idukki	9°41'45''N	76°59'47''E	850m
T_3(Thalayolaparambu)	Thalayolaparambu	Thalayolaparambu Kottayam	9°78'0''N	76°44'E	24m
T_4 (Haripad)	Haripad	Haripad Alappuzha	9°18' 0''N	76°28'0''E	10m
T_5 (Kottarakkara)	Kottarakkara	Kottarakkara Kollam	8°59'0''N	76°46'00''E	41m
T_6 (Ambalavayal)	Ambalavayal	Ambalavayal Wayanad	11°61'9''N	76°21'01''E	974m
T_7 (Kothamangalam)	Kothamangalam	Kothamangalam Ernakulam	10°4'48''N	76°37'12''E	34m
T_8(Karunagapally)	Karunagapally	Karunagapally Kollam	9°30'16''N	76°32'70'' E	14m
T_9(Mannarkkad)	Mannarkkad	Mannarkkad, Palakkad	11°0'0''N	77°0'0''E	76m
T_{10}(Kattapana)	Kattapana	Kattapana Idukki	9°84'30''N	77°15'1''E	900m
T_{11}(Kazhakootam)	Kazhakootam	Kazhakootam, Trivandrum	8°33'56''N	76°52'29'' E	11m
T_{12}(Irinjalakkuda)	Irinjalakkuda	Irinjalakkuda, Thrissur	10°30'0''N	76°15'25'' E	39m

Table 2a (Cont.)

Genotype	Location	Village, Taluk, District	Latitude	Longitude	Altitude
T_{13} (Sulthan Bathery)	Sulthan Bathery	Sulthan Bathery, Wayanad	11°0'0''N	76°0'0''E	901m
T_{14} (Murickassery)	Murickassery	Murickassery, Kottayam	9°57'20''N	77°10'0''E	28m
T_{15} (Nedumkandam)	Nedumkandam	Udumbanchola, Idukki	9°84'30''N	77°15'19''E	975m
T_{16} (Pozhuthana)	Pozhuthana	Pozhuthana, Wayanad	11°41'49''N	76°03'21''E	700m
T_{17} (Kalliyur)	Kalliyur	Kalliyur, Trivandrum	8°25'0''N	77°0'0''E	28m
T_{18} (Kottiyoor)	Kottiyoor	Kottiyoor, Kannur	11°52'35''N	75°51'15''E	11m
T_{19} (Thariyode)	Thariyode	Thariyode, Wayanad	11°41'49''N	76°11'09''E	52m
T_{20} (Thalavur)	Thalavur	Thalavur, Kollam	9°2'40''N	76°49'46''E	41m

Table 2b. Passport data of the collected ginger genotypes

Genotype	Habitat	Ethnobotanical information	Pest and disease (Resistance/ susceptible/tolerance)	Special characters if any
T_1 (Mananthavady)	Cultivated	Used for culinary purposes	Susceptible to Stem borer, Rhizome rot	for dry ginger purpose.
T_2 (Kanchiar)	Cultivated	Used for culinary purposes	Susceptible to Stem borer, Rhizome rot	
T_3 (Thalayolaparambu)	Cultivated	Used for culinary purposes	Susceptible to Rhizome maggot, Rhizome rot	
T_4 (Haripad)	Cultivated	Used for culinary purposes	Susceptible to Bacterial wilt, Rhizome rot	
T_5 (Kottarakkara)	Cultivated	Used for culinary purposes	Susceptible to Rhizome rot	
T_6 (Ambalavayal)	Cultivated	Used for culinary purposes	Susceptible to Rhizome rot	Suited for making "chukku"
T_7 (Kothamangalam)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	
T_8 (Karunagapally)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	
T_9 (Mannarkkad)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	
T_{10} (Kattapana)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	
T_{11} (Kazhakootam)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	Bold rhizome

Table 2b (Cont.)

Genotype	Habitat	Ethnobotanical information	Pest and disease (Resistance/ susceptible/tolerance)	Special characters if any
T_{12} (Irinjalakkuda)	Cultivated	Used for culinary purposes	Tolerant to Rhizome rot	More pungent ginger
T_{13} (Sulthan Bathery)	Cultivated	Used for culinary purposes,	Tolerant to Rhizome rot	for dry ginger purpose
T_{14} (Murickassery)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	
T_{15} (Nedumkandam)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	Appealing yellow rhizome flesh colour
T_{16} (Pozhuthana)	Cultivated	Used for culinary purposes	Susceptible to wilt, rhizome rot	
T_{17} (Kalliyur)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	
T_{18} (Kottiyoor)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	
T_{19} (Thariyode)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	
T_{20} (Thalavur)	Cultivated	Used for culinary purposes	Susceptible to rhizome rot	

4.1.2.1 Plant characters

4.1.2.1.1 Plant growth habit

Expressions of plant growth habit are presented in table 3. The growth habit of collected genotypes included erect and semi erect types. However, spreading type was not observed among the collected genotypes. Among the genotypes, majority of the genotypes were of erect types (90 %) followed by semi erect types (10 %). T_3 (Thalayolaparambu) and T_{17} (Kalliyur) were semi erect types while all other genotypes were erect types.

4.1.2.1.2 Plant height

Expressions of plant height of twenty genotypes collected are presented in table 3. Based on plant height, ginger genotypes can be divided into three categories. They are short, medium and tall types. All genotypes belonged to short type, which have a plant height less than 100 cm.

4.1.2.2 Shoot characters

4.1.2.2.1 Number of shoots

Expressions of number of shoot are presented in table 4. Few (<10) and medium (10-15) number of shoots were observed in the selected ginger genotypes. Few shoots (86 %) were common, followed by medium shoots (14 %) as found in T_1 (Mananthavady), T_{11} (Kazhakootam), and T_{12} (Irinjalakkuda).

4.1.2.2.2 Height of shoot

Expressions of height of shoot are presented in table 4. All genotypes possessed short (<75cm) shoot height.

4.1.2.2.3 Shoot diameter

Expressions of shoot diameter are presented in table 4. Majority of the genotypes possessed narrow (< 3 cm) shoot diameter (86 %), followed by medium (3-

Table 3. Qualitative characterization of the selected ginger genotypes for plant characters based on DUS guidelines

Genotype	Plant growth habit	Plant height
T_1 (Mananthavady)	Erect	Short
T_2 (Kanchiar)	Erect	Short
T_3 (Thalayolaparambu)	Semi erect	Short
T_4 (Haripad)	Erect	Short
T_5 (Kottarakkara)	Erect	Short
T_6 (Ambalavayal)	Erect	Short
T_7 (Kothamangalam)	Erect	Short
T_8 (Karunagapally)	Erect	Short
T_9 (Mannarkkad)	Erect	Short
T_{10} (Kattapana)	Erect	Short
T_{11}(Kazhakootam)	Erect	Short
T_{12}(Irinjalakkuda)	Erect	Short
T_{13}(Sulthan Bathery)	Erect	Short
T_{14}(Murickassery)	Erect	Short
T_{15}(Nedumkandam)	Erect	Short
T_{16}(Pozhuthana)	Erect	Short
T_{17}(Kalliyur)	Semi erect	Short
T_{18}(Kottiyoor)	Erect	Short
T_{19}(Thariyode)	Erect	Short
T_{20}(Thalavur)	Erect	Short
T_{21} (Control)	Erect	Short

Table 4. Qualitative characterization of the selected ginger genotypes for shoot characters based on DUS guidelines

Genotype	Number of shoots	Height of shoot	Shoot diameter	Shoot intensity of green colour
T_1 (Mananthavady)	Medium	Short	Narrow	134B Green
T_2 (Kanchiar)	Few	Short	Narrow	135B Dark green
T_3 (Thalayolaparambu)	Few	Short	Narrow	134B Green
T_4 (Haripad)	Few	Short	Narrow	135C Green
T_5 (Kottarakkara)	Few	Short	Narrow	135C Green
T_6 (Ambalavayal)	Few	Short	Narrow	135C Green
T_7 (Kothamangalam)	Few	Short	Narrow	135C Green
T_8 (Karunagapally)	Few	Short	Narrow	134B Green
T_9 (Mannarkkad)	Few	Short	Medium	135C Green
T_{10} (Kattapana)	Few	Short	Narrow	135C Green
T_{11}(Kazhakootam)	Medium	Short	Medium	134B Green
T_{12}(Irinjalakkuda)	Medium	Short	Medium	134B Green
T_{13}(Sulthan Bathery)	Few	Short	Narrow	134B Green
T_{14}(Murickassery)	Few	Short	Narrow	135C Green
T_{15}(Nedumkandam)	Few	Short	Narrow	134B Green
T_{16}(Pozhuthana)	Few	Short	Narrow	135C Green
T_{17}(Kalliyur)	Few	Short	Narrow	134B Green
T_{18}(Kottiyoor)	Few	Short	Narrow	135B Dark green
T_{19}(Thariyode)	Few	Short	Narrow	135C Green
T_{20}(Thalavur)	Few	Short	Narrow	134B Green
T_{21} (Control)	Few	Short	Narrow	135C Green

5 cm) shoot diameter (14 %). Medium shoot diameter were found in T_9 (Mannarkkad), T_{11} (Kazhakootam) and T_{12} (Irinjalakkuda).

4.1.2.2.4 Shoot intensity of green colour

Expressions of shoot intensity of green colour are presented in table 4. The shoot intensity of green colour among the selected ginger genotypes were green and dark green. Among the 20 genotypes and control evaluated, 90.5 per cent were green and rest were dark green. Based on RHS colour chart the shoot intensity colour belonged to 134 B, 135 B and 135 C.

4.1.2.3 Leaf characters

4.1.2.3.1 Leaf length

Expressions of leaf length are presented in table 5. All the twenty selected ginger genotypes and control possessed short (<25 cm) leaf length.

4.1.2.3.2 Leaf width

Expressions of leaf width are presented in table 5. All the selected ginger genotypes possessed medium (2.5cm – 3.5 cm) leaf width.

4.1.2.3.3 Leaf intensity of green colour

Expressions of leaf intensity of green colour are presented in table 5. The leaf intensity of green colour were light green, green and dark green. Among the selected 20 genotypes and control evaluated, 33 per cent were light green, followed by green (57 %), dark green (10 %).

4.1.2.3.4 Leaf petiole length

Expressions of leaf petiole length are presented in table 5. Majority of the genotypes possessed short (95 %) petiole length, followed by medium petiole length (5%) in T_{17} (Kalliyur).

Table 5. Qualitative characterization of the selected ginger genotypes for leaf characters based on DUS guidelines

Genotype	Leaf length	Leaf width	Leaf intensity of green colour	Leaf petiole length
T_1 (Mananthavady)	Short	Medium	128A light green	Short
T_2 (Kanchiar)	Short	Medium	134B green	Short
T_3 (Thalayolaparambu)	Short	Medium	135C green	Short
T_4 (Haripad)	Short	Medium	135C green	Short
T_5 (Kottarakkara)	Short	Medium	141C light green	Short
T_6 (Ambalavayal)	Short	Medium	141B green	Short
T_7 (Kothamangalam)	Short	Medium	141B green	Short
T_8 (Karunagapally)	Short	Medium	141A green	Short
T_9 (Mannarkkad)	Short	Medium	141A green	Short
T_{10} (Kattapana)	Short	Medium	141B green	Short
T_{11}(Kazhakootam)	Short	Medium	140D light green	Short
T_{12}(Irinjalakkuda)	Short	Medium	135C green	Short
T_{13}(Sulthan Bathery)	Short	Medium	135C green	Short
T_{14}(Murickassery)	Short	Medium	134B light green	Short
T_{15}(Nedumkandam)	Short	Medium	135C green	Short
T_{16}(Pozhuthana)	Short	Medium	134B light green	Short
T_{17}(Kalliyur)	Short	Medium	134B dark green	Medium
T_{18}(Kottiyoor)	Short	Medium	135C green	Short
T_{19}(Thariyode)	Short	Medium	134B light green	Short
T_{20}(Thalavur)	Short	Medium	134A light green	Short
T_{21} (Control)	Short	Medium	135B dark green	Short

4.1.2.4 Inflorescence characters

4.1.2.4.5 Spike length

Expressions of spike length are presented in table 6. Among the selected ginger genotypes, spike was formed only in three genotypes T_5 (Kottarakkara), T_{13} (Sulthan bathery) and T_{16} (Pozhuthana). Spike length was short in the above genotypes.

4.1.2.4.6 Colour of bract of fully developed spike

Expressions of colour of bract of fully developed spike are presented in table 6. Among the three genotypes, T_{16} (Pozhuthana) had yellowish white bract tip and T_5, (Kottarakkara), T_{13} (Sulthan Bathery) had crimson bract tip.

4.1.2.5 Rhizome characters

4.1.2.5.1 Rhizome thickness

Expressions of colour of rhizome thickness are presented in table 7. Rhizome thickness was found to be thin (<2cm) for all the genotypes except for T_{11} (Kazhakootam) which had medium (2-3 cm) thickness.

4.1.2.5.2 Rhizome shape

Expressions of rhizome shape are presented in table 7. Rhizome shape observed in the selected ginger genotypes included straight, curved and zig-zagged types. Majority of the genotypes possessed straight shape (52 %), followed by curved (29 %) and zig – zagged shapes (19 %).

4.1.2.5.3 Rhizome skin colour

Expressions of colour of rhizome skin are presented in table 7. Rhizome skin colour observed in the selected ginger genotypes were greyish yellow and yellowish white. Greyish yellow colour was predominant among the genotypes (95 %) followed by yellowish white colour (5 %) in T_8 (Karunagapally).

Table 6. Qualitative characterization of the selected ginger genotypes for inflorescence characters based on DUS guidelines

Genotype	Spike length	Colour of bract tip of fully developed spike
T_1 (Mananthavady)	Spike not formed	–
T_2 (Kanchiar)	Spike not formed	–
T_3 (Thalayolaparambu)	Spike not formed	–
T_4 (Haripad)	Spike not formed	–
T_5 (Kottarakkara)	Short	Crimson
T_6 (Ambalavayal)	Spike not formed	–
T_7 (Kothamangalam)	Spike not formed	–
T_8 (Karunagapally)	Spike not formed	–
T_9 (Mannarkkad)	Spike not formed	–
T_{10} (Kattapana)	Spike not formed	–
T_{11}(Kazhakootam)	Spike not formed	–
T_{12}(Irinjalakkuda)	Spike not formed	–
T_{13}(Sulthan Bathery)	Short	Crimson
T_{14}(Murickassery)	Spike not formed	–
T_{15}(Nedumkandam)	Spike not formed	–
T_{16}(Pozhuthana)	Short	yellowish white tip
T_{17}(Kalliyur)	Spike not formed	–
T_{18}(Kottiyoor)	Spike not formed	–
T_{19}(Thariyode)	Spike not formed	–
T_{20}(Thalavur)	Spike not formed	–
T_{21} (Control)	Spike not formed	–

Table 7. Qualitative characterization of the selected ginger genotypes for rhizome characters based on DUS guidelines.

Genotype	Rhizome thickness	Rhizome shape	Rhizome skin colour	Rhizome flesh colour
T_1 (Mananthavady)	Thin	Straight	148C greyish yellow	151B Light yellowish grey
T_2 (Kanchiar)	Thin	Curved	146C greyish yellow	153D Greyish yellow
T_3 (Thalayolaparambu)	Thin	Zig-zagged	146C greyish yellow	151A Greyish yellow
T_4 (Haripad)	Thin	Straight	146D greyish yellow	153C Greyish yellow
T_5 (Kottarakkara)	Thin	Straight	152B greyish yellow	151C Yellow
T_6 (Ambalavayal)	Thin	Straight	148B greyish yellow	151A Greyish yellow
T_7 (Kothamangalam)	Thin	Zig-zagged	152B greyish yellow	151AGreyish yellow
T_8 (Karunagapally)	Thin	Straight	148C yellowish white	151A Greyish yellow
T_9 (Mannarkkad)	Thin	Straight	152D greyish yellow	152D Greyish yellow
T_{10} (Kattapana)	Thin	Curved	152B greyish yellow	151A Greyish yellow
T_{11}(Kazhakootam)	Medium	Straight	152D greyish yellow	151B Light yellowish grey
T_{12}(Irinjalakkuda)	Thin	Straight	152B greyish yellow	153A Greyish yellow
T_{13}(Sulthan Bathery)	Thin	Zig-zagged	152C greyish yellow	151B Light yellowish grey
T_{14}(Murickassery)	Thin	Straight	152D greyish yellow	153D Greyish yellow
T_{15}(Nedumkandam)	Thin	Zig-zagged	152D greyish yellow	151C yellow
T_{16}(Pozhuthana)	Thin	Curved	153D greyish yellow	151B Light yellowish grey
T_{17}(Kalliyur)	Thin	Straight	152D greyish yellow	153D Greyish yellow
T_{18}(Kottiyoor)	Thin	Curved	152C greyish yellow	151C yellow
T_{19}(Thariyode)	Thin	Straight	152D greyish yellow	153A Greyish yellow
T_{20}(Thalavur)	Thin	Curved	152D greyish yellow	151A Greyish yellow
T_{21} (Control)	Thin	Curved	152B greyish yellow	153D Greyish yellow

4.1.2.5.4 Rhizome flesh colour

Expressions of colour of rhizome flesh are presented in table 7. Rhizome flesh colour observed in the selected ginger genotypes included light yellowish grey, greyish yellow and yellow. Majority of the genotypes possessed greyish yellow flesh colour (67 %), followed by light yellowish grey (19 %) and yellow (14 %).

4.1.3 Quantitative characterization of selected ginger genotypes

4.1.3.1 Days to sprouting

Days taken for sprouting ranged from 7 to 20 days after planting. T_5 (Kottarakkara) recorded early sprouting of 7 days while T_1 (Mananthavady), T_3 (Thalayolaparambu), T_8 (Karunagapally), T_{11} (Kazhakootam), T_{12} (Irinjalakkuda), T_{14} (Murickassery), T_{17} (Kalliyur) and T_{21} (Control variety Aswathy) took 8 days. Thariyode (T_{19}) reported late sprouting of 20 days.

4.1.3.1 Plant characters

4.1.3.1.1 Plant height

The mean plant height of selected ginger genotypes at different crop periods are shown in table 9. Significant variation in plant height was observed in the selected ginger genotypes during 3, 5 and 7 MAP. T_{12} (Irinjalakkuda) recorded the highest plant height during all growth periods. At 3 MAP, T_{12} (Irinjalakkuda) was found to be on par with T_8 (Karunagapally). T_{12} and T_8 recorded a plant height of 54.53 cm and 54.10 cm respectively at 3 MAP.

T_{12} (Irinjalakkuda) recorded a plant height of 66.30 cm at 5 MAP, followed by T_2 (Kanchiar), T_{15} (Nedumkandam) with a plant height of 63.28 cm. T_{12} (Irinjalakkuda) recorded a plant height of 68.75 cm at 7 MAP. This was followed by T_{15} (Nedumkandam) which was on par with T_{11} (Kazhakootam) at 7 MAP.

Table 8. Days to sprouting of the selected ginger genotypes

Genotype	Days to sprouting
T_1 (Mananthavady)	8
T_2 (Kanchiar)	10
T_3 (Thalayolaparambu)	8
T_4 (Haripad)	14
T_5 (Kottarakkara)	7
T_6 (Ambalavayal)	10
T_7 (Kothamangalam)	13
T_8 (Karunagapally)	8
T_9 (Mannarkkad)	14
T_{10} (Kattapana)	9
T_{11}(Kazhakootam)	8
T_{12}(Irinjalakkuda)	8
T_{13}(Sulthan Bathery)	12
T_{14}(Murickassery)	8
T_{15}(Nedumkandam)	10
T_{16}(Pozhuthana)	12
T_{17}(Kalliyur)	8
T_{18}(Kottiyoor)	14
T_{19}(Thariyode)	20
T_{20}(Thalavur)	12
T_{21} (Control)	8

Table 9. Plant height of the selected genotypes of ginger

Genotype	Plant height (cm)		
	3MAP	5MAP	7MAP
T_1 (Mananthavady)	49.20	56.65	60.54
T_2 (Kanchiar)	51.65	63.45	61.80
T_3 (Thalayolaparambu)	43.65	56.75	58.80
T_4 (Haripad)	44.15	61.40	63.65
T_5 (Kottarakkara)	45.45	59.10	61.91
T_6 (Ambalavayal)	34.00	48.85	53.44
T_7 (Kothamangalam)	44.65	54.30	57.00
T_8 (Karunagapally)	54.10	61.30	63.43
T_9 (Mannarkkad)	43.78	59.80	60.25
T_{10} (Kattapana)	34.53	47.75	51.92
T_{11}(Kazhakootam)	53.18	60.95	63.74
T_{12}(Irinjalakkuda)	54.53	66.30	68.75
T_{13}(Sulthan Bathery)	44.05	55.30	57.22
T_{14}(Murickassery)	44.50	55.85	57.57
T_{15}(Nedumkandam)	45.38	63.28	64.56
T_{16}(Pozhuthana)	43.60	59.25	60.35
T_{17}(Kalliyur)	34.30	52.95	54.56
T_{18}(Kottiyoor)	46.63	62.05	63.07
T_{19}(Thariyode)	53.00	61.20	58.00
T_{20}(Thalavur)	43.70	52.60	54.37
T_{21} (Control)	44.30	58.08	61.60
SE (m) $\pm$	0.457	0.379	0.301
CD (0.05)	1.296	1.074	0.854

4.1.3.1.2 Number of tillers

The mean number of tillers of selected ginger genotypes at different crop periods is presented in table 10. At 3 MAP, T_1 (Mananthavady) and T_{13} (Sulthan Bathery) recorded the highest number of tillers, which was on par T_3 (Thalayolaparambu), T_9 (Mannarkkad), T_2 (Kanchiar) and T_8 (Karunagapally). In 5th month, highest number of tillers was observed in T_1 (Mananthavady) which was on par with T_{11} (Kazhakoottam), T_{12} (Irinjalakkuda), T_9 (Mannarkkad) and T_{13} (Sulthan Bathery). T_{11} (Kazhakootam) recorded highest number of tillers (11.50) at 7 MAP.

4.1.3.1.3 Dry matter production

The mean dry matter production of selected ginger genotypes at 7 MAP are presented in table 11. Significant variation was observed in dry matter production among the selected ginger genotypes. T_{11} (Kazhakootam) recorded the highest dry matter production (5160.84 kg/ha), which was on par with T_6 (Ambalavayal), T_{15} (Nedumkandam) and T_9 (Mannarkkad). Significant variation in dry matter production was noticed between control and genotypes. The dry matter production recorded by the control was 4705.83 kg/ha.

4.1.3.2 ***Leaf characters***

4.1.3.2.1 Leaf length

The mean leaf length of selected ginger genotypes at different growth stages are presented in table 12. Significant variation was observed in leaf length among the selected ginger genotypes. Highest leaf length was observed in T_{12} (Irinjalakkuda) during 3rd, 5th and 7th month. At 3 MAP, it had a leaf length of 17.36 cm and was on par with T_{11} (Kazhakootam), T_7 (Kothamangalam), T_2 (Kanchiar) and T_{10} (Kattapana). At 5 MAP, T_{12} (Irinjalakkuda) recorded a leaf length of 23.35 cm. This was followed by T_{17} (Kalliyur), T_7 (Kothamangalam), T_{10} (Kattapana), T_8 (Karunagapally) and T_9 (Mannarkkad) which were on par with each other. At 7 MAP, T_{12} (Irinjalakkuda) had a significantly superior leaf length of 23.75 cm.

Table 10. Number of tillers of the selected genotypes of ginger

Genotype	Number of tillers		
	3MAP	5MAP	7MAP
T_1 (Mananthavady)	6.25	10.4	10.59
T_2 (Kanchiar)	5.53	9.25	10.05
T_3 (Thalayolaparambu)	6	9.85	10.10
T_4 (Haripad)	5.25	8.3	9.56
T_5 (Kottarakkara)	5	9.5	10.10
T_6 (Ambalavayal)	4.5	8.4	9.10
T_7 (Kothamangalam)	4.25	7.85	9.10
T_8 (Karunagapally)	5.52	8.1	8.65
T_9 (Mannarkkad)	5.75	9.95	10.52
T_{10} (Kattapana)	4.25	8.35	9.05
T_{11} (Kazhakootam)	5.25	10.1	11.50
T_{12} (Irinjalakkuda)	5.5	10	10.40
T_{13} (Sulthan Bathery)	6.25	9.8	9.85
T_{14} (Murickassery)	5	9.2	9.55
T_{15} (Nedumkandam)	4.5	8.5	10.35
T_{16} (Pozhuthana)	5.5	8.51	10.21
T_{17} (Kalliyur)	5.25	8.52	9.45
T_{18} (Kottiyoor)	4.49	8.59	9.10
T_{19} (Thariyode)	4.5	8.65	9.15
T_{20} (Thalavur)	4.51	8.6	9.45
T_{21} (Control)	4.5	9.4	9.95
SE (m) $\pm$	0.297	0.235	0.218
CD (0.05)	0.843	0.666	0.6170

Table 11. Dry matter production of the selected genotypes of ginger

Genotype	Dry matter production (g plant^{-1})	Dry matter production (kg ha^{-1})
T_1 (Mananthavady)	38.75	4,495.29
T_2 (Kanchiar)	33.74	3,913.55
T_3 (Thalayolaparambu)	35.97	4,172.52
T_4 (Haripad)	38.35	4,448.60
T_5 (Kottarakkara)	40.40	4,686.98
T_6 (Ambalavayal)	43.89	5,091.24
T_7 (Kothamangalam)	35.34	4,099.15
T_8 (Karunagapally)	40.16	4,658.85
T_9 (Mannarkkad)	43.56	5,052.38
T_{10} (Kattapana)	36.97	4,288.52
T_{11}(Kazhakootam)	44.49	5,160.84
T_{12}(Irinjalakkuda)	40.76	4,728.45
T_{13}(Sulthan Bathery)	39.97	4,636.20
T_{14}(Murickassery)	41.19	4,778.91
T_{15}(Nedumkandam)	43.56	5,052.96
T_{16}(Pozhuthana)	34.57	4,010.41
T_{17}(Kalliyur)	37.23	4,318.68
T_{18}(Kottiyoor)	40.69	4,719.75
T_{19}(Thariyode)	34.29	3,977.93
T_{20}(Thalavur)	38.68	4,487.17
T_{21} (Control)	40.57	4,705.83
SE (m) $\pm$	0.491	56.892
CD (0.05)	1.392	161.342

Table 12. Leaf length of the selected genotypes of ginger

Genotype	Leaf length (cm)		
	3MAP	5MAP	7MAP
T_1 (Mananthavady)	16.11	20.33	21.43
T_2 (Kanchiar)	17.03	20.50	22.15
T_3 (Thalayolaparambu)	15.92	20.38	21.51
T_4 (Haripad)	14.63	19.70	20.87
T_5 (Kottarakkara)	16.09	20.25	21.23
T_6 (Ambalavayal)	16.25	20.33	21.77
T_7 (Kothamangalam)	17.27	21.73	21.89
T_8 (Karunagapally)	16.67	21.23	21.52
T_9 (Mannarkkad)	16.29	21.13	21.67
T_{10} (Kattapana)	16.90	21.50	21.71
T_{11}(Kazhakootam)	17.27	20.68	21.84
T_{12}(Irinjalakkuda)	17.36	23.35	23.75
T_{13}(Sulthan Bathery)	15.56	19.55	20.49
T_{14}(Murickassery)	16.11	20.53	21.28
T_{15}(Nedumkandam)	16.09	20.60	21.58
T_{16}(Pozhuthana)	16.38	19.88	21.23
T_{17}(Kalliyur)	16.52	21.85	22.01
T_{18}(Kottiyoor)	16.55	20.70	21.84
T_{19}(Thariyode)	16.36	20.77	21.11
T_{20}(Thalavur)	15.89	19.60	20.27
T_{21} (Control)	16.23	20.18	20.85
SE (m) $\pm$	0.188	0.257	0.141
CD (0.05)	0.532	0.729	0.400

4.1.3.2.2 Leaf breadth

The mean leaf breadth of selected ginger genotypes at different growth stages are shown in table 13. Significant variation was observed in leaf breadth among the selected ginger genotypes. At 3 MAP, T_2 (Kanchiar) recorded the highest leaf breadth which was followed by T_6 (Ambalavayal) and were on par withT_{12} (Irinjalakkuda) and T_3 (Thalayolaparambu). At 5 MAP, T_6 (Ambalavayal) had the highest leaf breadth which was on par with with T_{12} (Irinjalakkuda), T_{13} (Sulthan bathery), T_{14} (Murickassery), T_{15} (Nedumkandam) and T_{16} (Pozhuthana). At 7 MAP, T_6 (Ambalavayal) recorded highest leaf breadth which was on par with T_2 (Kanchiar) and T_1 (Mananthavady).

4.1.3.2.3 Leaf area

The mean leaf area of selected ginger genotypes at different growth stages are presented in table 14. Significant variation in leaf area was observed among the genotypes at 3, 5 and 7 MAP. The highest leaf area (29.08 cm^2) was observed in T_2 (Kanchiar) which was on par with T_{12} (Irinjalakkuda) at 3 MAP. At 5 MAP, T_{12} (Irinjalakkuda) observed significantly higher leaf area (46.44 cm^2). At 7 MAP, the highest leaf area was observed in T_8 (Karunagapally), which was on par with T_{12} (Irinjalakkuda).

4.1.3.3 Rhizome characters

4.1.3.3.1 Rhizome spread

The mean rhizome spread of selected ginger genotypes at harvest is presented in table 15. A significant variation in rhizome spread was found among the selected ginger genotypes. T_{11} (Kazhakootam) recorded the highest rhizome spread of 13.91 cm at harvest, which was on par with T_{12} (Irinjalakkuda). T_{21} (Control) recorded a rhizome spread of 11.91 cm and genotypes such as T_{11} (Kazhakootam), (Irinjalakkuda), T_2 (Kanchiar), T_3 (Thalayolaparambu), T_4 (Haripad), T_{13} (Sulthan Bathery), T_{14} (Murickassery), T_{15} (Nedumkandam), T_{16} (Pozhuthana), T_{17} (Kalliyur) and T_{20} (Thalavur) recorded higher rhizome spread than the control variety Aswathy.

Table 13. Leaf breadth of the selected genotypes of ginger

Genotype	Leaf breadth (cm)		
	3MAP	5MAP	7MAP
T_1 (Mananthavady)	2.46	2.99	3.08
T_2 (Kanchiar)	2.62	2.97	3.09
T_3 (Thalayolaparambu)	2.50	2.94	3.07
T_4 (Haripad)	2.40	2.94	3.03
T_5 (Kottarakkara)	2.44	2.85	2.92
T_6 (Ambalavayal)	2.55	3.07	3.13
T_7 (Kothamangalam)	2.44	2.94	3.06
T_8 (Karunagapally)	2.45	2.97	3.03
T_9 (Mannarkkad)	2.36	2.94	3.04
T_{10} (Kattapana)	2.39	2.99	3.02
T_{11}(Kazhakootam)	2.39	2.95	3.01
T_{12}(Irinjalakkuda)	2.53	3.02	3.07
T_{13}(Sulthan Bathery)	2.45	3.04	3.06
T_{14}(Murickassery)	2.49	3.00	3.03
T_{15}(Nedumkandam)	2.40	3.02	3.04
T_{16}(Pozhuthana)	2.40	3.00	3.04
T_{17}(Kalliyur)	2.42	2.98	3.00
T_{18}(Kottiyoor)	2.37	2.97	3.04
T_{19}(Thariyode)	2.35	2.98	2.99
T_{20}(Thalavur)	2.34	2.96	2.99
T_{21} (Control)	2.36	2.95	3.01
SE (m) $\pm$	0.016	0.022	0.017
CD (0.05)	0.046	0.062	0.048

Table 14. Leaf area of the selected genotypes of ginger

Genotype	Leaf area (cm^2)		
	3MAP	5MAP	7MAP
T_1 (Mananthavady)	25.76	39.96	43.38
T_2 (Kanchiar)	29.08	40.00	42.89
T_3 (Thalayolaparambu)	25.86	39.27	43.39
T_4 (Haripad)	22.70	38.05	41.49
T_5 (Kottarakkara)	25.56	37.78	40.76
T_6 (Ambalavayal)	26.94	41.09	43.14
T_7 (Kothamangalam)	27.44	41.93	44.01
T_8 (Karunagapally)	26.56	41.47	48.20
T_9 (Mannarkkad)	24.68	40.82	43.33
T_{10} (Kattapana)	26.25	42.35	43.17
T_{11}(Kazhakootam)	26.86	40.08	45.06
T_{12}(Irinjalakkuda)	28.60	46.44	47.96
T_{13}(Sulthan Bathery)	24.72	39.02	41.24
T_{14}(Murickassery)	26.05	40.63	42.41
T_{15}(Nedumkandam)	25.07	40.86	44.84
T_{16}(Pozhuthana)	25.54	39.14	43.25
T_{17}(Kalliyur)	26.00	42.82	42.37
T_{18}(Kottiyoor)	25.48	40.29	43.60
T_{19}(Thariyode)	24.98	40.62	41.58
T_{20}(Thalavur)	24.08	38.03	39.75
T_{21} (Control)	24.89	38.94	41.19
SE (m) ±	0.343	0.667	0.353
CD (0.05)	0.974	1.890	1.001

Table 15. Rhizome characters of the selected genotypes of ginger

Genotype	Rhizome spread (cm)	Rhizome thickness (cm)
T_1 (Mananthavady)	11.49	1.12
T_2 (Kanchiar)	12.79	1.14
T_3 (Thalayolaparambu)	11.98	1.28
T_4 (Haripad)	11.94	1.19
T_5 (Kottarakkara)	10.77	1.15
T_6 (Ambalavayal)	11.19	1.08
T_7 (Kothamangalam)	11.68	1.25
T_8 (Karunagapally)	11.80	1.24
T_9 (Mannarkkad)	11.54	1.10
T_{10} (Kattapana)	11.46	1.14
T_{11}(Kazhakootam)	13.91	2.02
T_{12}(Irinjalakkuda)	13.76	1.17
T_{13}(Sulthan Bathery)	12.03	1.14
T_{14}(Murickassery)	13.13	1.19
T_{15}(Nedumkandam)	13.02	1.30
T_{16}(Pozhuthana)	13.03	1.18
T_{17}(Kalliyur)	12.09	1.09
T_{18}(Kottiyoor)	11.70	1.15
T_{19}(Thariyode)	11.47	1.17
T_{20}(Thalavur)	12.26	1.18
T_{21} (Control)	11.91	1.16
SE (m) $\pm$	0.10	0.01
CD (0.05)	0.29	0.049

4.1.3.3.2 Rhizome thickness

The mean rhizome thickness of selected ginger genotypes at harvest are presented in table 15. Selected genotypes showed a significant variation in rhizome thickness. T_{11} (Kazhakootam) recorded the highest rhizome thickness of 2.02 cm followed by T_{15} (Nedumkandam) which was on par with T_3 (Thalayolaparambu) and T_7 (Kothamangalam)at harvest.

4.1.3.4 Yield characters

4.1.3.4.1 Fresh yield (kg/plant, kg/plot)

The data on mean fresh yield per plant and mean fresh yield per plot of selected genotypes are presented in table 16.

The mean of fresh yield per plant varied from 0.049 to 0.150 kg. The highest fresh yield per plant (0.150 kg) was observed in T_{11} (Kazhakootam), followed by T_{15} (Nedumkandam) with a fresh yield per plant of 0.110 kg. Genotypes such as T_{16} (Pozhuthana) and T_{12} (Irinjalakkuda) recorded an yield of 0.096 and 0.095 kg per plant and these four genotypes recorded significantly higher mean fresh yield than control variety T_{21} (Aswathy) which had a per plant fresh yield of 0.091 kg.

The fresh yield per plot of selected genotypes varied from 0.84 to 2.33kg. T_{11} (Kazhakootam) recorded the highest fresh yield per plot of 2.33 kg. Genotypes such as T_4 (Haripad), T_5 (Kottarakkara), T_6 (Ambalavayal), T_{10} (Kattapana), T_{12} (Irinjalakkuda), T_{13} (Sulthan Bathery), T_{14} (Murickassery), T_{15} (Nedumkandam), T_{16} (Pozhuthana), T_{19} (Thariyode) and T_{20} (Thalavur) recorded higher fresh yield per plot compared to control (T_{21}) which recorded a per plot fresh yield of 1.105 kg.

4.1.3.4.2 Dry yield (kg/plant, kg/plot)

The data on mean dry yield per plant and mean dry yield per plot of selected genotypes are presented in table 16.

The dry yield per plant varied from 0.010 to 0.031 kg. The highest dry yield per plant (0.031 kg) was noted in T_{11} (Kazhakootam) followed by T_{15}

Table 16. Fresh and dry ginger yield of the selected genotypes of ginger

Treatment	Fresh weight (kg plant^{-1})	Fresh weight (kg plot^{-1})	Dry weight (kg plant^{-1})	Dry weight (kg plot^{-1})
T_1 (Mananthavady)	0.049	0.840	0.010	0.165
T_2 (Kanchiar)	0.061	1.023	0.012	0.200
T_3 (Thalayolaparambu)	0.060	1.038	0.011	0.188
T_4 (Haripad)	0.071	1.125	0.015	0.243
T_5 (Kottarakkara)	0.065	1.418	0.012	0.198
T_6 (Ambalavayal)	0.065	1.113	0.012	0.193
T_7 (Kothamangalam)	0.067	1.053	0.012	0.178
T_8 (Karunagapally)	0.078	1.033	0.015	0.240
T_9 (Mannarkkad)	0.084	1.063	0.016	0.293
T_{10} (Kattapana)	0.065	1.243	0.012	0.193
T_{11} (Kazhakootam)	0.150	2.330	0.031	0.475
T_{12} (Irinjalakkuda)	0.095	1.160	0.021	0.350
T_{13} (Sulthan Bathery)	0.068	1.783	0.014	0.238
T_{14} (Murickassery)	0.065	1.518	0.012	0.183
T_{15} (Nedumkandam)	0.110	1.615	0.023	0.398
T_{16} (Pozhuthana)	0.096	1.128	0.017	0.275
T_{17} (Kalliyur)	0.065	1.010	0.012	0.203
T_{18} (Kottiyoor)	0.067	1.420	0.014	0.235
T_{19} (Thariyode)	0.078	1.793	0.014	0.235
T_{20} (Thalavur)	0.062	1.543	0.012	0.200
T_{21} (Control)	0.091	1.105	0.018	0.298
SE (m) $\pm$	0.001	0.131	0.000	0.006
CD (0.05)	0.002	0.372	0.001	0.016

(Nedumkandam) (0.023 kg). Genotypes such as T_{11} (Kazhakootam), T_{15} (Nedumkandam) and T_{12} (Irinjalakkuda) produced higher dry yield compared to control (T_{21}) which had a dry yield of 0.018 kg per plant.

The dry yield per plot varied from 0.165 to 0.475 kg. T_{11} (Kazhakootam) recorded the highest dry yield per plot (0.475 kg) followed by T_{15}(Nedumkandam) (0.398 kg). T_{12} (Irinjalakkuda) produced 0.350 kg per plot followed by control (T_{21}) which produced dry yield of 0.298 kg per plot.

4.1.3.4.3 Harvest index

The mean harvest index of selected ginger genotypes are presented in table 17. Significant differences in harvest index were observed among the selected genotypes. Harvest index of selected genotypes varied from 0.25 to 0.60. T_{11} (Kazhakootam) showed significantly higher harvest index of 0.60. This was followed by T_{15} (Nedumkandam) with an harvest index of 0.54. T_{21} (Control) recorded a harvest index of 0.43.

4.1.3.4.4 Dry recovery

The data on mean dry recovery of selected ginger genotypes are presented in table 17. T_{12} (Irinjalakkuda) showed significantly higher dry recovery of 21.75 per cent, which was on par with T_4 (Haripad) (21.66), Nedumkandam (21.41 %) and T_{13} (Sulthan Bathery) (20.95%). The dry recovery recorded by the control was 19.38 per cent.

4.1.3.5 Quality parameters

4.1.3.5.1 Starch

Starch content of the selected genotypes is presented in table 18. Significant variation in starch content of was noticed among the genotypes. Starch content ranged between 32.53 to 41.90 per cent in selected genotypes. Significantly higher starch content was recorded fromT_{12} (Irinjalakkuda) (41.90%) which was on par with

Table 17. Harvest index and dry recovery of the selected genotypes of ginger

Genotype	Harvest index	Dry recovery (%)
T_1 (Mananthavady)	0.25	19.73
T_2 (Kanchiar)	0.34	18.89
T_3 (Thalayolaparambu)	0.31	18.41
T_4 (Haripad)	0.40	21.66
T_5 (Kottarakkara)	0.29	17.87
T_6 (Ambalavayal)	0.27	18.37
T_7 (Kothamangalam)	0.34	17.72
T_8 (Karunagapally)	0.37	19.32
T_9 (Mannarkkad)	0.37	19.18
T_{10} (Kattapana)	0.33	18.95
T_{11}(Kazhakootam)	0.60	20.48
T_{12}(Irinjalakkuda)	0.50	21.75
T_{13}(Sulthan Bathery)	0.36	20.95
T_{14}(Murickassery)	0.30	18.93
T_{15}(Nedumkandam)	0.54	21.41
T_{16}(Pozhuthana)	0.49	17.71
T_{17}(Kalliyur)	0.32	18.43
T_{18}(Kottiyoor)	0.34	20.56
T_{19}(Thariyode)	0.40	17.80
T_{20}(Thalavur)	0.30	19.36
T_{21} (Control)	0.43	19.38
SE (m) $\pm$	0.010	0.286
CD (0.05)	0.027	0.810

T_1 (Mananthavady). Lowest starch content was observed in T_6 (Ambalavayal). The starch content of control, Aswathy variety was 39.34 per cent.

4.1.3.5.2 Crude fibre

Crude fibre contents of selected ginger genotypes are presented in table 18. Significant variation was noticed among genotypes in the crude fibre content. Crude fibre content of the selected genotypes ranged between 1.2 to 5.75 per cent. The highest crude fibre content was observed in T_{16} (Pozhuthana) and the lowest in T_7 (Kothamangalam). Crude fibre content of T_{11} (Kazhakootam) was 1.32 per cent while that for T_{12} (Irinjalakkuda) was 2.45 per cent.

4.1.3.5.3 Essential oil

Essential oil content of selected genotypes is presented in table 18. Significant difference in essential oil content was noticed among the selected genotypes. Essential oil content of selected ginger genotypes varied from 0.90 to 2.42 per cent. The highest percentage of essential oil content (2.42 %) was observed in T_{20} (Thalavur) followed by T_{16} (Pozhuthana). The lowest essential oil content was in T_{14} (Murickassery) which recorded 0.90 per cent.

4.1.3.5.4 Oleoresin

Oleoresin in the selected genotypes showed significant variation and is presented in (Table 18). Oleoresin among genotypes varied from 4.00 to 12.50 per cent. Significantly superior oleoresin content was observed in T_{12} (Irinjalakkuda) (12.50 %) followed by T_{16} (Pozhuthana) (10.47 %). T_{11} (Kazhakootam) recorded an oleoresin content of 6.53 per cent. The lowest oleoresin content (4.00 %) was observed in T_6 (Ambalavayal) while an oleoresin of 5.20 per cent was recorded from control (T_{21}).

Table 18. Quality parameters of the selected genotypes of ginger

Genotype	Starch (%)	Crude fibre (%)	Essential oil (%)	Oleoresin (%)	Total phenol (mg standard/ 100g)
T_1 (Mananthavady)	40.82	2.30	1.21	4.45	20.63
T_2 (Kanchiar)	37.70	2.80	1.10	6.55	82.44
T_3(Thalayolaparambu)	35.91	2.40	1.00	5.97	64.79
T_4 (Haripad)	35.75	2.60	1.40	9.42	22.77
T_5 (Kottarakkara)	36.21	3.45	1.45	5.55	64.45
T_6 (Ambalavayal)	32.53	3.48	0.98	4.00	61.62
T_7 (Kothamangalam)	35.56	1.20	1.28	5.55	55.25
T_8 (Karunagapally)	37.60	2.55	1.50	6.05	22.34
T_9 (Mannarkkad)	36.93	1.57	1.28	7.05	72.99
T_{10} (Kattapana)	33.16	2.55	0.95	4.44	22.21
T_{11}(Kazhakootam)	35.85	1.32	1.02	6.53	57.80
T_{12}(Irinjalakkuda)	41.90	2.45	1.05	12.50	66.14
T_{13}(Sulthan Bathery)	33.06	2.02	1.17	5.48	57.87
T_{14}(Murickassery)	38.62	4.65	0.90	6.15	47.97
T_{15}(Nedumkandam)	37.45	2.31	1.12	6.47	52.93
T_{16}(Pozhuthana)	35.24	5.75	1.97	10.47	56.42
T_{17}(Kalliyur)	36.13	3.17	1.10	9.22	51.53
T_{18}(Kottiyoor)	33.21	1.77	1.10	4.23	76.62
T_{19}(Thariyode)	35.73	1.52	1.00	4.42	33.29
T_{20}(Thalavur)	37.52	1.60	2.42	4.45	22.59
T_{21} (Control)	39.34	1.47	1.07	5.20	70.19
SE (m)±	0.78	0.08	0.06	0.092	0.827
CD (0.05)	2.23	0.23	0.18	0.262	2.346

4.1.3.5.5 Total phenol

Total phenol content of the selected genotypes is presented in (Table 18). A significant variation in the total phenol content was observed among the genotypes. Total phenol content varied from 20.63 to 82.44 mg standard/100 g in the selected genotypes. The highest total phenol content was found in T_2 (Kanchiar) (82.44mg standard/100g). This was followed by T_{18} (Kottiyoor) with a total phenol content of 76.62 mg standard/100 g, T_9 (Mannarkkad) with 72.99 mg standard/100 g and control (T_{21}) with a total phenol content of 70.19 mg standard/100 g. T_1 (Mananthavady) recorded the lowest total phenol content (20.63mg standard/100 g).

4.1.4 Natural Disease incidence

At four months after planting, natural incidence of rhizome rot caused by *Pythium aphanidermatum* was observed. Maximum disease incidence was observed in T_5 (Kottarakkara) and T_{14} (Murickassery) which recorded 29.15 and 29.10 per cent respectively. Disease incidence was lowest in T_{12} (Irinjalakkuda) (4.11%). Disease incidence of genotypes T_1 (Mananthavady), T_9 (Mannarkkad), T_{11} (Kazhakootam), T_{12} (Irinjalakkuda) and T_{18} (Kottiyoor) were less than 10 per cent.

4.1.5 Natural pest incidence

No pest incidence was reported in the field.

4.1.6 Genetic analysis

Genetic parameters like phenotypic variation, genotypic variation, coefficient of variation, heritability, genetic advance and path analysis were worked out and presented in table 20a and 20b.

4.1.6.1 Phenotypic variation

Phenotypic variance was found to be the highest for rhizome yield (500.20) which was followed by total phenol (394.38). Phenotypic variance for plant height was 17.78, for starch was 7.83 and for oleoresin it was 5.09.

Table 19. Natural disease incidence of soft rot in the selected genotypes of ginger

Genotype	Disease incidence (%)
T_1 (Mananthavady)	8.08
T_2 (Kanchiar)	16.66
T_3 (Thalayolaparambu)	20.63
T_4 (Haripad)	16.55
T_5 (Kottarakkara)	29.15
T_6 (Ambalavayal)	25.30
T_7 (Kothamangalam)	16.75
T_8 (Karunagapally)	17.18
T_9 (Mannarkkad)	8.28
T_{10} (Kattapana)	20.95
T_{11}(Kazhakootam)	8.28
T_{12}(Irinjalakkuda)	4.11
T_{13}(Sulthan Bathery)	20.83
T_{14}(Murickassery)	29.10
T_{15}(Nedumkandam)	12.75
T_{16}(Pozhuthana)	21.15
T_{17}(Kalliyur)	16.58
T_{18}(Kottiyoor)	8.28
T_{19}(Thariyode)	16.50
T_{20}(Thalavur)	21.00
T_{21} (Control)	24.93
SE (m) $\pm$	0.298
CD (0.05)	0.846

Table 20a. Genetic parameters of the selected genotypes of ginger

Characters	Phenotypic variance	Genotypic variance	Genotypic coefficient of variation	Phenotypic coefficient of variation
Plant height	17.78	17.41	6.98	7.05
Number of tillers	0.55	0.36	6.13	7.60
Leaf length	0.56	0.48	3.21	3.47
Leaf breadth	0.0025	0.0015	1.28	1.65
Leaf area	4.74	4.24	4.77	5.04
Rhizome yield	500.20	498.96	29.08	29.11
Rhizome spread	0.72	0.68	6.8	7.01
Rhizome thickness	0.04	0.04	15.84	16.05
Starch	7.83	5.35	6.34	7.67
Crude fibre	1.28	1.25	44.36	44.84
Oleoresin	5.09	5.06	35.2	35.32
Essential oil	0.15	0.13	28.86	30.71
Total phenol	394.38	391.64	38.38	38.51

Table 20b. Genetic parameters of the selected genotypes of ginger

Characters	Heritability	Genetic advance (as % of means)
Plant height	97.97	14.23
Number of tillers	65.14	10.20
Leaf length	85.77	6.13
Leaf breadth	57.64	2.05
Leaf area	89.49	9.30
Rhizome yield	99.75	59.82
Rhizome spread	94.24	13.60
Rhizome thickness	96.86	32.13
Starch	68.34	10.79
Crude fibre	97.91	90.43
Oleoresin	99.33	72.26
Essential oil	88.32	55.87
Total phenol	99.31	78.78

4.1.6.2 Genotypic variation

Genotypic variance was highest for rhizome yield (498.96) followed by total phenol (391.64). The genotypic variance for plant height, starch and oleoresin were 17.41, 5.35 and 5.06 respectively.

4.1.6.3 Coefficient of variation

4.1.6.3.1 Genotypic coefficient of variation

The genotypic coefficient of variation (GCV) ranged from 1.28 per cent for leaf breadth to 44.36 per cent for crude fibre. High GCV was observed for crude fibre (44.36 %), total phenol (38.38 %), oleoresin (35.2 %), essential oil (28.86 %) and rhizome yield (29.08 %). Moderate genotypic coefficient of variation was observed in rhizome thickness (15.84 %). The characters like plant height (6.98 %), rhizome spread (6.8 %), starch (6.34 %), number of tillers (6.13 %), leaf area (4.77 %), leaf length (3.21 %) and leaf breadth (1.28 %) recorded lower values of genotypic coefficient of variation.

4.1.6.3.2 Phenotypic coefficient of variation

The value of phenotypic coefficient of variation (PCV) ranged from 1.65 per cent for leaf breadth to 44.84 per cent for crude fibre content. The characters like crude fibre content (44.84 %), total phenol content (38.51 %), oleoresin content (35.32 %), essential oil (30.71 %) and rhizome yield (29.11 %) showed high value of phenotypic coefficient of variation. Moderate phenotypic coefficient of variation was observed in rhizome thickness (16.05%). The characters like starch content (7.67 %), number of tillers (7.60 %), plant height (7.05 %), rhizome spread (7.01 %), leaf area (5.04 %), leaf length (3.47 %) and leaf breadth (1.65 %) recorded lowest values of phenotypic coefficient of variation.

4.1.3.5 Heritability

Heritability of the characters is shown in table 20b. High heritability was observed for rhizome yield (99.75 %), followed by oleoresin content (99.33 %), total phenol content (99.31 %), plant height (97.97 %), crude fibre content (97.91 %), rhizome thickness (96.86 %), rhizome spread (94.24 %), leaf area (89.49 %), essential oil content (88.32 %), leaf length (85.77 %), starch content (68.34 %) and number of tillers (65.14 %). Moderate heritability was observed for leaf breadth (57.64 %).

4.1.3.6 Genetic advance (as percentage of mean)

Genetic advance of the characters is shown in table 20b. The highest estimate of genetic advance was observed for crude fibre content (90.43 %), followed by total phenol content (78.78 %), oleoresin (72.26 %), rhizome yield (59.82 %), essential oil (55.87 %) and rhizome thickness (32.13 %). Moderate genetic advance was observed for plant height (14.23 %), rhizome spread (13.60 %), starch content (10.79 %) and number of tillers (10.20 %). The lower value of genetic advance was obtained for leaf area (9.30 %), leaf length (6.13 %) and leaf breadth (2.05 %).

4.1.3.7 Path analysis

The path correlation coefficients representing direct and indirect effects are presented in table 21.

Plant height showed a negative direct effect on yield plant^{-1} (-0.16). Positive indirect effect was showed through number of tillers (0.39), leaf area (0.52), rhizome spread (0.23), oleoresin (0.008). Negative indirect effect was showed through rhizome thickness (-0.11).

The direct effect of number of tillers on yield plant^{-1} was positive (0.74). Positive indirect effect was showed through leaf area (0.11), rhizome spread (0.35), oleoresin (0.007). Negative indirect effect was showed through plant height (-0.08) and rhizome thickness (-0.24).

Leaf area indicated a positive direct effect on yield plant $^{-1}$ (0.96). Positive indirect effect was showed through number of tillers (0.09), rhizome spread (0.21),

Table 21. Path analysis of the selected genotypes of ginger

	Plant height	Number of tillers	Leaf area	Rhizome spread	Rhizome thickness	Oleoresin
Plant height	-0.16	0.39	0.52	0.23	-0.11	0.008
Number of tillers	-0.08	0.74	0.11	0.35	-0.24	0.007
Leaf area	-0.09	0.09	0.96	0.21	-0.12	0.007
Rhizome spread	-0.07	0.51	0.40	0.50	-0.20	0.010
Rhizome thickness	-0.05	0.47	0.31	-0.27	0.37	0.001
Oleoresin	-0.08	0.29	0.36	0.29	-0.01	0.017

oleoresin (0.007). Negative indirect effect was shown through plant height (-0.09) and rhizome thickness (-0.12).

Rhizome spread recorded a positive direct effect on yield plant $^{-1}$ (0.50). Positive indirect effect was shown through number of tillers (0.51), leaf area (0.40) and oleoresin (0.01). Negative indirect effect was shown through plant height (-0.07) and rhizome thickness (-0.20).

Rhizome thickness recorded a positive direct effect on yield plant $^{-1}$ (0.37). Positive indirect effect was shown through number of tillers (0.47), leaf area (0.31) and oleoresin (0.001). Negative indirect effect was shown through plant height (-0.05) and rhizome spread (-0.27).

Oleoresin recorded a positive direct effect on yield plant $^{-1}$ (0.017). Positive indirect effect was shown through number of tillers (0.29), leaf area (0.36) and rhizome spread (0.29). Negative indirect effect was shown through plant height (-0.08) and rhizome thickness (-0.01).

4.2 SCREENING OF GINGER GENOTYPES AGAINST RHIZOME ROT UNDER NATURAL CONDITION

4.2.1 Biochemical parameters (before and after inoculation)

4.2.1.1 Total phenol

Total phenol of the genotypes before and after artificial inoculation of rhizome rot are shown in table 22.

Significant variation in total phenol was noticed among genotypes before and after inoculation of *Pythium aphanidermatum*. Before inoculation, total phenol was maximum (26.85 $mg^{-1}g^{-1}$) in T_8 (Karunagapally) and minimum (19.09) in T_{17} (Kalliyur). After inoculation, total phenol increased in all genotypes. At 2 week after inoculation at the time of enzyme analysis the disease incidence was minimum for T_1 (Mananthavady), T_{12} (Irinjalakkuda) and Control 1. The total phenol content of T_1 (Mananthavady), T_{12} (Irinjalakkuda) and Control 1 before inoculation were 19.36,

Table 22. Total phenol of the selected genotypes of ginger

Genotype	Before inoculation (mg g^{-1})	After inoculation (mg g^{-1})	Difference (mg g^{-1})	DI (%)	PDI
T_1 (Mananthavady)	19.36	47.38	28.01	40	8.8
T_2 (Kanchiar)	25.31	56.40	31.09	60	24.4
T_3(Thalayolaparambu)	23.39	66.64	43.24	60	33.3
T_4 (Haripad)	20.43	55.54	35.11	60	11.1
T_5 (Kottarakkara)	24.80	52.40	27.59	60	20
T_6 (Ambalavayal)	21.56	48.78	27.22	100	55.5
T_7 (Kothamangalam)	21.90	67.18	45.27	100	42.2
T_8 (Karunagapally)	26.85	31.24	4.39	100	33.3
T_9 (Mannarkkad)	20.61	59.36	38.75	60	20
T_{10} (Kattapana)	20.21	31.84	11.63	80	20
T_{11}(Kazhakootam)	19.99	41.53	21.53	60	20
T_{12}(Irinjalakkuda)	19.11	51.78	32.67	40	11.1
T_{13}(Sulthan Bathery)	19.78	40.93	21.15	100	37.7
T_{14}(Murickassery)	19.35	64.28	44.93	60	20
T_{15}(Nedumkandam)	22.11	44.10	21.99	80	31.1
T_{16}(Pozhuthana)	25.90	39.47	13.56	60	35.5
T_{17}(Kalliyur)	19.09	41.21	22.12	80	53.3
T_{18}(Kottiyoor)	26.38	43.68	17.31	80	11.1
T_{19}(Thariyode)	21.37	42.74	21.36	60	20
T_{20}(Thalavur)	20.31	46.04	25.71	60	20
T_{21} (Control 1)	20.09	36.15	16.05	40	17.7
T_{22}(Control 2)	21.50	31.57	10.07	100	28.8
SE (m) $\pm$	0.191	0.923	0.856		
CD (0.05)	0.539	2.600	2.410		

DI: Disease incidence ; PDI : Percent disease index
Control 1: Karthika ; Control 2 : Rio de Janeiro

19.11 and 20.09 $mg^{-1}g^{-1}$ respectively. Two weeks after inoculation, the total phenol content increased to 47.38, 51.78 and 36.15 $mg^{-1}g^{-1}$ respectively. Maximum increase in phenol content was observed in T_7 (Kothamangalam) (45.27 $mg^{-1}g^{-1}$), which was on par with T_3 (Thalayolaparambu) (43.24 $mg^{-1}g^{-1}$) and T_{14} (Murickassery) (44.93 $mg^{-1}g^{-1}$).

4.2.1.2 Peroxidase

Peroxidase activity of the genotypes before and after artificial inoculation of rhizome rot showed significant variation and are presented in table 23.

Peroxidase activity increased and decreased following infection among genotypes. Peroxidase activity of T_7 (Kothamangalam) before inoculation was significantly higher and recorded 41.52 ΔOD_{436nm} mg^{-1} protein min^{-1}. However after inoculation, the peroxidase activity reduced to 23.67ΔOD_{436nm} mg^{-1} protein min^{-1}. Genotypes such as T_3 (Thalayolaparambu), T_6 (Ambalavayal), T_7 (Kothamangalam), T_8 (Karunagapally), T_9 (Mannarkkad), T_{10} (Kattapana), T_{11} (Kazhakootam), T_{13} (Sulthan Bathery), T_{14} (Murickassery), T_{15} (Nedumkandam), T_{16} (Pozhuthana), T_{18} (Kottiyoor), T_{19} (Thariyode) and T_{22} (Control 2) showed decreased peroxide activity after inoculation. All these genotypes had disease severity >20 per cent except T_{18} (Kottiyoor). An increase in peroxidase activity after inoculation was noticed in T_1 (Mananthavady), T_2 (Kanchiar), T_4 (Haripad), T_5 (Kottarakkara), T_{12} (Irinjalakkuda), T_{17} (Kalliyur), T_{20} (Thalavur) and T_{21} (Control 1). Peroxidase activity was higher for genotypes of lower disease severity and disease incidence while it decreased for genotypes with higher disease severity and disease incidence. Maximum peroxidase activity (16.41 ΔOD_{436nm} mg^{-1} protein min^{-1}) was observed in T_1 (Mananthavady), which had a least disease severity of 8.8 and a disease incidence of 40 per cent. Minimum peroxidase activity was found in T_8 (Karunagapally) (-26.08 ΔOD_{436nm} mg^{-1} protein min^{-1}) which had a high disease severity of 31.1.

Table 23. Peroxidase activity of the selected genotypes of ginger before and after inoculation of *Pythium aphanidermatum*

Genotype	Before inoculation (ΔOD_{436nm} mg^{-1} protein min^{-1})	After inoculation (ΔOD_{436nm} mg^{-1} protein min^{-1})	Difference (ΔOD_{436nm} mg^{-1} protein min^{-1})	DI (%)	PDI
T_1 (Mananthavady)	12.91	29.32	16.41	40	8.8
T_2 (Kanchiar)	16.69	23.75	7.06	60	24.4
T_3(Thalayolaparambu)	26.81	12.72	-14.09	60	33.3
T_4 (Haripad)	3.02	5.59	2.58	60	11.1
T_5 (Kottarakkara)	12.48	25.41	12.92	60	20
T_6 (Ambalavayal)	30.94	15.89	-15.05	100	55.5
T_7 (Kothamangalam)	41.52	23.67	-17.84	100	42.2
T_8 (Karunagapally)	29.66	3.58	-26.08	100	33.3
T_9 (Mannarkkad)	16.65	2.41	-14.24	60	20
T_{10} (Kattapana)	13.08	11.47	-1.60	80	20
T_{11}(Kazhakootam)	11.33	6.12	-5.21	60	20
T_{12}(Irinjalakkuda)	6.65	9.57	2.91	40	11.1
T_{13}(Sulthan Bathery)	8.21	6.24	-1.97	100	37.7
T_{14}(Murickassery)	27.10	4.83	-22.26	60	20
T_{15}(Nedumkandam)	20.19	5.89	-14.30	80	31.1
T_{16}(Pozhuthana)	7.84	4.95	-2.88	60	35.5
T_{17}(Kalliyur)	5.77	10.54	4.76	80	53.3
T_{18}(Kottiyoor)	7.90	4.00	-3.90	80	11.1
T_{19}(Thariyode)	11.16	6.45	-4.71	60	20
T_{20}(Thalavur)	2.84	10.08	7.24	60	20
T_{21} (Control 1)	14.15	23.38	9.23	40	17.7
T_{22}(Control 2)	9.69	5.30	-4.38	100	28.8
SE (m) ±	4.006	0.370	4.012		
CD (0.05)	11.286	1.043	11.303		

DI: Disease incidence ; PDI : Percent disease index
Control 1: Karthika ; Control 2 : Rio de Janeiro

4.2.1.3 Polyphenyl oxidase

Polyphenol oxidase activity (PPO) of the genotypes before and after artificial inoculation of *Pythium aphanidermatum* is shown in table 24.

Significant variation in polyphenol oxidase activity was observed before and after inoculation. Polyphenol oxidase activity increased in all genotypes after inoculation. Polyphenyl oxidase activity was significantly higher for Nedumkandam (T_{15}) before ($0.710\Delta OD_{490nm}$ mg^{-1} protein min^{-1}) and after inoculation with an activity of $2.798\Delta OD_{490nm}$ mg^{-1} protein min^{-1}. The Lowest polyphenol oxidase activity was observed in T_{14} (Murickassery) ($0.026\Delta OD_{490nm}$ mg^{-1} protein min^{-1}). The enhancement of polyphenol oxidase activity of control varieties were 0.109 and 0.180 ΔOD_{490nm} mg^{-1} protein min^{-1} for T_{21}(control 1) and T_{22} (control 2) respectively. Lower PPO enhancement was observed in T_1 (Mananthavady), T_{12} (Irinjalakkuda), T_{14} (Murickassery) and T_{21} (Control - variety Karthika), in plants with less disease severity and less disease incidence.

4.2.1.4 Lipoxygenase

Lipoxygenase activity (LOX) of the genotypes before and after artificial inoculation of *Pythium aphanidermatum* is presented in table 25.

Lipoxygenase activity increased in all genotypes after inoculation. The difference in lipoxygenase activity was significantly higher in T_{12} (Irinjalakkuda) (6.668 μ mol conjugated diene mg^{-1} protein min^{-1}) and was on par with T_{11} (Kazhakoottam) which recorded 6.420 μ mol conjugated diene mg^{-1} protein min^{-1}. The difference in lipoxygenase production was the least in T_4 (Haripad) (0.024 μ mol conjugated diene mg^{-1} protein min^{-1}). The difference in lipoxygenase activity for the control varieties were 2.769 and 1.256 μ mol conjugated diene mg^{-1} protein min^{-1} respectively for T_{21} and T_{22} respectively.

Table 24. Polyphenyl oxidase activity of the selected genotypes of ginger before and after inoculation of *Pythium aphanidermatum*

Genotype	Before inoculation (ΔOD_{490nm} mg^{-1} protein min^{-1})	After inoculation (ΔOD_{490nm} mg^{-1} protein min^{-1})	Difference (ΔOD_{490nm} mg^{-1} protein min^{-1})	DI (%)	PDI
T_1 (Mananthavady)	0.056	0.116	0.060	40	8.8
T_2 (Kanchiar)	0.565	1.870	1.305	60	24.4
T_3(Thalayolaparambu)	0.024	0.798	0.774	60	33.3
T_4 (Haripad)	0.284	1.063	0.779	60	11.1
T_5 (Kottarakkara)	0.085	1.294	1.209	60	20
T_6 (Ambalavayal)	0.045	1.272	1.227	100	55.5
T_7 (Kothamangalam)	0.028	0.746	0.719	100	42.2
T_8 (Karunagapally)	0.029	0.447	0.418	100	33.3
T_9 (Mannarkkad)	0.030	0.820	0.790	60	20
T_{10} (Kattapana)	0.266	2.048	1.782	80	20
T_{11}(Kazhakootam)	0.058	1.506	1.448	60	20
T_{12}(Irinjalakkuda)	0.054	0.349	0.295	40	11.1
T_{13}(Sulthan Bathery)	0.027	0.944	0.917	100	37.7
T_{14}(Murickassery)	0.118	0.143	0.026	60	20
T_{15}(Nedumkandam)	0.710	3.508	2.798	80	31.1
T_{16}(Pozhuthana)	0.072	0.801	0.729	60	35.5
T_{17}(Kalliyur)	0.100	1.320	1.221	80	53.3
T_{18}(Kottiyoor)	0.136	0.752	0.616	80	11.1
T_{19}(Thariyode)	0.148	1.552	1.404	60	20
T_{20}(Thalavur)	0.060	0.391	0.330	60	20
T_{21} (Control 1)	0.319	0.428	0.109	40	17.7
T_{22}(Control 2)	0.265	0.444	0.180	100	28.8
SE (m) $\pm$	0.020	0.067	0.058		
CD (0.05)	0.056	0.190	0.165		

DI: Disease incidence ; PDI : Percent disease index
Control 1: Karthika ; Control 2 : Rio de Janeiro

Table 25. Lipoxygenase activity of the selected genotypes of ginger before and after inoculation of *Pythium aphanidermatum*

Genotype	Before inoculation (μ mol conjugated diene mg^{-1} protein min^{-1})	After inoculation(μ mol conjugated diene mg^{-1} protein min^{-1})	Difference (μ mol conjugated diene mg^{-1}protein min^{-1})	DI (%)	PDI
T_1 (Mananthavady)	0.132	3.082	2.950	40	8.8
T_2 (Kanchiar)	3.432	3.412	0.080	60	24.4
T_3 (Thalayolaparambu)	0.141	3.414	3.273	60	33.3
T_4 (Haripad)	3.698	3.722	0.024	60	11.1
T_5 (Kottarakkara)	3.864	3.912	0.048	60	20
T_6 (Ambalavayal)	3.306	3.434	0.128	100	55.5
T_7 (Kothamangalam)	3.408	8.558	5.150	100	42.2
T_8 (Karunagapally)	3.704	7.530	3.826	100	33.3
T_9 (Mannarkkad)	4.000	9.426	5.426	60	20
T_{10} (Kattapana)	3.97	4.018	0.030	80	20
T_{11}(Kazhakootam)	3.826	10.246	6.420	60	20
T_{12}(Irinjalakkuda)	3.282	9.950	6.668	40	11.1
T_{13}(Sulthan Bathery)	2.946	4.024	1.078	100	37.7
T_{14}(Murickassery)	3.686	4.712	1.020	60	20
T_{15}(Nedumkandam)	3.360	7.712	4.352	80	31.1
T_{16}(Pozhuthana)	3.386	3.836	0.450	60	35.5
T_{17}(Kalliyur)	2.954	3.346	0.392	80	53.3
T_{18}(Kottiyoor)	3.004	3.748	0.744	80	11.1
T_{19}(Thariyode)	4.192	6.966	2.774	60	20
T_{20}(Thalavur)	3.754	4.054	0.300	60	20
T_{21} (Control 1)	5.838	8.607	2.769	40	17.7
T_{22}(Control 2)	2.678	3.934	1.256	100	28.8
SE (m) ±	0.279	0.316	0.282		
CD (0.05)	0.786	0.891	0.795		

DI: Disease incidence ; PDI : Percent disease index
Control 1: Karthika ; Control 2 : Rio de Janeiro

4.2.1.5 Phenylalanine ammonia lyase

Phenylalanine ammonia lyase activity of the genotypes before and after artificial inoculation of *Pythium aphanidermatum* is presented in table 26.

Phenylalanine ammonia lyase (PAL) activity increased in all genotypes after inoculation. Significantly higher difference in phenylalanine ammonia lyase activity was observed in T_{18} (Kottiyoor) and T_{21} (control) which produced 1.74 μ mol cinnamic acid mg^{-1} protein min^{-1}). Least phenylalanine ammonia lyase activity was observed in T_{10} (Kattapana) (0.21 μ mol cinnamic acid mg^{-1} protein min^{-1}).

4.2.2 Percentage disease incidence and percentage disease severity

The percentage disease incidence and disease severity of selected genotypes at one, two and three weeks after inoculation are presented in table 27.

After one week of inoculation of *Pythium aphanidermatum* culture, no symptom development was observed. Hence the disease incidence (DI) and percentage disease index (PDI) or disease severity were zero. After 2 weeks of inoculation, symptoms were developed. Percentage disease incidence varied from 60 to 100 per cent, whereas percentage disease index or severity varied from 20 to 60 at 2 weeks after inoculation. The least disease incidence of 60 per cent was exhibited by T_1 (Mananthavady), T_2 (Kanchiar) and T_{12} (Irinjalakkuda). T_1 (Mananthavady) exhibited least disease severity (20). Maximum disease severity (60) was found in T_{17} (Kalliyur). At three weeks after inoculation, percentage disease incidence varied from 80 to 100% whereas percentage disease severity varied from 31.1 to 64.4. T_1 (Mananthavady) exhibited least disease severity of 31.1, whereas maximum disease severity was exhibited by T_{10} (Kattapana) and T_{17} (Kalliyur).

4.2.2 Soil temperature from the day of inoculation till disease development.

During the period of symptom development, soil temperature ranged from 25.1°C to 29.7°C. At the day of inoculation, soil temperature noted was 28.6°C. There

Table 26. Phenylalanine ammonia lyase activity of the selected genotypes of ginger before and after inoculation of *Pythium aphanidermatum*

Genotype	Before inoculation (μ mol cinnamic acid mg^{-1} protein min^{-1})	After inoculation (μ mol cinnamic acid mg^{-1} protein min^{-1})	Difference (μ mol cinnamic acid mg^{-1} protein min^{-1})	DI (%)	PDI
T_1 (Mananthavady)	0.37	1.39	1.02	40	8.8
T_2 (Kanchiar)	0.44	1.33	0.89	60	24.4
T_3 (Thalayolaparambu)	0.46	1.72	1.26	60	33.3
T_4 (Haripad)	0.51	1.14	0.63	60	11.1
T_5 (Kottarakkara)	0.55	1.24	0.69	60	20
T_6 (Ambalavayal)	0.38	1.18	0.79	100	55.5
T_7 (Kothamangalam)	0.46	0.98	0.52	100	42.2
T_8 (Karunagapally)	0.05	0.98	0.93	100	33.3
T_9 (Mannarkkad)	0.51	0.91	0.40	60	20
T_{10} (Kattapana)	0.36	0.57	0.21	80	20
T_{11}(Kazhakootam)	0.48	1.31	0.83	60	20
T_{12}(Irinjalakkuda)	0.38	1.22	0.84	40	11.1
T_{13}(Sulthan Bathery)	0.22	1.09	0.88	100	37.7
T_{14}(Murickassery)	0.52	1.46	0.94	60	20
T_{15}(Nedumkandam)	0.42	0.66	0.24	80	31.1
T_{16}(Pozhuthana)	0.37	0.72	0.35	60	35.5
T_{17}(Kalliyur)	0.52	1.14	0.62	80	53.3
T_{18}(Kottiyoor)	0.29	2.03	1.74	80	11.1
T_{19}(Thariyode)	0.02	1.30	1.28	60	20
T_{20}(Thalavur)	0.48	0.98	0.51	60	20
T_{21} (Control 1)	0.28	2.02	1.74	40	17.7
T_{22}(Control 2)	0.35	0.80	0.45	100	28.8
SE (m) ±	0.055	0.123	0.096		
CD (0.05)	0.154	0.348	0.271		

DI: Disease incidence ; PDI : Percent disease index
Control 1: Karthika ; Control 2 : Rio de Janeiro

Table 27. Percentage disease incidence and disease severity of the selected genotypes of ginger after artificial inoculation of *Pythium aphanidermatum*

Genotype	After 1 week		After 2 week		After 3 week	
	DI(%)	PDI	DI(%)	PDI	DI (%)	PDI
T_1 (Mananthavady)	0	0	60	20	80	31.1
T_2 (Kanchiar)	0	0	60	28.8	80	35.5
T_3 (Thalayolaparambu)	0	0	80	40	80	53.3
T_4 (Haripad)	0	0	80	31.1	100	37.7
T_5 (Kottarakkara)	0	0	80	26.6	80	35.5
T_6 (Ambalavayal)	0	0	100	60	100	64.4
T_7 (Kothamangalam)	0	0	100	46.6	100	55.5
T_8 (Karunagapally)	0	0	100	37.7	100	46.6
T_9 (Mannarkkad)	0	0	80	31.1	100	42.2
T_{10} (Kattapana)	0	0	80	48.8	100	64.4
T_{11}(Kazhakootam)	0	0	80	26.6	100	46.6
T_{12}(Irinjalakkuda)	0	0	60	24.4	80	31.1
T_{13}(Sultanbathery)	0	0	100	42.2	100	46.6
T_{14}(Murickassery)	0	0	80	44.4	100	51.1
T_{15}(Nedumkandam)	0	0	100	42.4	100	51.5
T_{16}(Pozhuthana)	0	0	80	40	100	55.5
T_{17}(Kalliyur)	0	0	100	60	100	64.4
T_{18}(Kottiyoor)	0	0	80	24.4	100	42.2
T_{19}(Thariyode)	0	0	80	26.6	100	37.7
T_{20}(Thalavur)	0	0	80	31.1	100	42.2
T_{21} (Control 1)	0	0	80	31.1	80	42.2
T_{22}(Control 2)	0	0	100	37.7	100	46.6
CD (0.05)	0	0	23.22	4.097	16.374	4.097
SE (m) $\pm$	0	0	8.107	1.431	5.717	1.431

DI: Disease incidence ; PDI : Percent disease index
Control 1: Karthika ; Control 2 : Rio de Janeiro

was a gradual increase in soil temperature from the first day of inoculation till symptom development on the ninth day with a dip in soil temperature at second, fourth and seventh day. This decrease in soil temperature at second, fourth and seventh day was due to the increased rainfall which occurred during these days. However, no difference was noted in soil temperatures with respect to genotypes. The soil temperature noted in second day was 25.3°C and it increased to 25.8°C in the third day. The soil temperature at fourth day was 25.1°C and it increased to 26.4 and 28.1°C in the fifth and sixth day. Soil temperature on the seventh day decreased to 25.5°C and then it increased to 29.3 and 29.7°C on the eighth and ninth day of inoculation (Table 28).

10.3 ENVIRONMENTAL FACTORS

10.3.1 Relative humidity

The relative humidity during the period of inoculation to symptom development ranged from 85 to 98 %. During the first day of inoculation it was 85 % and on second day it was 95 %. There was a decrease in relative humidity (86%) during the third and fourth day of inoculation. Thereafter it increased to 98 % for three consecutive days and then reduced to 96 % and 93 % during the eighth and ninth day of inoculation (Table 29).

10.3.2 Maximum temperature

The maximum temperature during the period of inoculation to symptom development ranged from 29.2 to 32.3°C. The maximum temperature during the day of inoculation was 32.3°C and it further decreased upto 29.2°C on the seventh day of inoculation and thereafter increased to 30.2°C on the day of symptom development (Table 29).

Table 28. Soil temperature from the day of inoculation till disease development

Genotype	First day (° C)	Second day (° C)	Third day (° C)	Fourth day (° C)	Fifth day (° C)	Sixth day (° C)	Seventh day (° C)	Eight day (° C)	Ninth day (° C)
T_1 (Mananthavady)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_2 (Kanchiar)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_3 (Thalayolaparambu)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_4 (Haripad)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_5 (Kottarakkara)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_6 (Ambalavayal)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_7 (Kothamangalam)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_8 (Karunagapally)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_9 (Mannarkkad)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{10} (Kattapana)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{11}(Kazhakootam)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{12}(Irinjalakkuda)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{13}(Sulthan Bathery)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{14}(Murickassery)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{15}(Nedumkandam)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{16}(Pozhuthana)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{17}(Kalliyur)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{18}(Kottiyoor)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{19}(Thariyode)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{20}(Thalavur)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{21} (Control 1)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7
T_{22} (Control 2)	28.6	25.3	25.8	25.1	26.4	28.1	25.5	29.3	29.7

Control 1: Karthika ; Control 2 : Rio de Janeiro

Table 29. Environmental factors from the day of inoculation till disease development

Days after inoculation	Relative humidity	Maximum temperature	Minimum temperature	Rainfall (cm)
First day	85	32.3	26	0
Second day	95	31.4	24.9	1.75
Third day	86	31.4	26	0
Fourth day	86	30.9	26	0.06
Fifth day	98	30.4	24.1	2.26
Sixth day	98	29.8	24	2.42
Seventh day	98	29.2	23.2	4.76
Eighth day	96	30.1	22.1	8.77
Ninth day	93	30.2	23.1	1.29

10.3.3 Minimum temperature

The minimum temperature during the period of inoculation was 26°C and it decreased on second day to 24.9°C. Thereafter it was stabilized to 26°C on the third and fourth day. Subsequently, it decreased and reached 22.1°C on the eight day. On the ninth day the minimum temperature was 23.1°C (Table 29).

10.3.4 Rainfall

Rainfall occurred during the period of inoculation. On the day of inoculation and on the third day there was no rainfall. On all other days rainfall occurred and it ranged from 0.06 cm to maximum of 8.77 cm (Table 29).

Discussion

5. DISCUSSION

The results of the experiment entitled "Variability in ginger (*Zingiber officinale* Rosc.) for yield and resistance to rhizome rot" conducted during 2017-2019 are discussed in this chapter.

5.1 COLLECTION OF GINGER GENOTYPES AND ANALYSIS FOR GENETIC VARIABILITY AND YIELD

5.1.1 Germplasm collection and preparation of passport data sheet.

Twenty ginger genotypes were collected locally from different regions of Kerala and the passport data sheet prepared contained information on location, village, taluk, district, latitude, longitude and habitat, ethnobotanical information, pest and disease (resistance/susceptibility/tolerance) and special characters. The collection of germplasm was made from plains as well as high range areas. Genotypes T_1 (Mananthavady), T_2 (Kanchiar), T_6 (Ambalavayal), T_{10} (Kattapana), T_{13} (Sulthan Bathery), T_{15} (Nedumkandam) and T_{16} (Pozhuthana) belonged to higher altitudes ie. 760 m, 850 m, 974 m, 900 m, 901 m, 975 m and 700 m respectively. Genotypes T_3 (Thalayolaparambu), T_4 (Haripad), T_5 (Kottarakkara), T_7 (Kothamangalam), T_8 (Karunagapally), T_9 (Mannarkkad), T_{11} (Kazhakootam), T_{12} (Irinjalakkuda), T_{14} (Murickassery), T_{17} (Kalliyur), T_{18} (Kottiyoor) and T_{19} (Thariyode) belonged to plains of 24 m, 10 m, 41 m, 34 m, 14 m, 76 m, 11 m, 39 m, 28 m, 28 m, 11 m and 52 m respectively. Genotype T_{20} (Thalavur) was collected from cultivated wetlands of Thalavur. The fundamental objective of collecting plant genetic resources is to capture the maximum amount of useful genetic variation in the smallest number of samples (Marshall and Brown, 1975). Thus, since the collection has been done from varied places, collection of sample might have met the basic objective of germplasm collection.

5.1.2 Qualitative characterization of selected ginger genotypes

Qualitative characterization of collected ginger genotypes and control variety 'Aswathy' were carried out using distinctiveness, Uniformity and Stability (DUS) guidelines by Protection of Plant Varieties and Farmer's Rights Authority for ginger. The qualitative characters observed in the selected ginger genotypes include plant, shoot, leaf, inflorescence and rhizome characters.

5.1.2.1 Plant characters

Plant characters evaluated in the present study include plant growth habit and plant height. The growth habit of collected genotypes included erect and semi-erect types. However, spreading type was not observed among the collected genotypes. Among the genotypes, majority of the genotypes were of erect types (90 %) followed by semi erect types (10 %). As per DUS guidelines, variety PGS-5, Thiruvalla belonged to erect type and variety Varada belonged to semi erect type (PPVFRA, 2007). All genotypes belonged to short type, with a plant height less than 100 cm. As per DUS guidelines, variety Sabarimala belonged to short type (PPVFRA, 2007).

5.1.2.2 Shoot characters

Variability was found among the genotypes on shoot characters like number of shoots, height of shoot, shoot diameter, shoot intensity of green colour. Few and medium number of shoots were observed in the selected ginger genotypes. Few shoots (86 %) were common in the selected ginger genotypes. As per DUS guidelines, variety Jamaica had few number of shoots. However T_1 (Mananthavady), T_{11} (Kazhakootam) and T_{12} (Irinjalakkuda) collection represented medium shoots (10-15). Varieties Mahima and Himachal belong to medium type (PPVFRA, 2007).

In the present study, all genotypes possessed short (<75cm) shoot height. Variety 'Sabarimala' also possessed short shoot height (PPVFRA, 2007).

Majority of the genotypes collected possessed narrow (< 3 cm) shoot diameter, followed by medium (3-5 cm) shoot diameter. Medium shoot diameter were found in T_9 (Mannarkkad), T_{11} (Kazhakootam) and T_{12} (Irinjalakkuda) collection. As per DUS guidelines, variety Sabarimala possessed narrow shoot diameter whereas, medium shoot diameter was found in China and Erattupetta. The shoot intensity of green colour observed among the selected ginger genotypes were green and dark green. As mentioned in DUS guidelines, variety Varada had green colour, whereas variety Jamaica had dark green colour (PPVFRA, 2007).

5.1.2.3 Leaf characters

Leaf characters studied in the present study included leaf length, leaf width, leaf intensity of green colour and leaf petiole length. All the twenty selected ginger genotypes and the control possessed short (<25 cm) leaf length. As per DUS guidelines, variety Sabarimala possessed short leaf length. All the selected ginger genotypes possessed medium (2.5–3.5 cm) leaf width. As mentioned in DUS guidelines, varieties Burdwan and Erattupetta had medium leaf width. The leaf intensity of green colour was light green, green and dark green. Among the 20 genotypes and control evaluated, 33 per cent were light green, followed by green (57 %), dark green (10 %). As per DUS guidelines, Supliang local, Varada and Jamaica had light green, green and dark green respectively. Majority of the genotypes possessed short (95 %) petiole length, followed by medium petiole length (5 %) in T_{17} (Kalliyur). As per DUS guidelines, short petiole length was seen in 'Konni local' and medium in 'Juggijan' (PPVFRA, 2007).

5.1.2.4 Inflorescence characters

Inflorescence characters like spike length and colour of bract tip of fully developed spike were evaluated among ginger genotypes. Among the selected ginger genotypes, spike was formed only in three genotypes T_5 (Kottarakkara), T_{13} (Sulthan bathery) and T_{16} (Pozhuthana collection). Spike length was short in the above genotypes. Variety Dehradun had short spike length as per DUS guidelines

(PPVFRA, 2007). Among the three genotypes, T_{16} (Pozhuthana collection) had yellowish white bract tip and T_5 (Kottarakkara), T_{13} (Sulthan bathery) had crimson bract tip. Variety H 687 had crimson inflorescence, whereas Maran had yellowish white bract tip (PPVFRA, 2007).

5.1.2.5 Rhizome characters

There was a remarkable variation in the rhizome characters like thickness, shape, skin colour and flesh colour. Rhizome thickness was found to be thin (< 2 cm) for all the genotypes except for T_{11} (Kazhakootam collection) which had medium (2-3 cm) thickness. As per DUS guideline of ginger (PPVFRA, 2007), Sabarimala had thin and Maran had medium thickness. Rhizome shape observed in the selected ginger genotypes included straight, curved and zig-zagged types. Majority of the genotypes possessed straight shape (52%), followed by curved (29 %) and zig – zagged shapes (19 %). As per DUS guidelines, straight rhizome was found in Sabarimala, curved in Kakkakalan, zig-zagged in Jamaica (PPVFRA, 2007).

Rhizome skin colour observed in the selected ginger genotypes were greyish yellow and yellowish white. Greyish yellow colour was predominant among the genotypes (95 %) followed by yellowish white colour. Rhizome flesh colour observed in the selected ginger genotypes included light yellowish grey, greyish yellow and yellow. Majority of the genotypes possessed greyish yellow flesh colour (67 %), followed by light yellowish grey (19 %) and yellow (14 %) (PPVFRA, 2007).

5.1.3 Quantitative characterization of selected ginger genotypes

5.1.3.1 Days to sprouting

A wide variation was noted in the days taken for sprouting among the ginger genotypes studied and it varied from 7 to 20 days after planting. While T_5 (Kottarakkara) recorded early sprouting of 7 days, T_1 (Mananthavady), T_3 (Thalayolaparambu), T_8 (Karunagapally), T_{11} (Kazhakootam), T_{12} (Irinjalakkuda), T_{14} (Murickassery), T_{17} (Kalliyur) and T_{21} (Control variety Aswathy) took 8 days. Thariyode (T_{19}) took 20 days for sprouting. This shows that based on the days taken

for sprouting ginger genotypes may be classified as early, mid and late germination types.

5.1.3.2 Plant characters

Significant variation was observed in plant characters like plant height, number of tillers and dry matter production among the selected ginger genotypes in 3, 5 and 7 MAP. T_{12} (Irinjalakkuda) recorded the highest plant height (68.75 cm) during all growth periods indicating a vigorous nature of growth. At 3 MAP, T_{12} (Irinjalakkuda) was found to be on par with T_8 (Karunagapally), T_{12} (Irinjalakkuda collection) recorded a plant height of 66.30 cm at 5 MAP, followed by Nedumkandam collection (T_{15}) with a plant height of 63.28 cm. T_{12} (Irinjalakkuda) recorded a plant height of 68.75 cm at 7 MAP. This was followed by T_{15} (Nedumkandam) which was on par with T_{11} (Kazhakootam) at 7MAP. The significant variation in plant height observed in the present study was supported by the findings of Nybe *et al.* (1982) and Basak *et al.* (2017) (Fig 2).

The number of tillers at 3 MAP was the highest for T_1 (Mananthavady) and T_{13} (Sulthan Bathery) which recorded a value of 6.25 and was on par with T_8 (Karunagapally) and T_{10} (Kattappana). In 5 MAP, highest number of tillers was observed in T_1 (Mananthavady) which was on par with T_{11} (Kazhakootam) (10.1) and T_{12} (Irinjalakkuda) (10). At 7 MAP month, T_{11} (Kazhakootam) recorded highest number of tillers of 11.50 (Fig 3). T_{11} (Kazhakootam) recorded the highest dry matter production of 5,160.84 kg ha^{-1} and was on par with T_6 (Ambalavayal) and T_9 (Mannarkad) with a dry matter production of 5,091.24 and 5,052.38 kg ha^{-1}. Higher number of tillers contributed to higher dry matter production in T_{11} (Kazhakootam)(Fig 4).Similar results were reported by Babu *et al.* (2017) where Suprabha recorded highest plant height, number of tillers among ten ginger varieties evaluated.

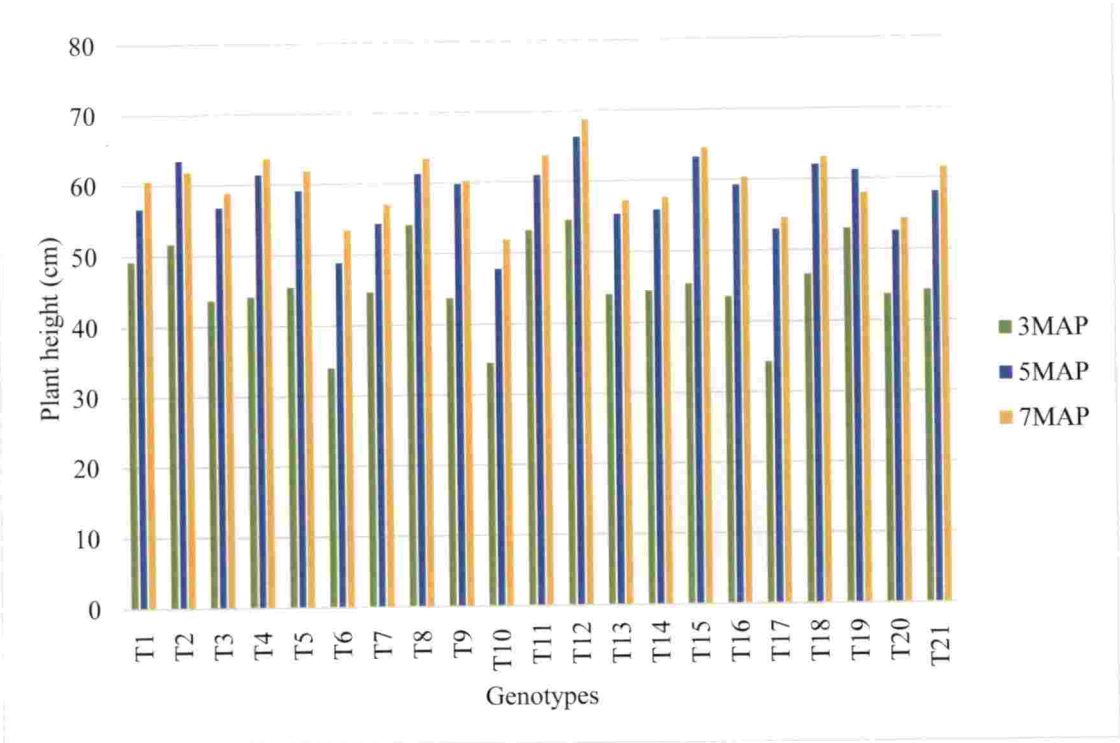


Fig 2: Plant height of the ginger genotypes

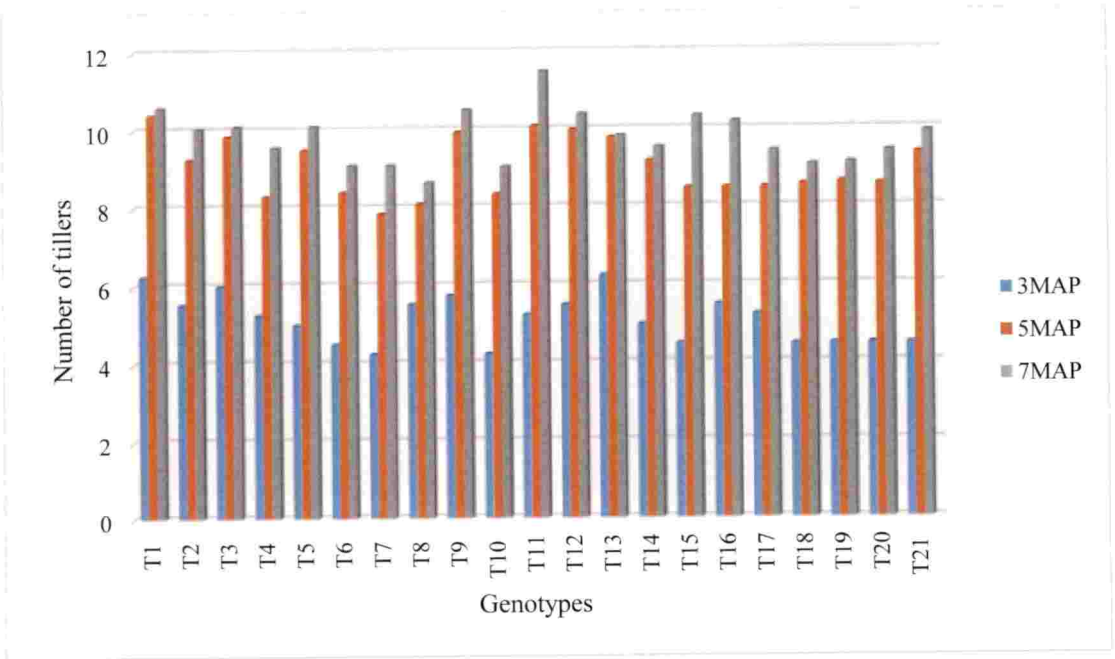


Fig 3: Number of tillers in the ginger genotypes

5.1.3.3 *Leaf characters*

Significant differences were observed in leaf characters like leaf length, leaf breadth and leaf area among the selected ginger genotypes. Highest leaf length was observed in T_{12} (Irinjalakkuda) during 3, 5 and 7 MAP. At 3 MAP, T_2 (Kanchiar) recorded the highest leaf breadth which was followed by T_6 (Ambalavayal) and were on par with T_{12} (Irinjalakkuda) and T_3 (Thalayolaparambu). At 5 MAP, T_6 (Ambalavayal) had highest leaf breadth which was on par with T_{12} (Irinjalakkuda), T_{13} (Sulthan Bathery), T_{14} (Murickassery), T_{15} (Nedumkandam) and T_{16} (Pozhuthana). At 7 MAP, T_6 (Ambalavayal) recorded the highest leaf breadth which was on par with T_2 (Kanchiar) and T_1 (Mananthavady). The highest leaf area (29.08 cm^2) was observed in T_2 (Kanchiar) which was on par with T_{12} (Irinjalakkuda) at 3 MAP. At 5 MAP, T_{12} (Irinjalakkuda) observed significantly higher leaf area (46.44 cm^2). At 7 MAP, the highest leaf area was observed in T_8 (Karunagapally), which was on par with T_{12} (Irinjalakkuda) (Fig 5). Shetty *et al.* (2015) also reported similar findings, among 10 ginger genotypes evaluated, Maran cultivar recorded the highest leaf length (25.07 cm), leaf breadth (2.08 cm) and leaf area (45.08 cm^2).

5.1.3.4 Rhizome characters

Rhizome characters analysed in the present study were rhizome spread and thickness. Rhizome spread and rhizome thickness among the ginger genotypes ranged from 10.77 to 13.91 cm and 1.08 to 2.02 cm respectively. Kazhakootam (T_{11}) collection recorded the highest rhizome spread of 13.91 cm and highest rhizome thickness of 2.02 cm at harvest (Fig 6,7). Shetty *et al.* (2015) reported that variety, Maran had highest rhizome spread of 16.12 cm which was on par with Rio de Janeiro.

5.1.3.5 Yield characters

5.1.3.5.1 Fresh yield (kg/plant, kg/plot)

In the present study, significant differences were observed among the selected ginger genotypes on fresh rhizome yield. The mean of fresh yield per plant varied

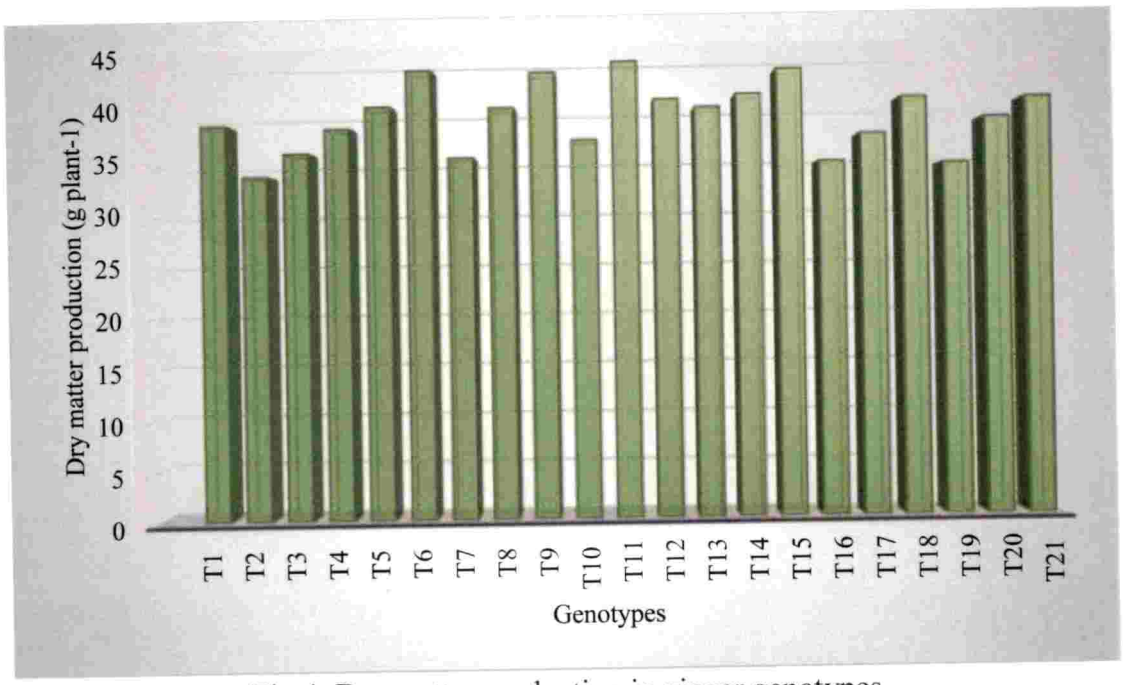


Fig 4: Dry matter production in ginger genotypes

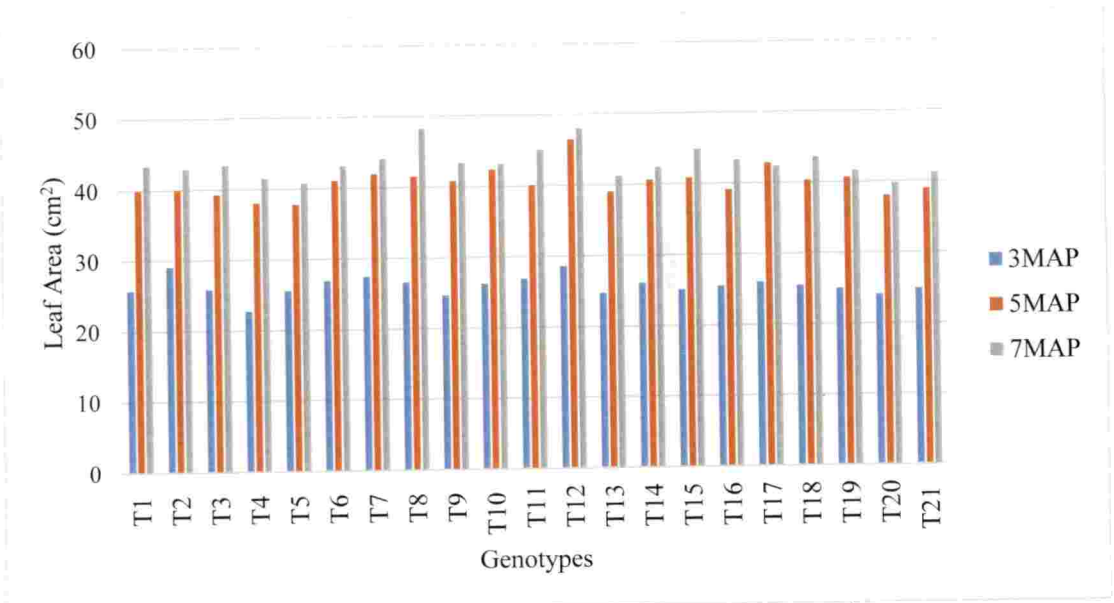


Fig 5: Leaf area of the ginger genotypes

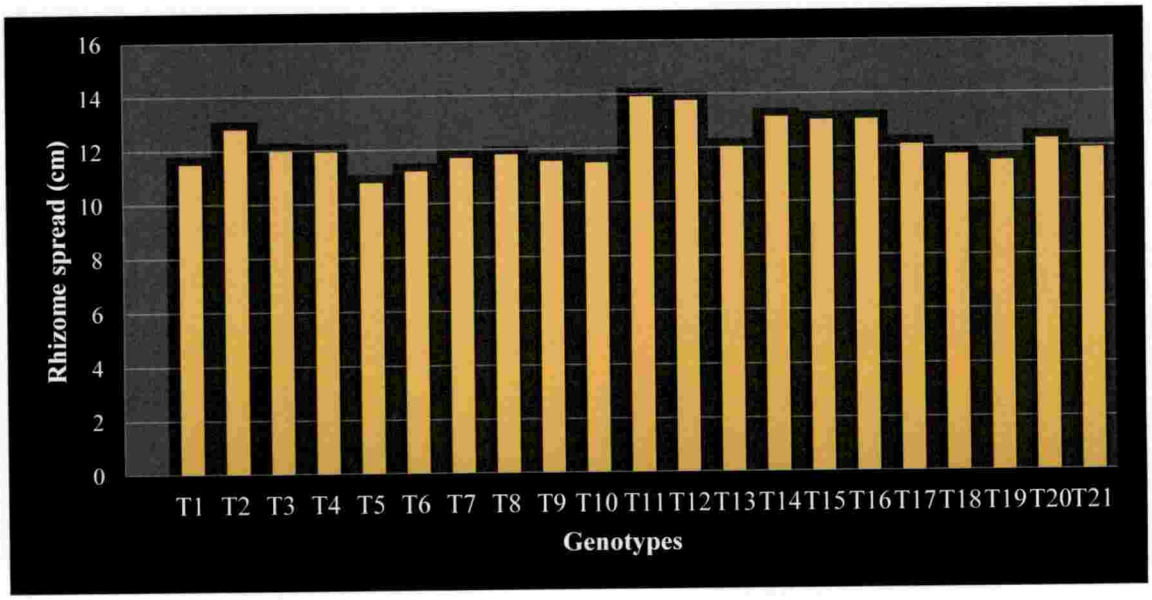


Fig 6: Rhizome spread of the ginger genotypes

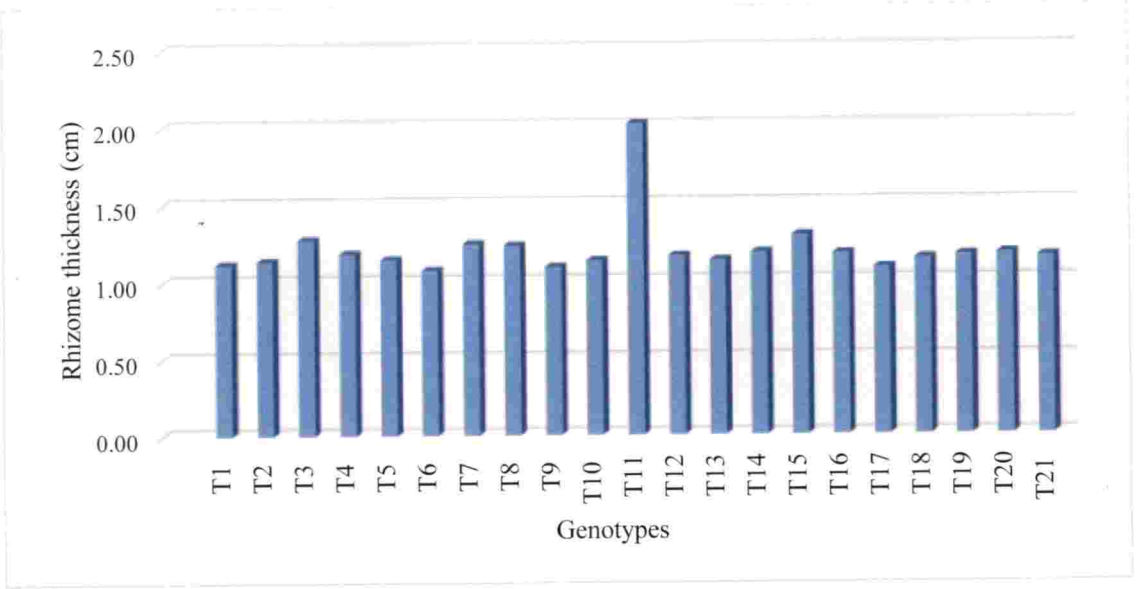


Fig 7: Rhizome thickness of the ginger genotypes

from 0.049 to 0.150 kg. T_{11} (Kazhakootam) recorded the highest fresh yield per plant (0.150 kg), followed by T_{15} (Nedumkandam) (0.110 kg). Genotypes such as T_{16} (Pozhuthana) and T_{12} (Irinjalakkuda) recorded an yield of 0.096 and 0.095 kg per plant and these four genotypes recorded significantly higher mean fresh yield per plant than control variety T_{21} (Aswathy) which recorded fresh yield of 0.091 kg per plant. The fresh yield per plot of selected genotypes varied from 0.84 to 2.33 kg. T_{11} (Kazhakootam) recorded the highest fresh yield per plot of 2.33 kg. Genotypes such as T_4 (Haripad), T_5 (Kottarakkara), T_6 (Ambalavayal), T_{10} (Kattapana), T_{12} (Irinjalakkuda), T_{13} (Sulthan Bathery), T_{14} (Murickassery), T_{15} (Nedumkandam), T_{16} (Pozhuthana), T_{19} (Thariyode) and T_{20} (Thalavur) recorded higher fresh yield per plot compared to T_{21} (control) which recorded a per plot fresh yield of 1.105 kg (Fig 8).The significantly higher fresh yield per plant and per plot in T_{11} (Kazhakootam) might be due to the significantly higher number of tillers (11.5), dry matter produced, rhizome spread and rhizome thickness observed in this genotype. Saikia and Shadeque (1999) evaluated twenty indigenous and exotic ginger varieties and reported variety, Nadia had the highest fresh ginger yield (67 q ha^{-1}) among twenty indigenous and exotic ginger varieties. Nayak *et al.* (2005) evaluated 16 ginger genotypes and found maximum fresh rhizome yield per plant (477.3g) in Gorubathaney. Chongtham *et al.* (2013) evaluated ten ginger varieties and Gorubathan recorded highest rhizome yield (18.25 t/ha). Rajyalakshmi and Umajyothi (2014) evaluated eight ginger genotypes and the highest fresh rhizome yield (21.71t/ha) was reported in Suprabha. Goudar *et al.* (2017) evaluated 12 ginger genotypes for yield and quality and observed the highest fresh rhizome yield per plant (235.26 g) in Humnabad local.

5.1.3.5.2 Dry yield (kg/plant, kg/plot)

Dry ginger yield per plant and per plot differed significantly among different genotypes. The dry yield per plant ranged from 0.010 to 0.031 kg. The highest dry yield per plant (0.031 kg) was noted in T_{11} (Kazhakootam) followed by T_{15}

(Nedumkandam)(0.023 kg). Genotypes such as T_{11} (Kazhakootam), T_{15} (Nedumkandam) and T_{12} (Irinjalakkuda) produced higher dry yield compared to T_{21} (control) which had a dry yield of 0.018 kg per plant (Fig 9). The higher dry yield per plant of T_{11} (Kazhakootam) might be due to higher fresh yield as well as comparatively higher dry recovery percentage of the genotype, however T_{16} (Pozhuthana) which recorded a higher fresh yield of 0.096 kg per plant compared to T_{21}(Control) produced lesser dry yield per plant than the control variety Aswathy. This might be due to the less dry recovery (17.71 %) of T_{16} (Pozhuthana) compared to (19.38 %) dry recovery of Aswathy. The minimum dry yield of 0.01g plant^{-1} was observed in T_1 (Mananthavady).

The dry yield per plot varied from 0.165 to 0.475 kg. T_{11} (Kazhakootam) recorded the highest dry yield per plot (0.475 kg) followed by T_{15} (Nedumkandam) (0.398 kg). T_{12} (Irinjalakkuda) produced 0.350 kg per plot followed by T_{21} (control) which produced dry yield of 0.298 kg per plot. Among 12 ginger genotypes evaluated in Karnataka, genotype Humnabad local recorded the highest dry rhizome yield of 6.29 t/ha (Goudar *et al.*, 2017).

5.1.3.5.3 Harvest index

Harvest index differed significantly among the selected genotypes. Harvest index of selected genotypes varied from 0.25 to 0.60. T_{11} (Kazhakootam) showed significantly higher harvest index of 0.60. This was followed by T_{15} (Nedumkandam) (0.54). The highest harvest index in T_{11} (Kazhakootam) was attributed due to high fresh yield per plant. Goudar *et al.* (2017) reported the highest harvest index in Humnabad local (59.70 %) which was on par with IISR Rejatha (57.46 %). The lowest harvest index was noted in Himachal (45.26 %). Harvest index is a measure of the reproductive efficiency. Higher the harvest index better is the variety in terms of dry matter partitioning.

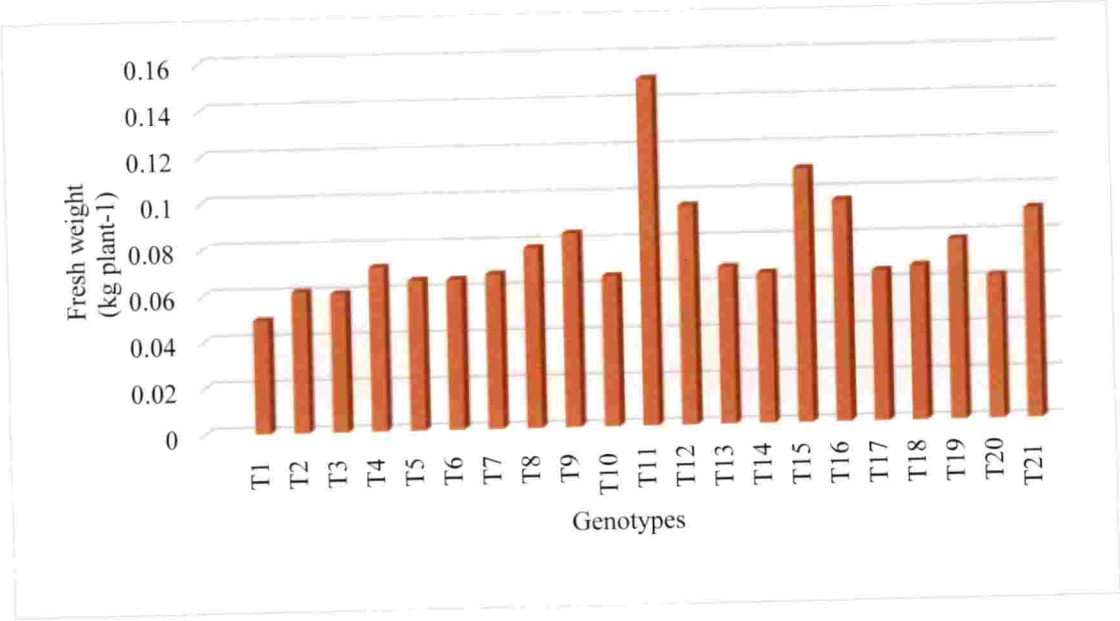


Fig 8: Fresh yield of the ginger genotypes

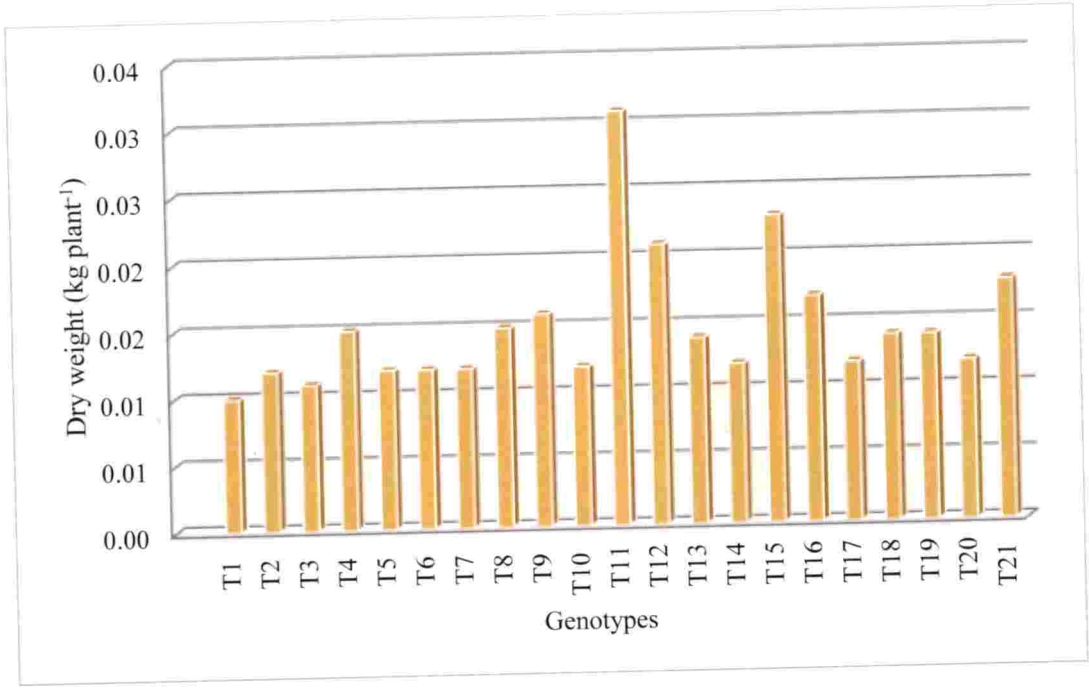


Fig 9: Dry yield of the ginger genotypes

5.1.3.5.4 Dry recovery

T_{12} (Irinjalakkuda) showed significantly higher dry recovery of 21.75 per cent, which was on par with T_4 (Haripad) (21.66 %), T_{15} (Nedumkandam) (21.41 %) and T_{13} (Sulthan bathery) (20.95 %). The dry recovery recorded by the control was 19.38 per cent. The high dry recovery together with the high oleoresin and starch contents suggest the suitability of the genotype for dry ginger production. Datta *et al.* (2003) evaluated quality of 12 ginger cultivars and reported the highest dry recovery percentage in Tura (26.77 %) followed by Suravi (23.45 %) and Suprabha (20.60 %). Evaluation of 30 ginger genotypes under coconut ecosystem revealed maximum dry recovery of 25.16 per cent in ZO 12 (Sangeetha and Subramanian, 2015).

5.1.3.6 Quality parameters

5.1.3.6.1 Starch

Starch is the most abundant constituent, which comprises of 40 to 60 per cent dry weight of rhizome in ginger (Lawrence, 1984). Significant variation in starch content of ginger genotypes were noticed among the genotypes. Starch content ranged between 32.53 to 41.90 per cent in the selected genotypes. Significantly higher starch content was recorded in T_{12} (Irinjalakkuda) (41.90 %) which was on par with T_1 (Mananthavady). The lowest starch content was observed in T_6 (Ambalavayal). The starch content of control, variety Aswathy was 39.34 per cent (Fig 10). According to Praveen *et al.* (2019), starch content of ginger was found to be crystalline and non-hygroscopic with swelling index value of 1.3 per cent. Its solubility index was found to be 37 per cent with gelatinization temperature at 80°C. Starch is an important component in ginger determining its quality. Hence, the ginger genotype with the highest starch content T_{12} (Irinjalakkuda) with comparatively higher dry ginger yield per plant and per plot would be a better ginger genotype considering the quality characters of ginger.

5.1.3.6.2 Crude fibre

Significant variation was noticed among genotypes in the crude fibre content. Among the genotypes, crude fibre content ranged between 1.2 to 5.75 per cent. The highest crude fibre was observed in T_{16} (Pozhuthana) and the lowest in T_7 (Kothamangalam). Crude fibre of T_{11} (Kazhakootam) was 1.32 per cent while that for T_{12} (Irinjalakkuda) was 2.45 per cent (Fig 11). Higher fresh ginger yield, and less crude fibre and medium starch in T_{11} (Kazhakootam) indicated that this genotype may be further evaluated for green ginger variety. Kizhakkayil and Sasikumar (2009) also reported remarkable variation among 46 ginger accessions in crude fibre content which ranged from 1.30 to 8.0 per cent.

Fibre content is the most important criteria for assessing the suitability of ginger rhizome for dry ginger production. The lower fibre content is desirable in ginger for the manufacture of processed food and also for vegetable purpose. Kurubar (2003) reported the lowest fibre content in genotype Basavakalyana (3.10 %) and the highest in Mahima (5.18 %). Sanwal *et al.* (2012) reported that the crude fibre content ranged from 5.16 in China to 8.03 percent in Burdwan. Goudar *et al.* (2017) evaluated twelve ginger genotypes for quality aspects. The minimum fibre content was recorded in Varada (3.34 %) which was on par with Rajatha (3.42 %), Suravi (3.62 %), Jorhat-2 (3.72 %) and Humnabad Local (3.86 %). The maximum fibre content was recorded in Himagiri (5.72 %).

5.1.3.6.3 Essential oil

Significant difference was observed in essential oil content among the genotypes. Essential oil content of selected ginger genotypes varied from 0.90 to 2.42 per cent. The highest percentage of essential oil content was observed in Thalavur (T_{20}) (2.42 %) followed by T_{16} (Pozhuthana) with 1.97 per cent essential oil. The lowest essential oil content (0.90 %) was in T_{14} (Murickassery) (Fig 12). Tiwari (2003) evaluated 24 ginger genotypes for quality traits under rain fed and irrigated

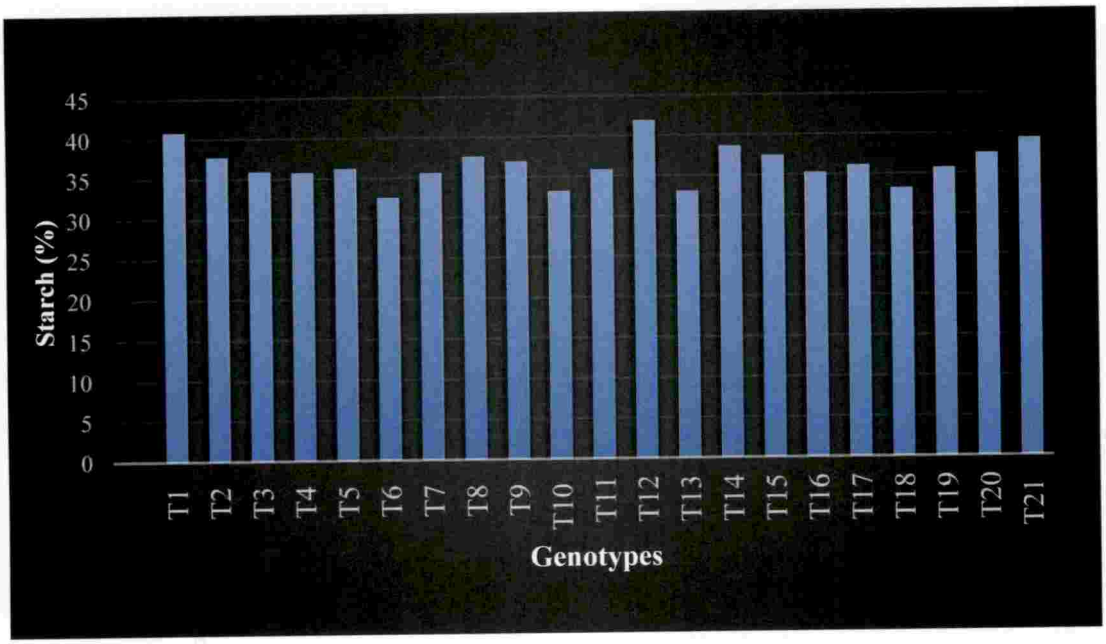


Fig 10. Starch content of the ginger genotypes

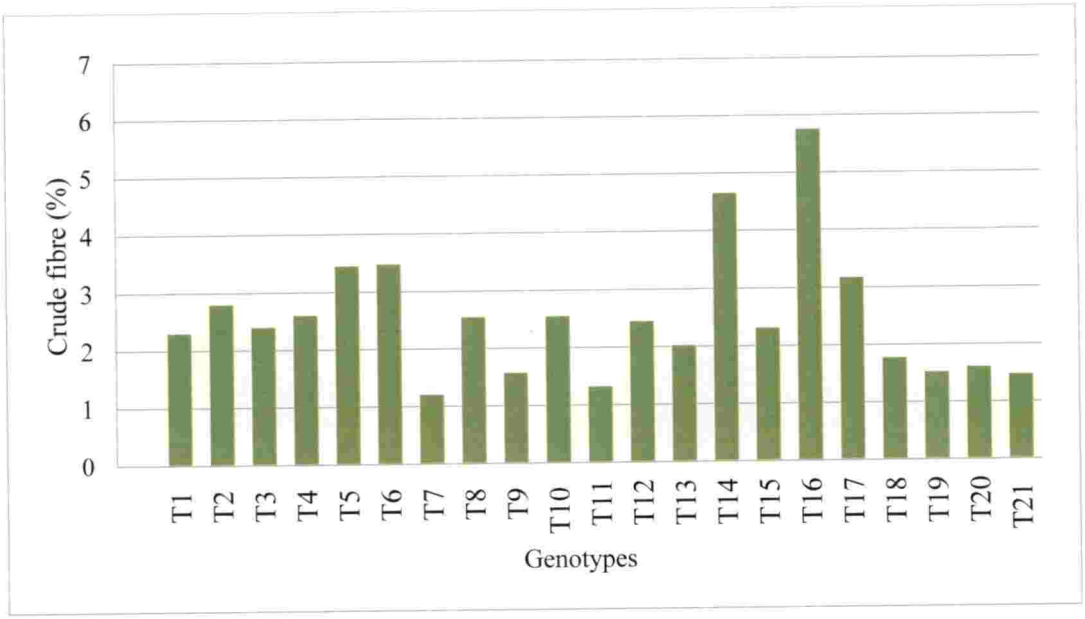


Fig 11. Crude fibre content of ginger genotypes

conditions; and the highest essential oil content was recorded in SG 61(2.28 %). Kizhakkayil and Sasikumar (2009) evaluated 46 ginger genotypes and found conspicuous variation in essential oil content which ranged from 0.9 per cent in Mananthody to 4 per cent in Pink ginger. Study by Sanwal *et al.* (2012) also revealed wide variation in essential oil content from 1.10 to 2.15 per cent in ginger genotypes. The essential oil is important in ginger as the cumulative effect of the essential oil components impart the perfumery smell to ginger (Goudar *et al.*, 2017).

5.1.3.6.4 Oleoresin

Oleoresin of ginger is the total extract of ginger containing all the flavouring principles of the spice. In this study, oleoresin content among genotypes ranged from 4.00 to 12.50 per cent. Significantly superior oleoresin content was observed in T_{12} (Irinjalakkuda) (12.50 %) followed by T_{16} (Pozhuthana) (10.47 %). T_{11} (Kazhakootam) recorded an oleoresin content of 6.53 %. The lowest oleoresin content was observed in T_6 (Ambalavayal) (4.00 %) while an oleoresin content of 5.20 % was recorded from T_{21} (control) (Fig 13). This result was supported by the findings of Kizhakkayil and Sasikumar (2009) wherein 46 ginger accessions were evaluated and the highest oleoresin was found in Kozhikkalan (8.2 %).

5.1.3.6.5 Total phenol

A significant variation in the total phenol content was observed among the genotypes. Total phenol content varied from 20.63 to 82.44 (mg g^{-1}) in the selected genotypes. The highest total phenol content was found in T_2 (Kanchiar) (82.44 mg g^{-1}). This was followed by T_{18} (Kottiyoor) with a total phenol content of 76.63 mg g^{-1}, T_9 (Mannarkkad) with 72.99 mg g^{-1} and T_{21} (control) with a total phenol content of 70.19 mg g^{-1}. T_1 (Mananthavady) recorded the lowest total phenol content (20.63 mg g^{-1}) (Fig 14).

Evaluation of the phenolic, flavonoid contents, antioxidant and antimicrobial activities of onion, garlic, mint, thyme, oak, *Aloe vera* and ginger revealed that the

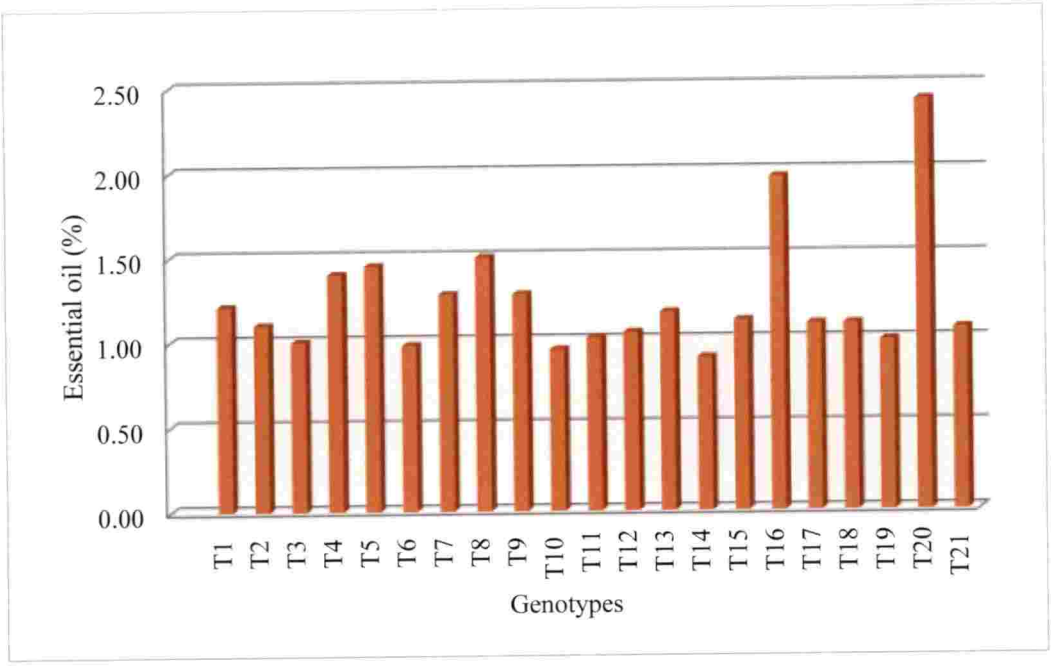


Fig 12. Essential oil content of the ginger genotypes

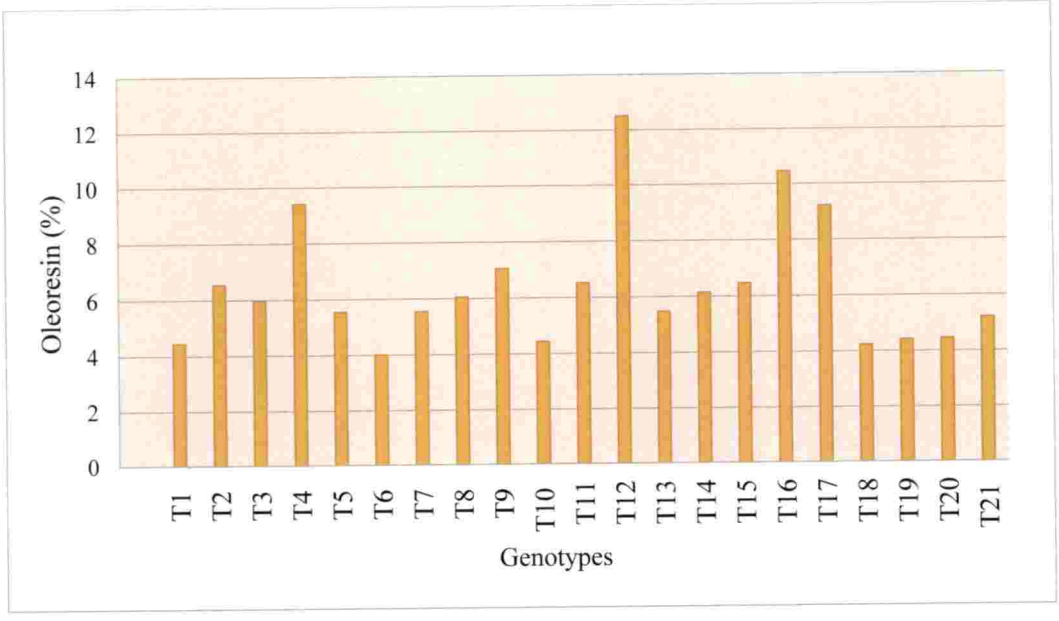


Fig 13. Oleoresin content of the ginger genotypes

total phenolic contents of extracts of 80 per cent ethanolic ginger extract was maximum (98.37 mg GAE/100 g) and that of aqueous extract of oak was the lowest (4.96 mg GAE/100 g) according to Bashir and Qadir (2017). The antioxidant activities of methanol extracts from the leaves, stems and rhizomes of two *Zingiber officinale* varieties, Halia Bentong and Halia Bara were assessed by Ghasemzadeh *et al.* (2010). Halia Bara had higher antioxidant activities as well as total contents of phenolic and flavonoid compared to Halia Bentong. The study also reported the positive relationship between total phenolics content and antioxidant activities in *Zingiber officinale.*

Polyphenolic compounds are known to have antioxidant activity and it is likely that the activity of the extracts is due to these compounds (Chen *et al.*, 2002; Djeridane *et al.*, 2006). This activity is believed to be mainly due to their redox properties, which plays an important role in adsorbing and neutralizing free radicals, quenching singlet and triplet oxygen, or decomposing peroxides (Yingming *et al.*, 2004; Louli *et al.* (2004).

5.1.4 Natural Disease incidence

At four months after planting, natural incidence of rhizome rot caused by *Pythium aphanidermatum* was observed. Maximum disease incidence was observed in T_5 (Kottarakkara) and T_{14} (Murickassery) which recorded 29.15 and 29.10 per cent respectively and were on par with each other. Disease incidence was the lowest in T_{12} (Irinjalakkuda) (4.11 %). Disease incidence of less than 10 percent was observed in genotypes T_1 (Mananthavady), T_9 (Mannarkkad), T_{11} (Kazhakootam), T_{12} (Irinjalakkuda) and T_{18} (Kottiyoor) (Fig 15). Among 25 ginger cultivars evaluated, Rio de Janeiro recorded maximum susceptibility (27.50 %), whereas the mild infections were recorded in Maran (3.20 %), Vengara (3.40 %), Wayanad Local (3.50 %), Mananthody (3.60 %) and Kuruppampady (3.60 %) (Nybe and Nair, 1979).

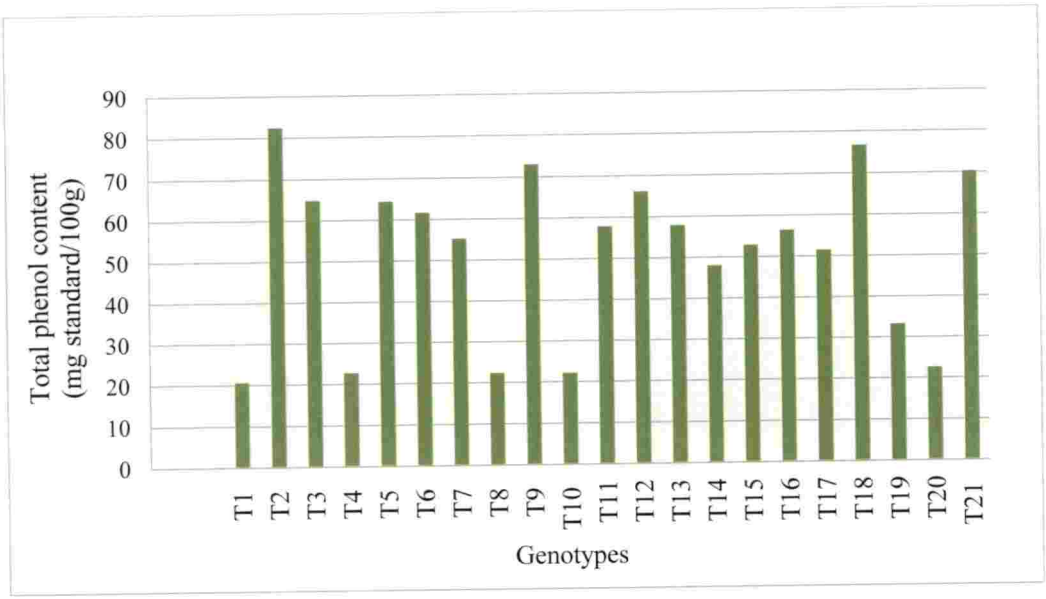


Fig 14. Total phenol content in rhizomes of ginger genotypes

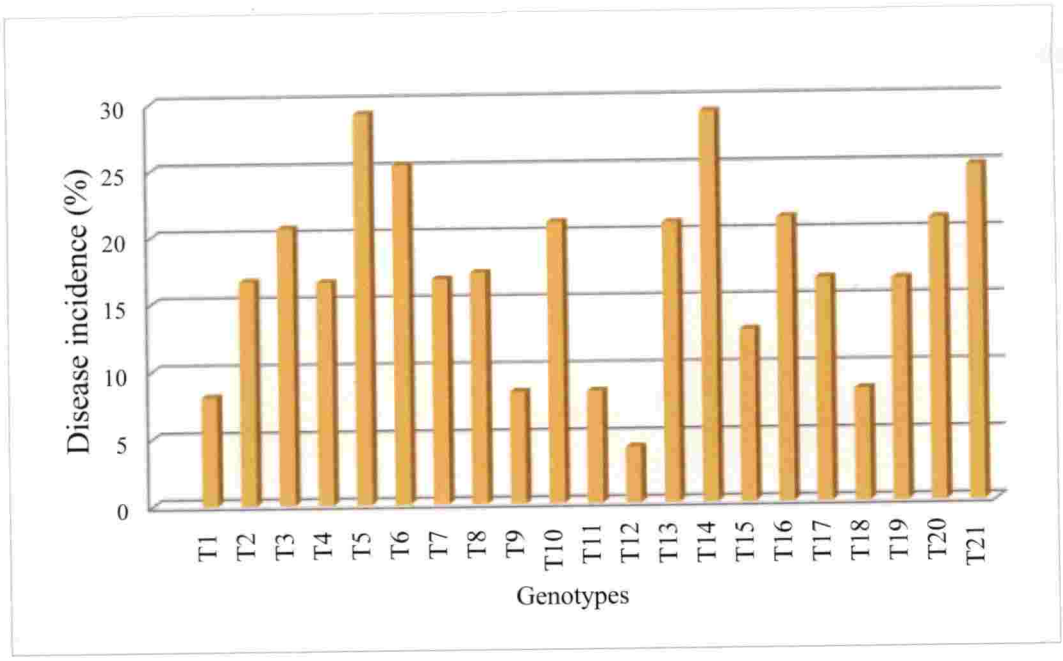


Fig 15. Natural disease incidence of soft rot in ginger genotypes

5.1.5 Natural pest incidence

No pest incidence was reported in the field.

5.1.6 Genetic analysis

An estimate of variability present in a population is having great importance, since it provides basis for effective selection. The components used to measure variability in a population include phenotypic variance, genotypic variance and coefficient of variation.

5.1.6.1 Phenotypic variation

Phenotypic variation is the variability that is observable. It is the total variation arising due to genotypic and environmental effects.

In the present study, phenotypic variance ranged from 0.0025 to 500.20. The highest value was recorded for rhizome yield (500.20) which was followed by total phenol content (394.38). Phenotypic variance for plant height, starch and oleoresin were 17.78, 7.83 and 5.09 respectively. The lowest was for essential oil (0.15). This result was in conformity with the study of Islam *et al.* (2008) who reported high phenotypic variance for rhizome yield per plant (7105.67) and the lowest for leaf breadth in 19 ginger genotypes evaluated. Ravisankar *et al.* (2013) also reported high phenotypic variance for fresh yield per plant (1647.25) and least phenotypic variance for girth of 25 ginger genotypes studied. Karthik *et al.* (2017) also reported high phenotypic variance for fresh rhizome yield per plant (2791.14) and lowest phenotypic variance for essential oil (0.06) in 16 ginger genotypes evaluated.

5.1.6.2 Genotypic variation

Genotypic variance ranged from 0.0015 for leaf breadth to 498.96 for rhizome yield. The highest genotypic variance for rhizome yield was followed by total phenol content (391.64). The genotypic variance for plant height, starch and oleoresin were 17.41, 5.35 and 5.06 respectively. The lowest was for essential oil (0.13). Islam *et al.*

(2014) reported high genotypic variance for rhizome yield per plant (6807.42) and lowest for leaf breadth (0.13) in 19 ginger genotypes. Ravisankar *et al.*, (2013) evaluated genetic variability in 25 ginger cultivars wherein the genotypic variance ranged from 0.01 to 1429.22. The highest value was for fresh yield per plant (1429.22) and the lowest for plant girth. Karthik *et al.* (2017) also reported high genotypic variance for fresh rhizome yield per plant (2708.14) and the lowest for essential oil (0.04) in 16 ginger genotypes evaluated.

5.1.6.3 Coefficient of variation

Variability in a population is also expressed as coefficients of variation. Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) are better indices for comparison. The GCV provides a valid base for comparing and assessing range of genetic variability for quantitative characters and PCV measures the extent of total variation. The similarity between PCV and GCV indicated low environmental influence and thus selection based on phenotypic performance can be reliable. Selection based on traits with high PCV and GCV is effective and the phenotypic expression of such character is a good indication of genetic potential.

5.1.6.3.1 Genotypic coefficient of variation

In the present study, GCV ranged from 1.28 per cent for leaf breadth to 44.36 per cent for crude fibre . High GCV was observed for crude fibre, total phenol, oleoresin, essential oil and rhizome yield. Moderate GCV was observed for rhizome thickness. Low GCV were recorded for characters like plant height, rhizome spread, starch content, number of tillers, leaf area, leaf length and leaf breadth. Islam *et al.* (2008) reported high GCV for rhizome yield per plant (57.18) followed by number of tertiary fingers per rhizome, tillers per plant and plant height and low GCV for leaf breadth (13.89) in 19 ginger genotypes studied. Ravisankar *et al.* (2013) reported high GCV for acidity percentage (44.46) followed by oleoresin content, ascorbic acid

content, yield per plant and number of secondary fingers; whereas low GCV for days taken to harvest in 25 ginger genotypes evaluated.

5.1.6.3.2 Phenotypic coefficient of variation

PCV assessed in the present study ranged from 1.65 per cent for leaf breadth to 44.84 per cent for crude fibre. The characters like crude fibre, total phenol, oleoresin, essential oil and rhizome yield showed high value of PCV. Moderate PCV was observed in rhizome thickness. Low PCV were recorded for characters like starch, number of tillers, plant height, rhizome spread, leaf area, leaf length and leaf breadth, which indicate low variability. Islam *et al.* (2008) reported high PCV for rhizome yield per plant (58.42) followed by number of tertiary fingers per rhizome, tillers per plant and plant height while leaf breadth scored low PCV (13.89) in 19 ginger genotypes evaluated. Ravisankar *et al.* (2013) reported high PCV for acidity percentage (44.46) followed by oleoresin content, ascorbic acid content, yield per plant, number of secondary fingers and low PCV for days taken to harvest in 25 ginger genotypes evaluated.

The close correspondence of the genotypic and phenotypic variance for almost all traits indicated less influence by environmental conditions, hence a wider scope to select genotypes for yield.

5.1.3.7 Heritability

In a population, sum total of heritable and non-heritable components constitute the existing variability. Heritability value indicates the degree of inheritance of characters from parents to its offspring. Characters with high heritability can be improved directly through selection.

In the present study, high heritability was noted for rhizome yield (99.75 %), followed by oleoresin content (99.33 %), total phenol (99.31 %), plant height (97.97 %), crude fibre (97.91 %), rhizome thickness (96.86 %), rhizome spread (94.24 %), leaf area (89.49 %), essential oil (88.32 %), leaf length (85.77 %), starch content

(68.34 %) and number of tillers (65.14 %). Moderate heritability was observed for leaf breadth (57.64 %). Similar findings were reported by Yadav (1999) in 26 ginger accessions. High heritability was observed for weight of primary rhizome (99.7 %), weight of mother rhizome, weight of secondary rhizome, rhizome yield per plant, number of secondary rhizome. High heritability of oleoresin content, ascorbic acid content, acidity and TSS were observed according to Ravisankar *et al.* (2013). According to Karthik *et al.* (2017), high heritability was observed for oleoresin content, fresh yield per plant and plant height in 16 ginger genotypes evaluated.

5.1.3.8 Genetic advance (as percentage of mean)

In the present study, genetic advance expressed as percentage of mean was low to high in nature and ranged from 2.05 to 90.43 per cent. The highest estimate of genetic advance was observed for crude fibre (90.43 %), followed by total phenol (78.78 %), oleoresin (72.26 %), rhizome yield (59.82 %), essential oil (55.87 %) and rhizome thickness (32.13 %). Moderate genetic advance was observed for plant height (14.23 %), rhizome spread (13.60 %), starch (10.79 %) and number of tillers (10.20 %). The lower value of genetic advance was obtained for leaf area (9.30 %), leaf length (6.13 %) and leaf breadth (2.05 %). High genetic gain was observed for acidity, oleoresin content and ascorbic acid content among 25 ginger genotypes evaluated (Ravisankar *et al.*, 2014). Karthik *et al.* (2017) reported high heritability coupled with high genetic gain for oleoresin content and fresh yield per plant in sixteen ginger genotypes evaluated. Moderate genetic advance were observed for number of leaves per tiller, leaf area index, length of fingers. The efficiency with which genotypic variability can be exploited by selection depends upon heritability and the genetic advance (GA) of individual traits (Bilgin *et al.*, 2010).

According to Murtadha *et al.* (2004) characters with high heritability, high genotypic coefficient of variation and high genetic advance might be good predictors of yield and could be used as index to select for yield improvement in breeding programs.

Ibrahim and Hussein (2006) and Nwangburuka *et al.* (2012) opined that characters with high heritability as well as high genotypic coefficient of variation and genetic advance could be explained by additive gene action and hence could be improved through mass selection. In the present experiment high genetic advance, high heritability as well as high genotypic coefficient of variation was recorded for characters like crude fibre, total phenol content, oleoresin, rhizome yield, essential oil and rhizome thickness indicating that selection for these characters could be more effective due to additive gene action.

5.1.3.9 Path analysis

Path coefficient analysis helps in partitioning the genotypic correlation coefficient into direct and indirect effect of the component character on yield which can be devised effectively for crop improvement programme. From the genotypic correlation, the highly correlated yield components like plant height, number of tillers, leaf area, rhizome spread, rhizome thickness and oleoresin were taken as independent characters for path coefficient analysis. According to Board *et al.* (1997) path coefficient is a standardized partial regression coefficient that measures the direct influence of one trait upon another and permits the separation of a correlation coefficient into components of direct and indirect effects. Thus path analysis provides clear idea of trait associations which will help to determine efficient selection strategy.

In the present study, number of tillers (0.74), leaf area (0.96), rhizome spread (0.50), rhizome thickness (0.37) and oleoresin (0.017) had positive direct effect on yield. Plant height showed a negative direct effect on yield plant^{-1} (-0.16).

Plant height indicated direct negative effect (-0.16) on yield plant^{-1} and positive genotypic correlation indicated the indirect effect through other independent characters like number of tillers (0.39), leaf area (0.52), rhizome spread (0.23), oleoresin (0.008). This result was supported by the study of Islam *et al.* (2008) who reported a negative direct effect of plant height (-0.315) on yield plant^{-1} in ginger.

Number of tillers had positive direct (0.74) and indirect effect through leaf area (0.11), rhizome spread (0.35) and oleoresin (0.007) on yield plant^{-1}. Negative indirect effect was showed through plant height (-0.08) and rhizome thickness (-0.24). Ravi *et al.* (2017) also reported high positive direct effect of number of tillers (3.488) on yield plant^{-1} in 16 ginger genotypes evaluated.

Leaf area showed a positive direct effect (0.96) and indirect effect through number of tillers (0.09), rhizome spread (0.21), oleoresin (0.007) on yield plant $^{-1}$. Negative indirect effect was shown through plant height (-0.09) and rhizome thickness (-0.12). Rai *et al.* (2008) reported positive direct effect of leaf area on yield plant $^{-1}$ among ginger genotypes.

Rhizome spread recorded a positive direct effect on yield plant^{-1} (0.50). Positive indirect effect was shown through number of tillers (0.51), leaf area (0.40) and oleoresin (0.01). Negative indirect effect was shown through plant height (-0.05) and rhizome thickness (-0.20). Abraham and Latha (2003) also reported positive direct effect of rhizome length (0.16) on yield plant $^{-1}$ in 40 ginger genotypes.

Rhizome thickness recorded a positive direct effect on yield plant $^{-1}$ (0.37). Positive indirect effect was shown through number of tillers (0.47), leaf area (0.31) and oleoresin (0.001). Negative indirect effect was shown through plant height (-0.05) and rhizome spread (-0.27). Pandey and Dhobal (1993) also reported positive direct effect of thickness of secondary rhizome on yield plant $^{-1}$(0.093) in 29 ginger genotypes evaluated.

Oleoresin recorded a positive direct effect on yield plant $^{-1}$ (0.017). Positive indirect effect was shown through number of tillers (0.29), leaf area (0.36) and rhizome spread (0.29). Negative indirect effect was shown through plant height (-0.08) and rhizome thickness (-0.01). Mehra (2012) also reported positive direct effect of oleoresin (0.238) on yield plant $^{-1}$ in 40 ginger genotypes evaluated.

The results of the present experiment suggest that selection for leaf area and number of tillers would increase yield of ginger. There exists wide variability among

the ginger genotypes and there was correlation of different yield components with the yield.

5.2 SCREENING OF GINGER GENOTYPES AGAINST RHIZOME ROT UNDER NATURAL CONDITION

5.2.1 Biochemical parameters (before and after inoculation)

In the present study, the selected ginger genotypes were screened for resistance to rhizome rot under natural conditions.

5.2.1.1 Total phenol

Phenols and their oxidation products are considered to be potentially toxic substances associated with reduction in development and multiplication of plant pathogens (Mahadevan, 1970).

Significant variation in total phenol content was noticed among genotypes before and after inoculation of *Pythium aphanidermatum*. Before inoculation, total phenol content was maximum (26.85 $mg^{-1}g^{-1}$) in T_8 (Karunagapally) and minimum (19.09) in T_{17} (Kalliyur). After inoculation, total phenol content increased in all genotypes. The total phenol content of T_1 (Mananthavady), T_{12} (Irinjalakkuda) and Control 1 (Karthika) before inoculation were 19.36, 19.11 and 20.09 mg^{-1} g^{-1} respectively. Two weeks after inoculation the total phenol content increased to 47.38, 51.78 and 36.15 mg^{-1} g^{-1} respectively. At 2 week after inoculation, the time of enzyme analysis the disease incidence was minimum for T_1 (Mananthavady), T_{12} (Irinjalakkuda) and T_{21} (Control 1). Maximum increase in phenol content was observed in T_7 (Kothamangalam) (45.27 $mg^{-1}g^{-1}$), which was on par with T_3 (Thalayolaparambu) (43.24 $mg^{-1}g^{-1}$) and T_{14} (Murickassery) (44.93 $mg^{-1}g^{-1}$)(Fig 16).

Among the diverse defense mechanisms evolved by plants, the arsenal of low-molecular weight phenolics represents inbuilt constitutive chemical barriers to infection (Nicholson and Hammerschmidt 1992; Osbourn 1996; Hammerschmidt 2005; Mary 2006). Phenolics, synthesized through shikimate-phenylpropanoid-

flavonoid pathway (Harborne, 1999) are implicated as resistance/incompatibility factors (Osbourn, 1996; Hammerschmidt 2005). Phenolic biosynthesis and their polymerization in the cell wall constitute an effective defense mechanism (Massei and Hartley 2000; Espinosa-Alonso *et al.* 2006) against necrotrophic fungal pathogens (Hammerschmidt, 2005). This thickening limited the infection process and played an important role as a physical barrier to stop the pathogen invasion. In addition, phenolics seem to inhibit disease development through different mechanisms involving the inhibition of extracellular fungal enzymes and inhibition of fungal oxidative phosphorylation (Hammerschmidt, 2005). PPO enzyme is involved in the oxidation of polyphenols into quinones (antimicrobial compounds) and lignification of plant cells during microbial invasion, and also may participate in the responding defense reaction and hypersensitivity by inducing plant resistance against fungi (Mayer 2006). These oxidized phenolic species have an enhanced antimicrobial activity and thus may be directly involved in stopping pathogen development. During the plant-pathogen interaction, oxidation processes are stimulated, which enhances the effectiveness of defense mechanisms. Thus in the present study also an increase in total phenol content was noticed as a defense mechanism. The biochemical basis of resistance in *Zingiber zerumbet* (L.) Smith, towards the soft-rot disease caused by *Pythium myriotylum* revealed higher total phenol (TP), total flavonoid (TF) and total tannin (TT) content in the uninfected susceptible ginger (*Z. officinale*) cultivar compared to the resistant taxon (Ganapathy *et al.*, 2016).

5.2.1.2 Peroxidase

In the present study, peroxidase activity increased as well as decreased following infection among the genotypes. Genotypes such as T_3 (Thalayolaparambu), T_6 (Ambalavayal), T_7 (Kothamangalam), T_8 (Karunagapally), T_9 (Mannarkkad), T_{10} (Kattapana), T_{11} (Kazhakootam), T_{13} (Sulthan Bathery), T_{14} (Murickashery), T_{15} (Nedumkandam), T_{16} (Pozhuthana), T_{18} (Kottiyoor), T_{19} (Thariyode) and T_{22} (Control 2) showed decreased peroxide activity after inoculation. All these genotypes had

disease severity >20 % except T_{18} (Kottiyoor). An increase in peroxidase activity after inoculation was noticed in T_1 (Mananthavady), T_2 (Kanchiar), T_4 (Haripad), T_5 (Kottarakkara), T_{12} (Irinjalakkuda), T_{17} (Kalliyur), T_{20} (Thalavur) and T_{21} (Control 1) (Fig 17).

Peroxidase activity was higher for genotypes of lower disease severity and disease incidence while it decreased for genotypes with higher disease severity and disease incidence. Enzyme peroxidase might have oxidized the phenols into quinones and released hydrogen peroxide and reactive radicals accelerating polymerization of phenol compounds into lignin like compounds; and thereby depositing in cell wall inhibiting further infection. Maximum peroxidase activity (16.41 ΔOD_{436nm} mg^{-1} protein min^{-1}) was observed in T_1 (Mananthavady), which had a least disease severity of 8.8 and a disease incidence of 40 %. Minimum peroxidase activity was found in T_8 (Karunagapally) (-26.08 ΔOD_{436nm} mg^{-1} protein min^{-1}) which had a high disease severity of 31.1. In a study on compost induced systemic resistance in cucumber to *Pythium* root rot and anthracnose, peroxidase activity was enhanced significantly in compost amended mixes (Zhang *et al.*, 1996). Pathogenesity test of *Pythium aphanidermatum* on Suprabha variety showed that peroxidase activity increased in leaves of inoculated plants upto 21 days of inoculation and then declined (Ghosh, 2015). Among the five ginger varieties inoculated with root- knot nematode, *Meloidogyne incognita,* highest peroxidase activity was found in IISR Mahima (Sunilkumar, 2016).

5.2.1.3 Polyphenyl oxidase

Activity of polyphenol oxidase (PPO) results in accumulation of higher concentrations of toxic products of oxidation and therefore greater degree of resistance to infection occurs (Ghosh, 2015).

Significant variation in polyphenol oxidase activity was observed before and after inoculation. Polyphenol oxidase activity increased in all genotypes after

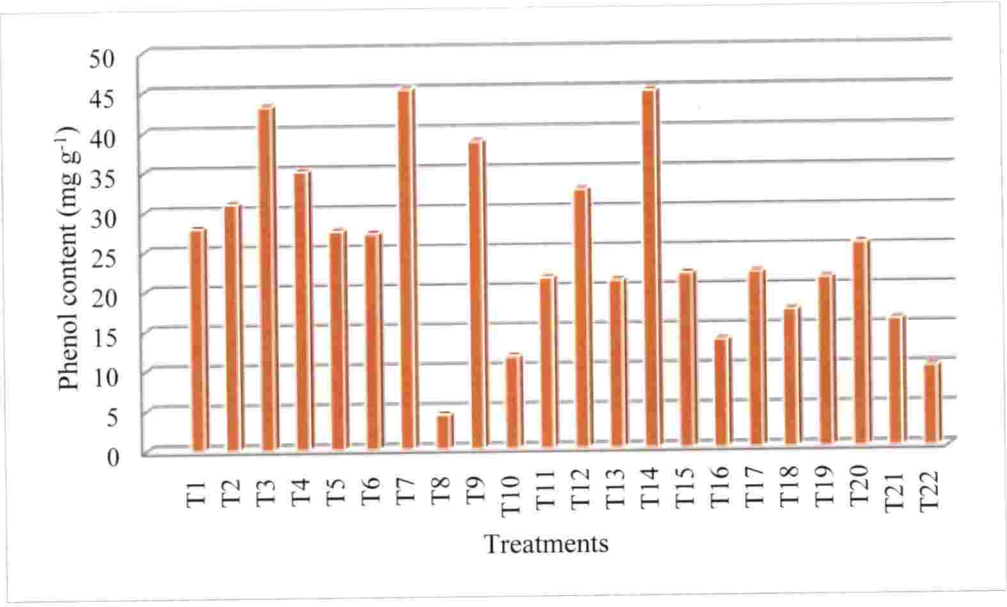


Fig 16. Total phenol content in leaf of ginger genotypes

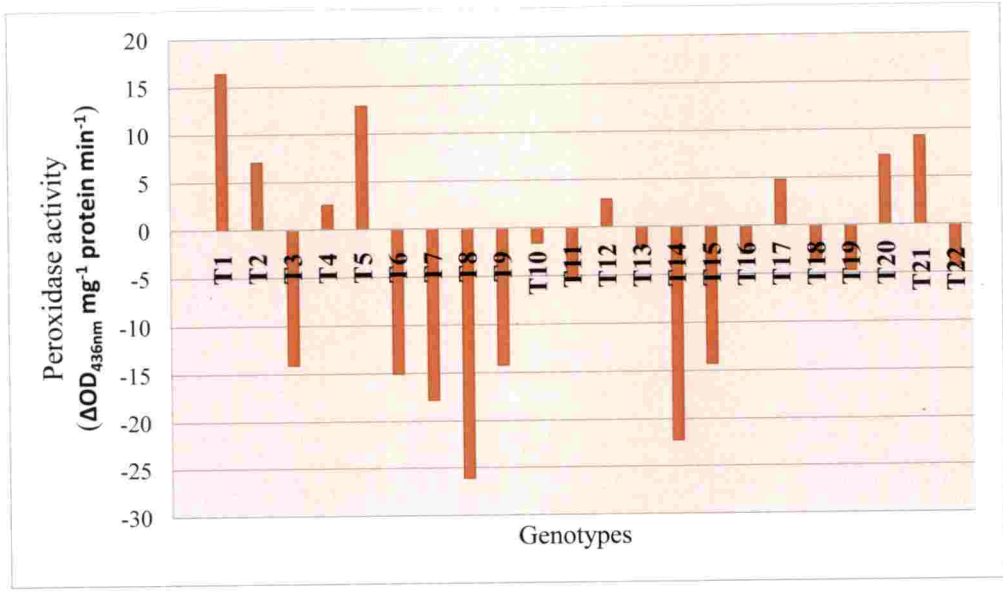


Fig 17. Peroxidase activity in ginger genotypes

inoculation. Polyphenol oxidase activity was significantly higher for T_{15} (Nedumkandam) before ($0.71\Delta OD_{490nm}$ mg^{-1} protein min^{-1}); and after inoculation with an activity of 3.51 (OD_{490nm} mg^{-1} protein min^{-1}). The lowest polyphenol oxidase activity was observed in T_{14} (Murickassery) ($0.026\Delta OD_{490nm}$ mg^{-1} protein min^{-1}). The enhancement of polyphenol oxidase activity of control varieties were 0.109 and 0.180 ΔOD_{490nm} mg^{-1} protein min^{-1} for control variety, T_{21} (Karthika) and control variety 2, T_{22} (Rio de Janeiro) respectively, following infection. Lower PPO enhancement was observed T_1 (Mananthavady), T_{12} (Irinjalakkuda), T_{14} (Murickassery) and T_{21} (Control variety Karthika) plants with less disease severity and less disease incidence(Fig 18). Ghosh (2015) evaluated enzymatic responses of ginger plants to *Pythium* infection after SAR induction and found that that polyphenol oxidase activity increased upto 14 days following inoculation and then gradually declined. The study on biochemical changes in ginger due to root-knot nematode *Meloidogyne incognita* revealed highest polyphenol oxidase activity in IISR Mahima (Sunilkumar, 2016).

5.2.1.4 Lipoxygenase

A significant difference in lipoxygenase activity was noticed before and after inoculation in all genotypes. The difference in lipoxygenase activity was significantly higher in T_{12} (Irinjalakkuda) (6.67 µ mol conjugated diene mg^{-1} protein min^{-1}) and was on par with T_{11} (Kazhakootam) which recorded 6.420 µ mol conjugated diene mg^{-1} protein min^{-1}. The difference in lipoxygenase production was the least in T_4 (Haripad) (0.02 µ mol conjugated diene mg^{-1} protein min^{-1}). The difference in lipoxygenase activity for the control varieties, T_{21} (Karthika) and T_{22} (Rio de Janeiro) were 2.769 and 1.256 µ mol conjugated diene mg^{-1} protein min^{-1} respectively (Fig 19). Lipoxygenases (LOX) use molecular oxygen to oxygenate unsaturated fatty acids such as linoleic acid and linolenic acid producing fatty acid hydroperoxide. Pathogenesity test of *Pythium aphanidermatum* on Suprabha variety showed that

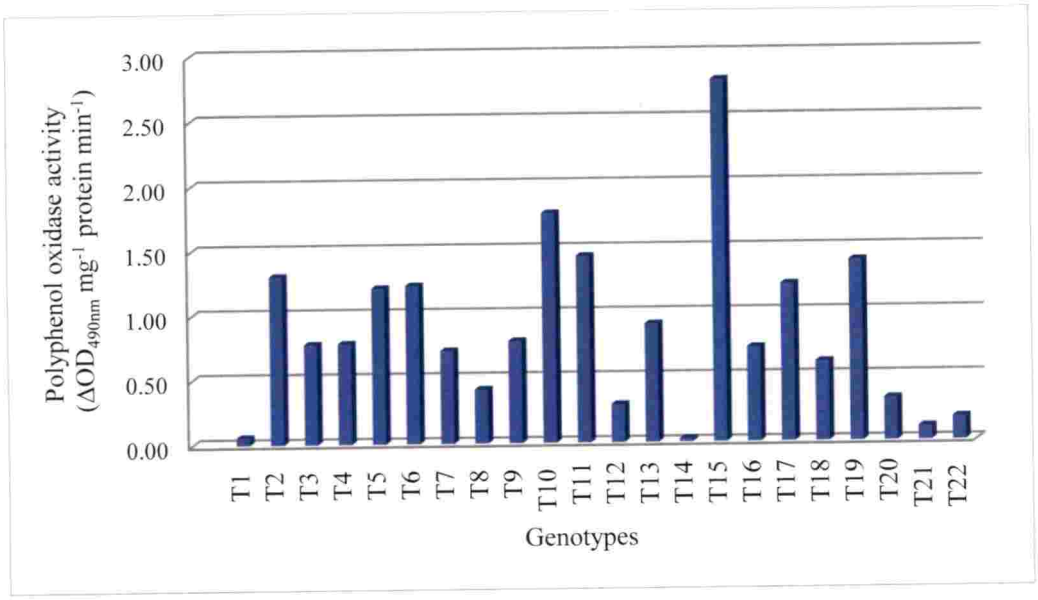


Fig 18. Polyphenyl oxidase activity in ginger genotypes

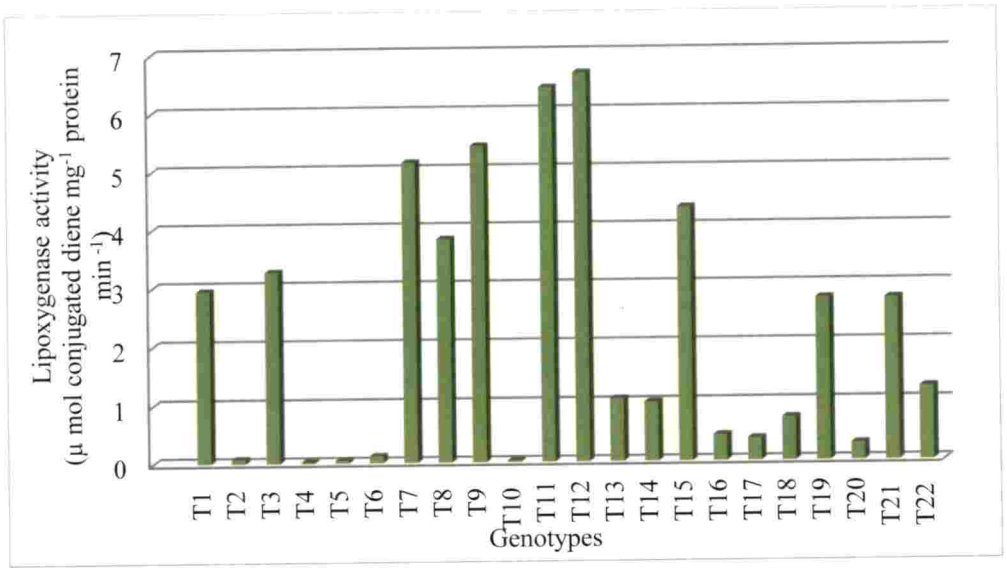


Fig 19. Lipoxygenase activity in ginger genotypes

lipoxygenase activity increased upto 14 days of inoculation and then declined (Ghosh, 2015).

Sabbagh *et al* (2017) reported a 21-fold change of *Lox* gene expression in infected plants of cucumber by (*Pythium aphanidermatum*) treated with jasmonic acid at concentration of 400 mg L^{-1} at 48 h post inoculation when compared to the control treatment. These results indicated that over expression of *Lox* gene is directly dependent on pathogen stimulation at the first days of post inoculation. These results indicated that a low concentration of jasmonic acid is able to induce systemic acquired resistance. The decretive role of *Lox* genes in systemic acquired resistance and the plant defense responses to abiotic stresses such as pathogenic fungi was thus demonstrated. The increase in lipoxygenase enzyme after infection in the present study might be due to the expression of Lox gene as a defense response against *Pythium* infection.

5.2.1.5 Phenylalanine ammonia lyase

Phenylalanine ammonia lyase (PAL), one of the key enzymes in the phenyl propanoid pathway, has a role in phytoalexin, phenolic compound and salicylic acid synthesis. Phenylalanine ammonia lyase, catalyzes a deamination of phenylalanine, a carbon-carbon double bond is formed during the release of NH_3, yielding *trans*-cinnamic acid. In some grasses, tyrosine is converted to 4-hydroxycinnamic acid in an analogous way by tyrosine ammonia lyase. The released NH_3 is probably re-fixed by the glutamine synthetase reaction (Heldt and Piechulla, 2011). The formation of phenylpropanoid phytolalexins after fungal infection involves a very rapid induction of PAL. PAL is inhibited by its product *trans*-cinnamic acid. The phenylalanine analogue aminoxyphenylpropionic acid is also a very potent inhibitor of PAL. Phenylpropanoids have an antioxidant activity and they can scavenge the reactive oxygen species (ROS), thus increasing tolerance to stressful conditions (Grace and Logan, 2000). ROS play a dual role as toxic byproducts of normal cell metabolism and as regulatory molecules in biotic and abiotic stress perception and signal

transduction. Therefore, crops that are able to increase the biosynthesis and the accumulation of these compounds usually had better tolerance to the stress conditions.

Plants with low PAL activity have thinner cell walls in the secondary xylem (Elkind *et al.*, 1990; Bate *et al.*, 1994) and reduced lignin content. In particular, the incorporation of G units into the non-condensed fraction of lignin is reduced and, consequently, S:G increases (Sewalt *et al.*, 1997a ; Korth *et al.*, 2001). The overexpression of PAL results in a small increase in Klason lignin and a decrease in the amount of S units, yielding a twofold reduction in the S:G ratio when lignin was analyzed by thioacidolysis (Korth *et al.*, 2001).

PAL activity significantly increased after inoculation in all genotypes. Significantly higher difference in PAL activity was observed in T_{18} (Kottiyoor) and T_{21} (control) which produced 1.74 μ mol cinnamic acid mg^{-1} protein min^{-1}. Least PAL activity was observed in T_{10} (Kattapana) (0.21 μ mol cinnamic acid mg^{-1} protein min^{-1}) (Fig 20). Ghosh (2015) reported an increase in PAL activity upto 14 days of inoculation and then declined in pathogenesity test of *Pythium aphanidermatum* on Suprabha variety. The study on biochemical changes in ginger due to root-knot nematode *Meloidogyne incognita* revealed highest PAL activity in IISR Mahima (Sunilkumar, 2016). Biochemical basis of resistance exhibited by a wild *Zingiber* species and *Zingiber zerumbet* (L.) Smith, against soft-rot disease caused by *Pythium myriotylum* revealed that PAL and tyrosine ammonia lyase (TAL) in the resistant wild taxon. In the ginger cultivar, even though the inherent PAL specific activity was observed to be higher (24.2 ± 1.9 U mg^{-1}) compared to the wild taxon (4.2 ± 0.8 U mg^{-1}), a subsequent gradual decrease in both PAL and TAL activities were observed following infection of rhizomes with *P. myriotylum*. But a gradual increase in PAL (13.1 ± 0.8 U mg^{-1}) and TAL (442.5 ± 35.1 U mg^{-1}) specific activity after 5 days post infection (dpi) was reported in the wild taxon (Ganapathy *et al.*,2016).

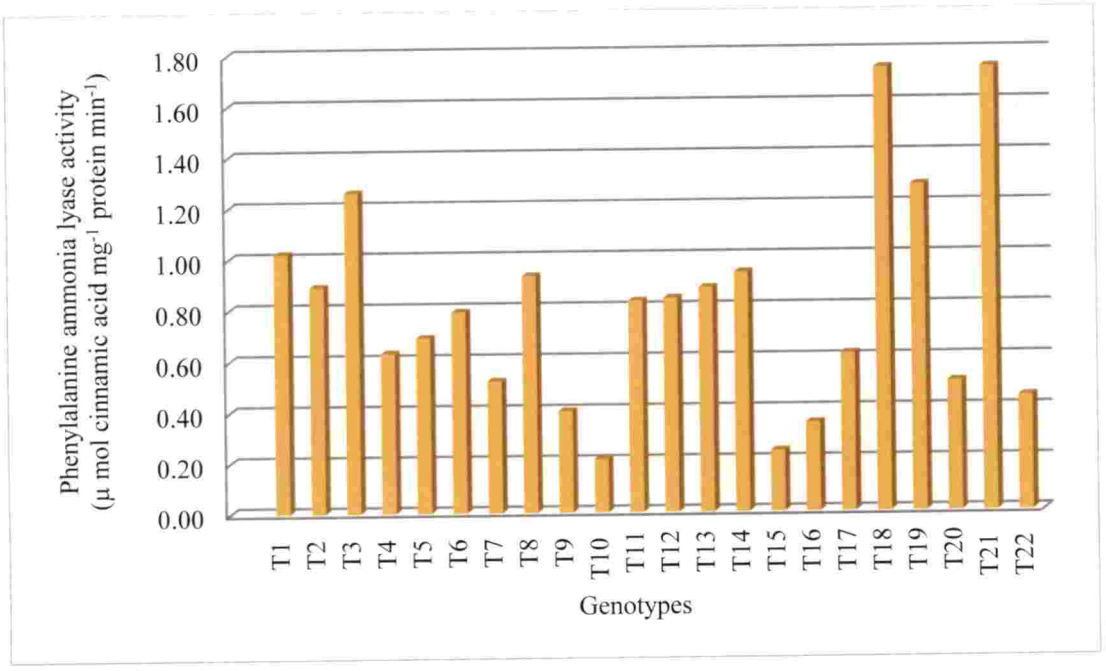


Fig 20. Phenylalanine ammonia lyase activity in ginger genotypes

5.2.2 Percentage disease incidence and percentage disease severity

In the present investigation, after one week of inoculation of *Pythium aphanidermatum* culture, no symptom development occurred. Hence the disease incidence (DI) and percentage disease index (PDI) or disease severity were 0. After 2 weeks of inoculation, symptoms were developed. Percentage disease incidence varied from 60 to 100 per cent whereas percentage disease index or severity varied from 20 to 60 at 2 weeks after inoculation. Least disease incidence of 60 per cent was exhibited by T_1 (Mananthavady), T_2 (Kanchiar) and T_{12} (Irinjalakkuda) after 2 week while T_1 (Mananthavady) exhibited least disease severity (20). Maximum disease severity (60) was found in T_{17} (Kalliyur). At three weeks after inoculation, percentage disease incidence varied from 80 to 100 per cent whereas percentage disease severity varied from 31.1 to 64.4. T_1 (Mananthavady) exhibited least disease severity of 31.1, whereas maximum disease severity was exhibited by T_{10} (Kattapana) and T_{17} (Kalliyur). The results revealed that none of the genotype was resistant to rhizome rot. However, less disease severity (31.1 %) was recorded in T_1 (Mananthavady) and T_{12} (Irinjalakkuda). Setty *et al.* (1995) evaluated 18 ginger cultivars and observed less than 3 per cent incidence in Suprabha and Himachal Pradesh. Similar results were reported by Panyanthatta (1997) who screened 148 ginger accessions in which all accessions were susceptible to rhizome rot.

5.2.2 Soil temperature from the day of inoculation till disease development

During the period of symptom development, soil temperature ranged from 25.1°C to 29.7°C. At the day of inoculation, soil temperature noted was 28.6 °C. There was a gradual increase in soil temperature from the first day of inoculation till symptom development in the ninth day with a decrease in soil temperature at second, fourth and seventh day. This decrease in soil temperature at second, fourth and seventh day was due to the increased rainfall which occurred during these days. However, no difference was noted in soil temperature between different genotypes. The soil temperature noted in second day was 25.3°C and it increased to 25.8°C on

the third day. The soil temperature at fourth day was 25.1° C and it increased to 26.4 and 28.1 ° C in the fifth and sixth day. Soil temperature on the seventh day decreased to 25.5° C and then it increased to 29.3 and 29.7° C on the eighth and ninth day of inoculation (Fig 21).

Most *Pythium* spp. prefer and even flourish in the field with high soil temperature (26-30°C) and high water content in soils (Lin *et al.*, 1971; Sarma, 1994; Stirling *et al.*, 2009). The wet soil conditions, high soil moisture and soil temperature are the most important factors influencing the development of this disease. A warm and humid climate predisposes the plant to infection at sprouting stage, because of its tender and succulent tissues (Dake, 1995). In a study on rhizome rot caused by *Pythium myriotylum* in Fiji, a soil temperature that ranged from 26 to 30°C favoured disease development (Stirling, 2009).

5.3 ENVIRONMENTAL FACTORS

5.3.1 Relative humidity

The relative humidity during the period of inoculation to symptom development ranged from 85 to 98 per cent. During the first day of inoculation, it was 85 per cent and on second day it was 95 per cent. There was a decrease in relative humidity (86 %) during the third and fourth day of inoculation. Thereafter it increased to 98 per cent for three consecutive days and then reduced to 96 per cent and 93 per cent during the eighth and ninth day of inoculation. This result is in line with the findings of Sharma and Jain (1977) who reported that extent of infection increases with the rise in temperature (23-29°C) and high relative humidity (85–95 %) in ginger.

5.3.2 Maximum temperature

The maximum temperature during the period of inoculation to symptom development ranged from 29.2 to 32.3°C. The maximum temperature during the day

of inoculation was 32.3 and it further decreased upto 29.2°C on the seventh day of inoculation and thereafter increased to 30.2°C on the day of symptom development.

5.3.3 Minimum temperature

The minimum temperature during the period of inoculation was 26°C and it decreased on second day to 24.9°C. Thereafter it was stabilized to 26°C on the third and fourth day. There after it decreased and reached 22.1°C on the eight day. On the ninth day the minimum temperature was 23.1°C.

5.3.4 Rainfall

Rainfall occurred during the period of inoculation. On the day of inoculation and on the third day there was no rainfall. On all other days, rainfall occurred and it ranged from 0.6 mm to maximum of 87.7 mm (Fig 22).

The ginger genotypes evaluated revealed higher yield for T_{11} (Kazhakootam) followed by T_{15} (Nedumkandam) which produced 65.27 and 20.87 per cent yield increase over control. Quality parameters such as starch, oleoresin and dry recovery was significantly superior for T_{12} (Irinjalakkuda) suggesting the suitability of the genotype for dry ginger. Though all the ginger genotypes including control were susceptible to rhizome rot, T_1 (Mananthavady) and T_{12} (Irinjalakkuda) exhibited comparatively less disease severity to rhizome rot. The genotype T_{11} (Kazhakootam) developed from the present study can thus be used for further evaluation for green ginger production, and T_{12} (Irinjalakkuda) for dry ginger production and resistance/tolerance to rhizome rot.

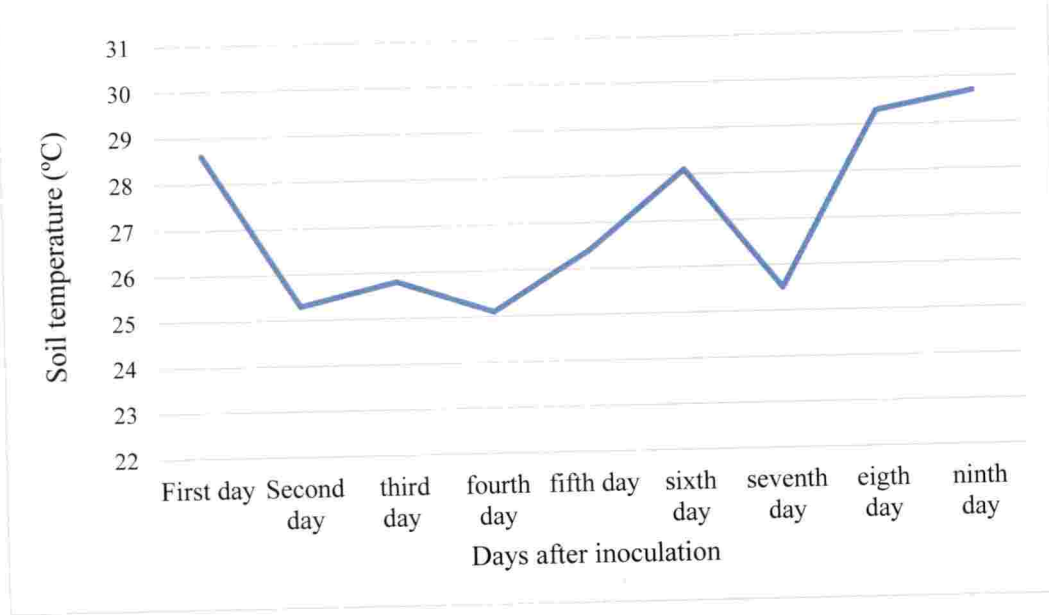


Fig 21. Soil temperature from the day of inoculation till disease development

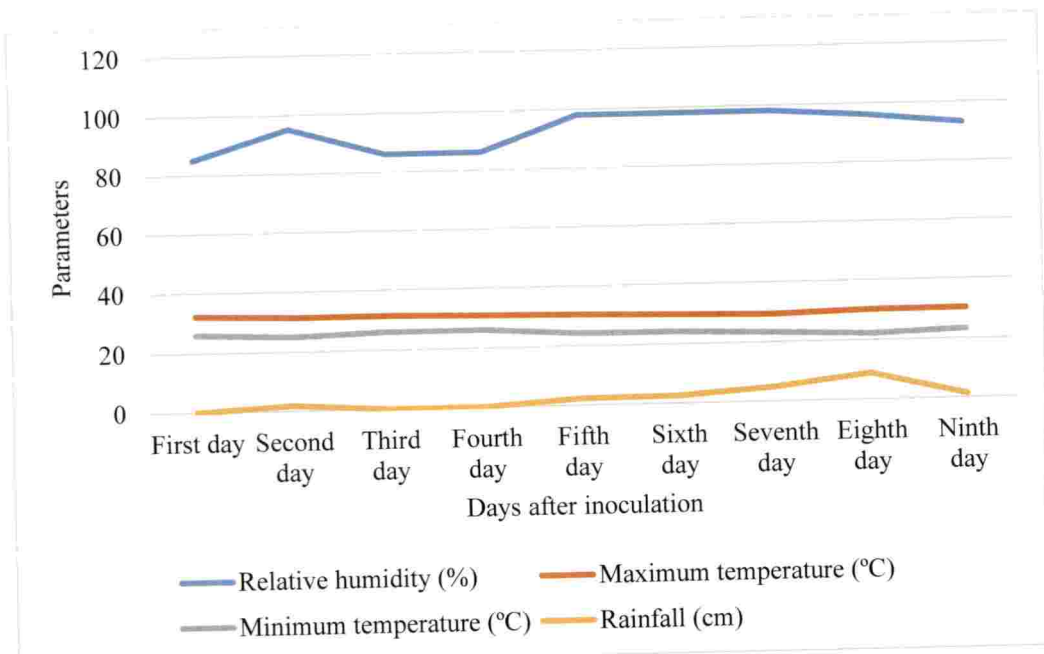


Fig 22. Weather data from the day of inoculation till disease development

Summary

6. SUMMARY

The findings obtained from the field experiment entitled "Variability in ginger (*Zingiber officinale* Rosc.) for yield and resistance to rhizome rot" is summarized in this chapter.

A field experiment was conducted at Department of Plantation Crops and Spices, College of Agriculture, Vellayani during 2017-2019 with the objective to evaluate ginger genotypes for yield and resistance / tolerance to rhizome rot.

The study was conducted as two experiments *viz.,* (i) Collection of ginger genotypes and analysis for genetic variability and yield (ii) Screening of ginger genotypes against rhizome rot under natural condition. Twenty genotypes of ginger were collected from different regions of Kerala and a control variety Aswathy were planted in Instructional Farm, College of Agriculture, Vellayani in a randomized block design (RBD) with four replications and evaluated for qualitative and quantitative characters. The twenty genotypes were designated as T_1 (Mananthavady), T_2 (Kanchiar), T_3 (Thalayolaparambu), T_4 (Haripad), T_5 (Kottarakkara), T_6 (Ambalavayal), T_7 (Kothamangalam, T_8 (Karunagapally), T_9 (Mannarkkad), T_{10} (Kattapana), T_{11} (Kazhakootam), T_{12} (Irinjalakkuda), T_{13} (Sulthan Bathery), T_{14} (Murickassery), T_{15} (Nedumkandam), T_{16} (Pozhuthana), T_{17} (Kalliyur), T_{18} (Kottiyoor), T_{19} (Thariyode) and T_{20} (Thalavur). Qualitative characterization of the genotypes was carried out based on DUS guidelines. The details of collection regarding location, village, taluk, district, latitude, longitude, altitude, habitat, ethanobotanical information, resistance/susceptibility/tolerance to pests and diseases and special characters of the collected genotypes were recorded.

The plant growth habit of the collected genotypes was mostly erect except for Thalayolaparmbu and Kalliyur, having semi-erect growth habit. All the genotypes were short type (height<100 cm) with few shoots (<10) except for T_1 (Mananthavady), T_{11} (Kazhakootam) and T_{12} (Irinjalikuda) which had medium shoot

number (10-15). Eighty five percent of the genotypes had narrow shoot diameter (<3 cm). The intensity of shoot green colour varied from green to dark green representing 134 B and 135 B and C of RHS colour chart. All the collected genotypes had short leaf length (<25 cm) with medium leaf width (<2.5-3.5 cm). The intensity of green colour of leaf varied from light green to dark green. The leaf petiole length was short (<0.5 cm) for all the genotypes except T_{17} (Kalliyoor) with medium leaf petiole length (<0.5-0.7 cm). Spike were formed only in three genotypes of which T_{16} (Pozhuthana) had yellowish white bract tip and T_5, (Kottarakkara), as well as T_{13} (Sulthanbathery) had crimson bract tip. Rhizome thickness was thin (<2cm) for all genotypes with 50 per cent straight, 30 percent curved and 20 percent zig-zagged. Rhizome skin colour was greyish yellow for all genotypes except T_8 (Karunagapally) while the flesh colour were light yellowish grey, greyish yellow and yellow.

The collected genotypes started sprouting from 7 days after planting and continued sprouting upto 20 days after planting. T_5 (Kottarakkara) recorded early sprouting of 7 days. Significant variation in plant height was observed in the selected ginger genotypes during 3, 5 and 7 MAP. Plant height was significantly superior for T_{12} (Irinjalakkuda) at 7 MAP (68.75 cm). T_{11} (Kazhakootam) recorded highest number of tillers (11.50) and dry matter production (5160.84 kg/ha) at 7 MAP. Significant variation was observed in leaf length, breadth and area among the selected ginger genotypes. Leaf length at 7 MAP was significantly higher for T_{12} (23.75cm) while leaf breadth was significantly higher for T_2 (Kanchiyar) which recorded a mean value of 3.13 cm. Leaf area was significantly higher for T_8 (Karunagapally) which was on par with T_{12} (Irinjalakkuda) and were 48.2 and 47.96 cm^2 respectively at 7 MAP. Rhizome spread (13.91 cm) and thickness (2.02 cm) were significantly superior for T_{11} (Kazhakootam). Fresh weight per plant (0.150 kg $plant^{-1}$) fresh weight per plot (2.33 kg $plot^{-1}$) as well as dry weight per plant (0.031 kg $plant^{-1}$) and per plot (0.475 kg $plot^{-1}$) and harvest index (0.60) was significantly higher for T_{11}

(Kazhakootam). Dry recovery was significantly superior for T_{12} (Irinjalakkuda) with a mean value of 21.75 per cent.

Quality attributes like starch, crude fibre, essential oil, oleoresin and total phenol varied significantly among ginger genotypes. The highest starch content of 41.90 per cent and Oleoresin (12.5 %) was recorded in T_{12} (Irinjalakkuda). The crude fibre (5.75 %) was significantly higher for T_{16} (Pozhuthana) while essential oil percentage (2.42 %) was significantly superior for T_{20} (Thalavur). The highest total phenol content (82.44 mg standard $100g^{-1}$) was recorded in T_2 (Kanchiar).

At four months after planting, natural incidence of rhizome rot caused by *Pythium aphanidermatum* was observed. Disease incidence was lowest in T_{12} (Irinjalakkuda) (4.11 %). No pest incidence was reported in the field.

Genetic analysis for characters revealed significant difference among the genotypes for characters such as plant height, number of tillers, leaf area, rhizome spread, rhizome thickness and oleoresin. Phenotypic (500.20) and Genotypic variance (498.96) was found to be highest for rhizome yield which was followed by total phenol content. Total phenol content recorded a phenotypic variance of 394.38 and genotypic variance of 391.64. Phenotypic coefficient of variation was a little bit higher than the genotypic coefficient of variation for all characters indicating that environment played very little role in the expression of the characters and hence a wider scope to select genotypes for yield. The genotypic coefficient of variation (GCV) ranged from 1.28 per cent for leaf breadth to 44.36 per cent for crude fibre content. The value of phenotypic coefficient of variation (PCV) ranged from 1.65 per cent for leaf breadth to 44.84 per cent for crude fibre content. High heritability (>60 %) coupled with high genetic advance (>20 %) was observed for rhizome yield, oleoresin, phenol content, crude fibre, rhizome thickness, yield and essential oil. The highest heritability was found for rhizome yield (99.75 %). The highest estimate of genetic advance was observed for crude fibre content (90.43 %). In the present experiment high genetic advance, high heritability as well as high genotypic

coefficient of variation was recorded for characters like crude fibre, total phenol content, oleoresin, rhizome yield, essential oil and rhizome thickness indicating that selection for these characters could be more effective due to additive gene action.

Yield per plant was found to be significantly and positively correlated with plant height, number of tillers, leaf area, rhizome spread, rhizome thickness and oleoresin content. Path analysis revealed that leaf area (0.96), number of tillers (0.74) and rhizome spread (0.50) had maximum positive direct effect on yield per plant. Rhizome thickness and oleoresin showed a positive direct effect of 0.37 and 0.017 on yield. Plant height showed a negative direct effect on yield plant^{-1} (-0.16).

Screening of ginger genotypes against rhizome rot using cultures of *Pythium aphanidermatum* under natural condition revealed significant variation in phenol content, peroxidase, polyphenyl oxidase, lipoxygenase and phenylalanine ammonia lyase activities among genotypes before and after inoculation. The phenol content in leaves increased in all genotypes after the inoculation. Maximum increase in phenol content was observed in T_7 (Kothamangalam) (45.27 mg^{-1}g^{-1}). Peroxidase activity increased as well as decreased following infection among the genotypes. The highest peroxidase activity of 16.41 ΔOD_{436nm} mg^{-1} protein min^{-1} was found in T_1 (Mananthavady) where the disease severity was the lowest (8.8). Polyphenol oxidase activity increased in all genotypes after inoculation. Polyphenyl oxidase activity of 2.79 ΔOD_{490nm} mg^{-1} protein min^{-1} was found to be significantly higher in T_{15} (Nedumkandam). Lipoxygenase activity also increased in all genotypes after inoculation. Lipoxygenase activity was significantly higher in T_{12} (Irinjalakkuda) (6.668 µ mol conjugated diene mg^{-1} protein min $^{-1}$). Significantly higher difference in phenylalanine ammonia lyase activity was observed in T_{18} (Kottiyoor) which produced 1.74 µ mol cinnamic acid mg^{-1} protein min $^{-1}$. After 2 weeks of inoculation of cultures of *Pythium aphanidermatum*, the characteristic symptoms were developed. The percentage disease incidence varied from 60 to 100 per cent, whereas percentage disease index or severity varied from 20 to 60. The percentage disease

incidence and disease severity were significantly lower for T_1 (Mananthavady). A gradual increase in soil temperature was found from the day of inoculation (25.3°C) till disease development (29.7°C). The relative humidity increased from 87.4 % in the day of inoculation to 94.6 % till disease development. Rainfall increased from 1.9 cm to 2.83 cm. Maximum temperature decreased from 33.5°C to 30°C and minimum temperature decreased from 26.5°C to 23.6°C during disease development. The environmental conditions of increased soil temperature, relative humidity, maximum and minimum temperature were congenial for the disease development.

In the present study, evaluation of the ginger genotypes revealed higher yield for T_{11} (Kazkakootam) followed by T_{15} (Nedumkandam) which produced 65.27 and 20.87 per cent yield increase over control. Quality parameters such as starch, oleoresin and dry recovery were significantly superior for T_{12} (Irinjalakkuda). All genotypes were susceptible to rhizome rot, however the percentage disease incidence and disease severity were comparatively lower for T_1 (Mananthavady) and T_{12} (Irinjalakkuda). Thus, the present study suggests the suitability of T_{11} (Kazhakoottam) for green ginger and T_{12} (Irinjalakkuda) with less rhizome rot severity for dry ginger production.

Future line of work

- The varieties with higher yield over the control need to be further evaluated.
- Variety with high quality need to be evaluated for dry ginger purpose.
- More varieties has to be screened for rhizome rot and bacterial wilt resistance.

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VARIABILITY IN GINGER (*Zingiber officinale* Rosc.) FOR YIELD AND RESISTANCE TO RHIZOME ROT

by

ANARGHA T.

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ABSTRACT

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COLLEGE OF AGRICULTURE

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ABSTRACT

A field experiment entitled "Variability in ginger (*Zingiber officinale* Rosc.) for yield and resistance to rhizome rot" was conducted at Department of Plantation Crops and Spices, College of Agriculture, Vellayani during 2017-2019 with the objective to evaluate ginger genotypes for yield and resistance/tolerance to rhizome rot.

The study on variability in ginger (*Zingiber officinale* Rosc.) for yield and resistance to rhizome rot was conducted as two experiments (i) Collection of ginger genotypes and analysis for genetic variability and yield (ii) Screening of ginger genotypes against rhizome rot under natural condition. Twenty genotypes of ginger collected from different regions of Kerala and a control variety Aswathy were planted in Instructional Farm, College of Agriculture, Vellayani in a randomized block design with four replications. Qualitative characterization of the genotypes was carried out based on DUS guidelines. Plant growth habit of collected genotypes included erect and semi-erect types. All the genotypes were short type (height<100cm) with short leaf length (<25cm), medium leaf width (2.5-3.5cm) having few (<10) and medium (10-15) shoots. The intensity of shoot colour noticed was green and dark green while that of leaf were light green, green and dark green. The leaf petiole length was short (<0.5cm) for all the genotypes except T_{17} (Kalliyur). Spikes were formed only in three genotypes of which two had crimson bract tip and other had yellowish white tip. Rhizome thickness was thin (<2cm) for all genotypes except T_{11} (Kazhakootam) with medium (2-3cm) thickness with straight, curved and zigzagged rhizome shape. Greyish yellow rhizome skin colour was predominant while the flesh colour were light yellowish grey, greyish yellow and yellow.

The collected genotypes sprouted from 7 days after planting and continued upto 20 days after planting. Plant height was significantly superior for T_{12} (Irinjalakkuda) while the number of tillers and dry matter content was significantly higher for T_{11} (Kazhakootam) at 7 MAP. Leaf area for T_8 (Karunagapally) was 48.2 cm^2 which was

significantly higher and on par with T_{12} (Irinjalakkuda) which had 47.96 cm^2 at 7 MAP. Rhizome spread (13.91 cm), rhizome thickness (2.02 cm) fresh weight per plant (0.150 kg $plant^{-1}$) fresh weight per plot (2.33kg $plot^{-1}$), dry weight per plant (0.031kg $plant^{-1}$), dry weight per plot (0.475kg $plot^{-1}$) and harvest index (0.60) were significantly higher for T_{11} (Kazhakootam). Dry recovery, starch content and oleoresin were significantly superior for T_{12} (Irinjalakkuda). Crude fibre content of T_{16} (Pozhuthana) was significantly higher (5.75 %) while the essential oil content (2.42 %) was significantly higher inT_{20} (Thalavur).

Significant variation existed among the genotypes for characters such as plant height, number of tillers, leaf area, rhizome spread, rhizome thickness and oleoresin. Phenotypic coefficient of variation (PCV) was a little bit higher than the genotypic coefficient of variation (GCV) indicating that environment played very little role in the expression of the characters. Crude fibre registered highest GCV (44.36) and PCV (44.84). High heritability coupled with high genetic advance was observed for rhizome yield, oleoresin, phenol, crude fibre, rhizome thickness and essential oil. Yield per plant was found to be significantly and positively correlated with plant height, number of tillers, leaf area, rhizome spread, rhizome thickness and oleoresin content. Path analysis revealed that leaf area, number of tillers and rhizome spread had maximum positive direct effect on yield per plant.

Ginger genotypes screened against rhizome rot using cultures of *Pythium aphanidermatum* under natural condition revealed increased phenol, polyphenyl oxidase, lipoxygenase and phenylalanine ammonia lyase activity in all genotypes after inoculation. Peroxidase activity was higher for genotypes of lower disease severity while it decreased for genotypes with higher disease severity. The percentage disease incidence and disease severity were significantly lower for T_1 (Mananthavady) and was on par with T_{12} (Irinjalakkuda). Soil temperature ranged from 25.3°C to 29.7°C while maximum temperature varied from 29.2°C to 32.4°C, minimum temperature from

24.9°C to 26°C, relative humidity from 93% to 98 % and rainfall from 2.5cm to 28.3cm during the period of symptom development.

The ginger genotypes evaluated revealed higher yield for T_{11} (Kazhakootam) followed by T_{15} (Nedumkandam) which produced 65.27 and 20.87 percent yield increase over control. Quality parameters such as starch, oleoresin and dry recovery was significantly superior for T_{12} (Irinjalakkuda) suggesting the suitability of the genotype for dry ginger. Screening the ginger genotypes for rhizome rot under natural condition, revealed less disease severity in T_1 (Mananthavady) and T_{12} (Irinjalakkuda). The genotype T_{11} (Kazhakootam) developed from the present study can thus be used for further evaluation for green ginger production, and T_{12} (Irinjalakkuda) for dry ginger production and resistance/tolerance to rhizome rot.