

Zingiber officinale L.

MONOGRAPH



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INTRODUCTION

Zingiber officinale, more commonly known as ginger, is a flowering plant based on rhizomes, commonly used as a spice and well renowned for its medicinal properties. It is widely used in South East Asia and is considered one of the most resilient spices for its versatility in growing strategies and natural resistances to a wide range of fungi and bacteria. Belonging to the oldest and largest family of the Old World, Ginger is thought to have origins and distribution in every continent on Earth (with the exception of Antarctica). It is a cyclical perennial plant, thriving in between 9-12 months after planting, with the successful production of ginger relying mainly on adopting suitable agronomic practices.

Characterized by having robust and fleshy rhizomes, *Zingiber officinale* is known to grow horizontally at a shallow depth, provoking terrain deformity in its immediate vicinity. It's robustness and resilience comes primarily from its vegetative propagation, its asexual reproduction causes for low genetic diversity, giving it a low chance of mutating; however, this also means that it has little protection against the few diseases and fungi that do affect it.

Natural and nursery regeneration and propagation of the species have resulted as great plant growth regulators and have similar outcomes. The most expeditious part of the management and control of ginger is found in the initial stages, where it can get overwhelmed by weeds due to its slow initial growth rate. These are found to cause a 65% reduction in yield if not properly addressed. Relatively, the yield can vary depending on the time of plantings in relation to the size of seed, which will be later shown in depth. Moving on, the harvesting procedure for this produce depends on the end use, which will be later shown.

The aforementioned components have made *Zingiber officinale* the third most important and traded spice globally. It contains vast amounts of uses; particularly medical ones. First records of use dates back to 500 BCE, and its culinary uses range from being pickled in vinegar, to tea-making, to used as a side dish or condiment. Medically, it's considered as one of the healthiest spices on the planet, and has a very long historical use in various forms of traditional and alternative medicine. It is used to reduce nausea, aid in digestion and fight the common cold. Moreover, it's components have powerful anti-inflammatory and anti-oxidant effects, along with anti-diabetic and anti-cancerous properties, being analyzed and categorized as a powerful agent against most diseases, found mainly in pharmacological presences as an ingredient in alternative supplements.

During the development of this monograph, four chapters rich in information will supply and answer any particular doubt regarding *Zingiber officinale*. The first chapter will be focused on the ecology behind ginger, and cover topics ranging from its distributional context, to its environmental factors and properties. The second chapter will cover the biology of *Zingiber officinale* and cover chromosome complements, phenology and life cycles, along with its reproductive biology. The third chapter will cover its Propagation and Management, along with its natural regeneration, nursery propagative stages, and its planting, management and procedures behind pest control, harvesting and quality control. Ultimately, this monograph will go into emerging products and markets when analyzing its commercial importance and *Zingiber officinale*'s role in the agricultural and medical industries, concluding the monograph.

The overall impact of *Zingiber officinale*, whether historical or current, is difficult to measure. Regardless, it is undoubtedly one of the most recognized and important spices that has propelled the economic agricultural sectors of many nations. This monograph will aim to highlight and emphasize the importance of this product and its global impact.

1. ECOLOGY

Ginger is grown primarily in the tropical regions, up to an altitude of 1500m, yet mostly found and cultivated in low altitudes (Kaufman S. 2016). It being a crop with a preference for warm, sunny conditions, grows with the aid of shade during hot periods, yet considered by many as unnecessary (Royal Botanic Gardens Kew, 2016). It has an optimal rainfall of 2500-3000 mm distributed throughout the year. Furthermore, Kaufman suggested that anything below 2000 mm would require supplementary irrigation, but ginger seldom succeeds as an irrigated crop in dry areas. It is very sensitive to water logging and has a preferred soils of medium loams with an adequate supply of organic matter, yet grows on a wide range of soils with a pH of 6.0-7.0 with preferably high soil fertility, provoking the use of manure to be applied in the planting process.

1.1 DISTRIBUTIONAL CONTEXT

Zingiber officinale L. (ginger) has been grown in Asia since ancient times. It was brought to Europe and East Africa by traders from India, along with pepper and other spices. It was one of the most commonly traded spices in the 12th-14th centuries, particularly by the hands of the Portuguese and Dutch (Sutarno et al., 1999). Wild forms of ginger have not been found, and its origin is uncertain, although it is thought to come from India or South East Asia. From East Africa, Portuguese ships brought ginger to West Africa and the tropics throughout the 16th century. At about the same time period, Spaniards began introducing ginger into Jamaica, which produced and still produces high quality ginger (Sutarno et al., 1999; NTB, 2016). In the modern era, ginger is cultivated primarily in the humid tropics, mainly in the Caribbean and South East Asia (Vascular Plants of Ecuador, 2016; Flora Mesoamericana, 2016), however is noted as naturalized in Central Africa (Randall, 2012).

1.1.1 Affinities

Zingiber officinale is a member of the kingdom of Plantae being allocated to the family of Zingiberaceae (Roscoe, 1753-1831) and being a Herbaceous perennial type. Zingiberaceae has been commonly divided into about 56 genera and about 1,300 species (Britannica. 2020). Phylogenetic analyses have been conducted on the Zingiber family in which metabolic profiling were used to investigate the diversity of plant material between *Zingiber officinale* and the rest of the Zingiberaceae family. Samples from different geographical origins were genetically indistinguishable whilst other members of the family were significantly divergent, allowing for the identification and separation of each

variant into its individual use and identification by the agricultural community. The metabolic profiling performed discovered that the *Z. officinale* samples drawn from several different origins showed no qualitative differences in major volatile compounds. On the other hand, they did show some significant quantitative differences in non-volatile composition, particularly the content of gingerols, the active anti-inflammatory compounds in this species which was then proved by the HPLC (*High-performance liquid chromatography*) (Horváth, 1970). Jiang (2006), suggested that comparative DNA sequences and chemotaxonomic phylogenetic trees showed that the chemical characters of the investigated species were able to generate essentially the same phylogenetic relationships as other samples of *Zingiber officinale*. This further supports the contention that chemical characters are effective to identify relationships between plant species. Furthermore, he suggested that even after identification by molecular and/or chemical tags, the actual bioactive compounds need to be identified and quantified to ensure the bioactivity of a given ginger sample. *Zingiber officinale* is one of the few that has used in vitro anti-inflammatory assays to study extracts of ginger species to inhibit "LPS-induced PGE(2) and TNF- α production", suggesting that crude metabolic profiling or phylogenetic analysis may not The biological activity of other ginger compounds is easily predicted. Therefore, identification and quantification of the actual bio active compounds are required to guarantee the bioactivity of a particular *Zingiber* sample even after performing authentication by molecular and/or chemical markers. Additionally, the Zingiberaceae family is closely related to the *Musaceae* family, or commonly known as bananas, being direct children of the Zingiberales. D'Hont, Denoeud, Aury *et al.*(2012) compared the distribution of GC3 content (G or C in the third codon position) in *Musa* coding sequences with different children of the Zingiberales, among them, *Zingiber officinale*. They found that this distribution was shown to be modal in Poaceae and unimodal in all analyzed eudicotyledons (Carels & Bernardi, 2000). Furthermore, D'Hont suggested that in *Musa*, GC-rich peaks were apparent but less distinct from the GC-poor one, a feature that was shared with ginger; contrasting the unimodal GC distribution of date-palm coding sequences.

Figure 1.

Taxonomic Hierarchy of Zingiber officinale Roscoe. Retrieved 14 Jan. 2022, from the Integrated Taxonomic Information System (ITIS) on-line database.

Taxonomic Hierarchy	
Kingdom	Plantae – plantes, Planta, Vegetal, plants
Subkingdom	Viridiplantae – green plants
Infra kingdom	Streptophyta – land plants
Superdivision	Embryophyta
Division	Tracheophyta – vascular plants, tracheophytes
Subdivision	Spermatophytina – spermatophytes, seed plants, phanérogames
Class	Magnoliopsida
Superorder	Liliana – monocots, monocotyledons, monocotylédones
Order	Zingiberales
Family	Zingiberaceae – Ginger Family
Genus	Zingiber Mill. – ginger
Species	Zingiber officinale Roscoe – garden ginger

Note: *Musaceae*(bananas) are closely related to ginger, being a part of the Zingiberales Order.

1.1.2 Fossil Record

The Zingiberaceae family can be traced back to staunch marks tracing back to approximately the 20-million-year range of the genus. *Zingiberopsis attenuata* (Hickey and Peterson, 1978) is a new species of a monocotyledon form from the Paleocene Paskapoo Formation of Alberta. These archaeologists found that leaves of this species with their parallel veins were grouped into three size sets which are intermediate between the Late Cretaceous. Furthermore, *Zingieropsis magnifolia* (Knowlton), a new combination was found to have four discrete sets and *Zingiberopsis isonervosa* (Hickey, 1978), of the late Paleocene and early Eocene age, with only one set of the genus. The morphology of this genus matches that of *Alpinia* in the Zingiberaceae, exceptioning a greater irregularity of the parallel vein set and lack of evidence of a ligule on the petiole as in *Alpinia*. Scientists of the *Zingiberopsis* have proven a clear trend towards the wider loss of the wider parallel vein subsets over this 20 million year range of said genus. Additionally, the overlooked character of this arrangement may have potential taxonomic determination of monocotyledonous leaves.

1.1.3 Origin

Zingiber officinale is thought by many to have originated in India or Southeast Asia (Flora of North America Editorial Committee, 2016; Royal Botanic Gardens Kew, 2016). It has been widely planted in tropical areas including other parts of Asia, the Caribbean, Central and South America, Australia, and Africa (Sutarno et al., 1999; Randall, 2012), but as plants are often cultivated in forests, it is difficult to distinguish whether plants are cultivated or if they have escaped cultivation. According to Whittmore(2000), Zingiberaceae are the most diverse family in the Old World. Several different species of this family have been often spicy in taste, and have been often used for medicinal purposes and flavoring, the most important of which are ginger (*Zingiber officinale.*), turmeric and cardamom. These

are identified via the pungent bio active principles of *Zingiber officinale* of which their variations in the HPLC profiles create a characteristic pattern of each origin. As a result, these ginger profiles tended to be grouped and separated on the basis of the geographical closeness of their countries of origin (Yudthavorasit, 2014).

1.1.4 Present distribution

Climate change has a crucial influence on plant resources distribution. Species belonging to the *Zingiber* genus are important crop resources in various countries, particularly in China, where their rhizomes are widely distributed in medicine and food. Zheng (2019), studied the ecological distribution and richness which showed that the genus is widely distributed in 28 provinces in China, with the greatest richness in Guangxi, Guangdong, and Yuannan. He states, “Based on our model, precipitation of the driest month, precipitation of the warmest quarter, and the minimum temperature of the coldest month were the most significant bioclimatic variables controlling the distribution of five selected *Zingiber* species. Future climate change will likely result in the increase of suitable habitat area for *Zingiber officinale* by 2.85%, but dramatically decrease that for *Zingiber striolatum* by 18.04%, *Zingiber zerumbet* by 17.87%, *Zingiber corallinum* by 12.40%, and *Zingiber mioga* by 9.46%. Thus, conservation measures should be taken to preserve these valuable resources.” As of the 25th of February, 2021, Ginger is present naturally in over 50 countries (Kaufman S, 2016). Figure 2 displays the top ten producers of ginger during 2020, in which countries in South East Asia produced the largest amounts due to their optimal tropical climates and amount of precipitation and fertility in these lands - table 1 below.

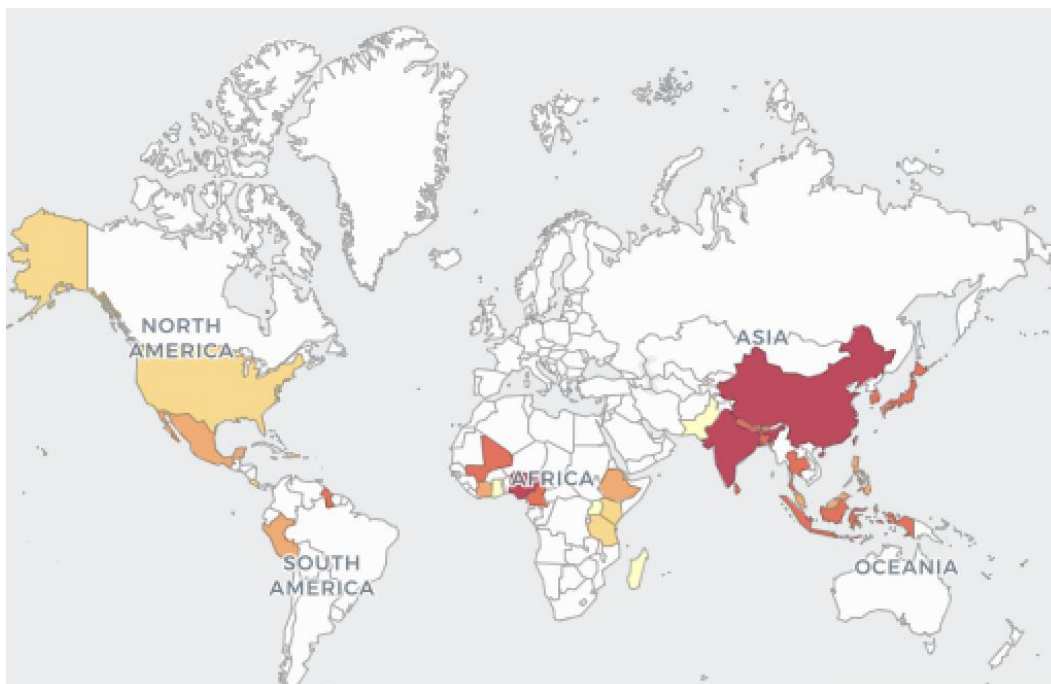
Table 1.

Largest Zingiber officinale producers worldwide in 2020 (FAOSTAT, 2020).

RANKING	COUNTRY	PRODUCTION(TONNES)
1	India	1,844,000
2	Nigeria	734,295
3	China, mainland	618,904
4	Nepal	298,945
5	Indonesia	183,518
6	Thailand	167,021
7	Bangladesh	84,887
8	Cameroon	65,453
9	Japan	46,136
10	Sri Lanka	42,019

Figure 2.

Distribution of worldwide average ginger production (1994 -2020) Amended from the Food and Agriculture Organization of the United Nations (FAOSTAT), (2020).



1.2 ENVIRONMENTAL FACTORS IN DISTRIBUTION

Huang and Zheng (2019), have predicted that as a cause of climate change, the production area suitable for the growth of *Zingiber officinale* will grow 2.85%, but drastically reduce suitable habitats for other genres of the Zingiberaceae family, particularly *Zingiber striolatum* by 18.04%, *zerumbet* by 17.87%, *cornallium* by 12.40%, and *mioga* by 9.46%. Furthermore, in the present study, the effects of climate change on Zingiber species distribution, diversity, and richness were predicted to protect the genetic richness of these resources and to help identify new areas for their cultivation. Regardless of this, conservation measures should be taken to preserve these valuable resources.

1.2.1 Elevation and Climate

Zingiber officinale is grown primarily in tropical and subtropical altitudes, ranging up to 1500m above sea level. This crop prefers warm, sunny conditions. Ranging from the absolute minimum being 0° C and the higher limit of 38° C. Mean annual temperature of these crops range from 20°-30° C (CABI, 2016). This is a constant with most of the Zingiberaceae with the exception of *Zingiber montanum* (cassumunar ginger), which can grow up to an elevation of 3,000m(Wolff et al., 1999).

1.2.2.1 Rainfall, potential evapotranspiration and water deficits

Studies conducted around the area of southern Nigeria within the agricultural zone proved to be ideal for the production of *Zingiber officinale* (Journal of Agricultural Science, 2014). The area maintains an average annual rainfall of 2500mm, mean minimum and maximum temperature of 23.50C and 32.10C respectively, with relative humidity ranging from 70- 85% and the annual evapotranspiration is 1450mm (NIMET, 2010). For optimum yield level, *Zingiber officinale* requires rich organic soil or valley clay that is well drained. Ultimately an annual rainfall level of about 1020 mm has been proven to be adequate for this crop to thrive well, otherwise, an annual rainfall level of 760 mm with supplementary irrigation will be required (Sharma, 2017). The crop will thrive well at any altitude up to 1500 m above sea level. Growing it requires a warm and moist climate with ample sunshine and heavy rainfall.

1.2.2.2 Temperature regime

Most variations of the Zingiberaceae enjoy temperatures around 20°-30° C, henceforth explaining the main environmental factor in distribution(Sharma, 2017; Kaufman S, 2016). Populations north of the equator prosper due to its well regulated temperature(mean annual temperature generally 22-29°C), with the only major crop fields below this line being in Indonesia on the island of Java.

1.2.2 Geology and soils

Zingiber officinale requires rich organic soil or valley clay that is well drained (Sharma, 2017). It is very sensitive to water logging and has a preferred soils of medium loams with an adequate supply of organic matter, yet grows on a wide range of soils with a pH of 6.0-7.0 with preferably high soil fertility, provoking the use of manure to be applied in the planting process. The soil should be high in organic matter, available calcium, and nutrients. It should be free of weeds that can harbor cutworms, which attack young shoots as they emerge, and disease-causing organisms. Field preparation begins in late fall with plowing of the soil to a depth of 46-61 cm (18-24 in) and incorporation of liming material to adjust the soil pH and supply the high calcium requirement of the ginger plant(Sutarno et al., 1999; Kaufman S, 2016).

2 BIOLOGY

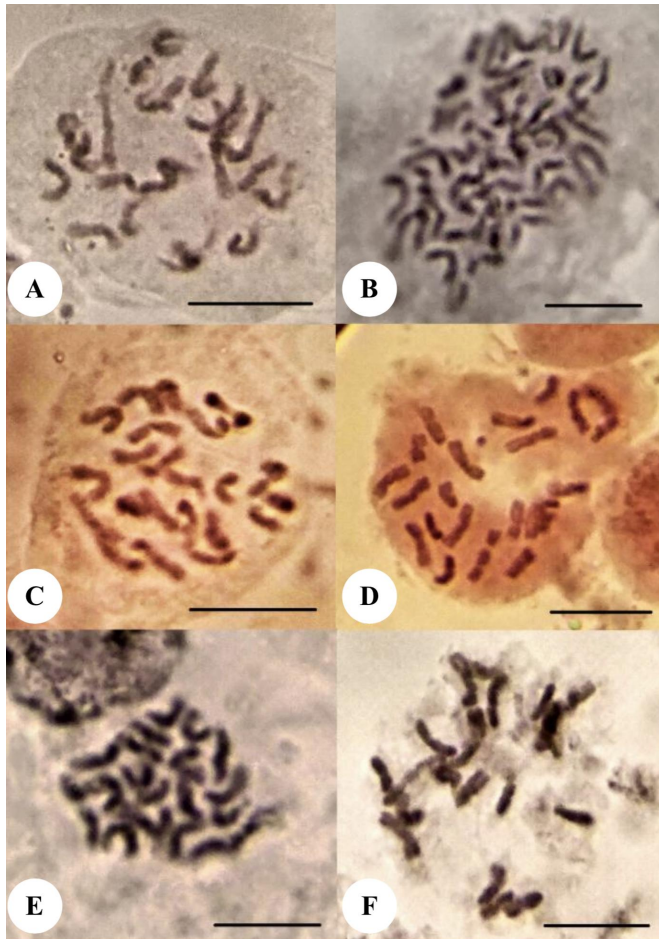
Zingiber officinale's complex biology is what this chapter will be concerned with understanding its chromosome complement, life cycle and phenology, and its reproductive biology and ecophysiology.

2.1 CHROMOSOME COMPLEMENT

The chromosome number in seedlings is an important trait in understanding the genetics of plants. The chromosome number of ginger was reported as $2n=22$ by Moringa et al.(1929) and Sugiura (1936). These mitotic studies led to a further report produced by Raghavan and Venkatasubban (1943) on the cytology of three species of ginger, among them *Zingiber officinale* which evidenced that all the three had the somatic chromosome number $2n=22$. Based on the above evidence, researchers concluded that the chromosome morphology of *Zingiber officinale* was different from that of the other two species. Furthermore Darlington and Janaki Ammal (1945) reported two “B” chromosomes in certain types of ginger in Addison to the normal complement. Chakravorti(1948) concluded that in view of the normal pairing of 11 bivalents in species, such as *Z. Cassumunar* and *Z. Zerumbet*, *Z. Mioga* having a somatic chromosome number $2n=55$ is to be considered a pentaploid. As is shown in figure 3—below, the cytological information and genetic relationships among six species of *Zingiber* in which the somatic chromosome numbers observed were all very similar yet all had their major differences. Particular emphasis was placed on *B* and *D* which as is shown in figure 3, were the main focus of the profiling. *Z. kangleipakense* in relation to the chromosome complement of *Zingiber officinale*.

Figure 3.

Chromosome numbers, RAPD and ISSR profiles of six *Zingiber* species. (Bidyaleima et al., 2019).



Note: Somatic metaphase chromosomes in six *Zingiber* species. A) *Zingiber capitatum* ($2n = 22$); B) *Z. kangleipakense* ($2n = 44$); C) *Z. montanum* ($2n = 22$); D) *Zingiber officinale* ($2n = 22$). E) *Z. zerumbet* ($2n = 22$) and F) *Z. kerrii* ($2n = 22$).

2.2 LIFE CYCLE AND PHENOLOGY

2.2.1 Life Cycle

Zingiber officinale is a cyclical perennial plant, meaning that it can grow for several years, taking between eight to ten months to grow (Idris, 2021). It thrives in zones 9-12(NCSU et al.), giving the option to grow this tropical plant in a container during cooler climates. As a whole plant, it forms via clumping and spreading its rhizomes in rich organic matter, characterized by a medium growth rate and maintenance required. Once growing, the rhizome root sends up firm stems, bearing widely spaced long

oval-lanced, green leaves. These stems reach a maximum height of nearly 6 feet over the course of a tropical summer (Zain, 2022).

The initial germination of ginger begins underground, where the initial root begins to swell, storing sugars and starches created by the foliage during photosynthesis. This rhizome develops a tan skin with numerous lobes or knobs, from which emerge new stems, effectively becoming new “plantlets”. Henceforth, undisturbed ginger plants may produce flower stalks with dense flower clusters called an inflorescence during the summer rainy season. The main active components in ginger are gingerols, which are responsible for its distinct fragrance and flavor.

2.2.2 Phenology

Successful production of ginger depends on efficient use of available resources by adopting suitable agronomic practices. Such practices include various different things such as land preparation, seed selection, seed rate, seed treatment, planting season, depth of planting, mulching, nutrient management, use of growth regulators, weed control, shade requirement and harvest management are reviewed in detail (Kandiannan et al., 1996).

2.2.2.1 Flowering and fruiting

Gadani(2018), suggested that flowering and fruiting time was between March and April, specifying that it does however have the capacity to be grown as an annual crop. Furthermore, *Zingiber officinale* is characterized for the robust and fleshy rhizomes, which can go up to 2 cm thick, growing horizontally underground, but at a shallow depth, provoking terrain deformation in its immediate vicinity. Kaufman (2016), suggests that some cultivars flower rarely, especially when grown undisturbed as perennials. Flowering is cultivar-dependent, and different cultivars vary in karyotype(Ravindran & Babu, 2005).The previously mentioned ginger rhizomes normally only branch in the vertical plane, so they are flat on the sides and stand upright with the soil. *Zingiber officinale* also has a very similar appearance to *Zingiber zerumbet*, with the difference being in the flowers cone-like growth, resembling pine cones and having wider leaves (Acevedo-Rodríguez & Strong, 2005).

2.2.3. Pests and diseases

During cultivation, the most important diseases are rhizome rots, which Sutarno et al. (1999)suggests are often caused by *Pythium* spp., *Fusarium* spp. and *Rosellinia* spp. This rot, also called soft rot, is one of the most devastating diseases of ginger. Initial symptoms appear as light yellowing of leaf tips which gradually spread down along the margins(Das & Dey, 2015). The disease is spread unintentionally by the use of infected seed pieces from the previous crop, who may appear normal and

healthy(Elliott, 2003). Das suggests that rhizomes treated with Trichoderma bio-control agent at a rate of 5g/kg of rhizome for 30 minutes proves effective. Furthermore, he suggests that seed rhizome dip treatment with Trichoderma harzianum 10g/liter of cow dung slurry before sowing is effective. Control in short term scenarios include discarding all seed pieces showing cracking injury or rot, dipping seed pieces in hot water at 50° C for 10 minutes. Long term solutions include planting a material from a disease free source and multiplying seed pieces by the use of tissue culture plants on lands that were not previously used for ginger production.

2.3 REPRODUCTIVE BIOLOGY

Zingiber officinale has a low genetic diversity because it reproduces asexually by vegetative propagation (Rodger, 2008). This form of asexual reproduction in multicellular organisms in which the new plants are created from the roots, stems, or leaves of the parent plant. *Zingiber officinale* primarily produces from spreading the rhizome. This stem forms a bud that eventually becomes a complete plant. This method of reproduction include rapid production of individuals in large quantities. An organism which closely mimics the reproductive biology of ginger is *Ipomoea batatas*(sweet potato).

2.3.1 Pollen

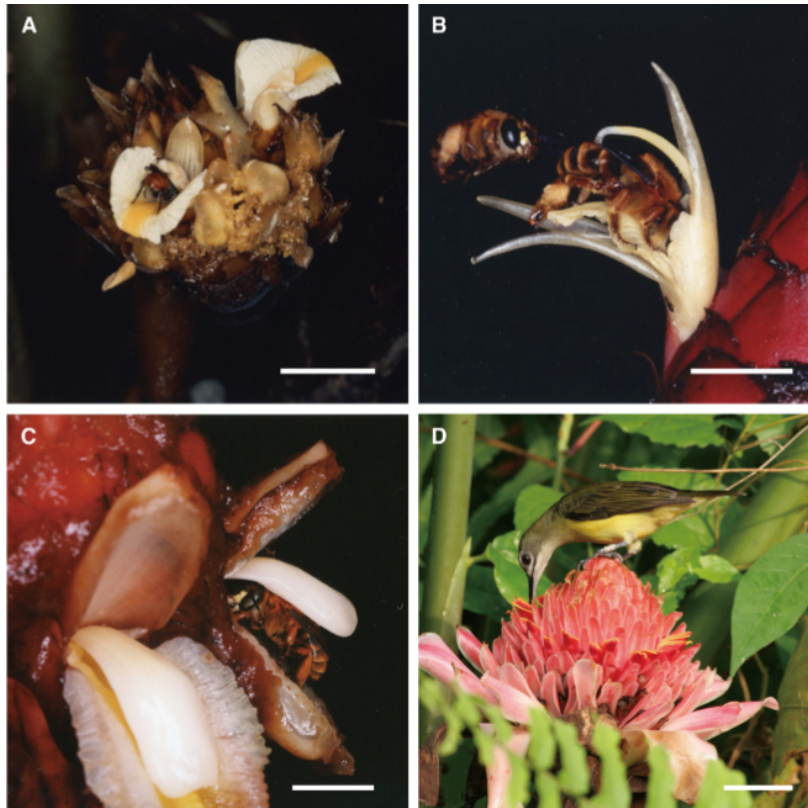
Pollination percentages in vitro of *Zingiber officinale* tended to be highest at around 20°C (Adaniya, 2001). Pollen tube growth in the styles was greatly enhanced at around 17°C, i.e., pollen tubes penetrated the entire stylar length in 66.7% of the styles used. Pollen germinability lost almost all of its germinability when stored for at least 3 hours under 40-80% relative humidity, whereas pollen incubated up to 3 hours under 100% relative humidity retained a relatively higher germinability. From these results, Adaniya concluded that the optimal pollination environment of the tetraploid ginger(*Zingiber officinale* L.) was at 17-20°C under 100% relative humidity.

There is no natural fruit or seed set in *Zingiber officinale* due to sterile pollen grains and self-incompatibility reactions. Nevertheless, artificial pollination and supplementation of required chemicals and nutrients to young flowers along with In vitro pollination helps the development of fruit and future plants generated from these fruits (Babu et al. 1992; Valsala et al. 1997). Sakai et al. (1999) reported the broad range of pollination and breeding systems in ginger. The considerable diversity of ginger flowers has stimulated a large number of pollination studies in the family (Ippolito and Armstrong, 1993;Kato et al., 1993;Kato 1996; Sakai et al., 1999; Li et al., 2002; Gao et al., 2004; Takano et al.,2005; Zhang and Li, 2008;Zhang et al., 2011). These works have demonstrated that each ginger species has a specialized pollination system involving bees or birds as important pollinators(Figure 4– below), which

due to the leaf formation and structure, facilitates entry and pollination in relation to other potential pollinators(Figure 5– below).

Figure 4.

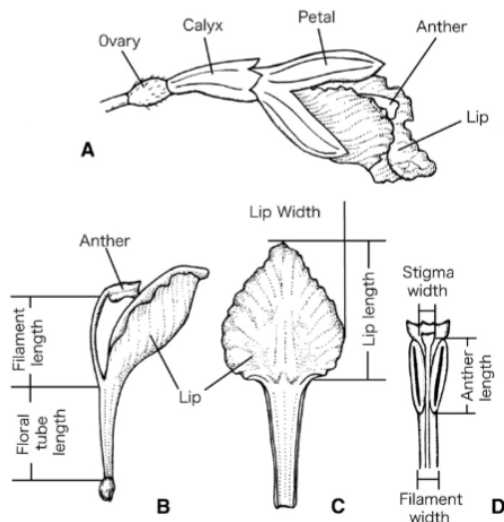
Three pollinator groups of Bornean gingers. (Sakai et al., 1999).



Note: *Halictid-bee (A); bee of the genus Amegilla (B, C); and spiderhunter-bird (D).*

Figure 5.

Floral structure of a ginger flower and seven morphological characters measured. (Amended from Sakai et al., 2015)



Note: (A) Ginger flower, with bract and bracteole removed.(B) Lateral view of corolla with petals removed. (C)Dissected corolla.(D)Pistil and stamen.

2.3.2 Sexuality

Zingiber officinale is typically monoecious(bisexual). Monocotyledons are composed of 50 genera and around 1500 species of perennial tropical herbs.

2.3.3 Anthesis

Das, et al., (1999) suggested that studies on the floral biology and meiotic behavior along with pollen straits in four cultivars of *Zingiberales officinale* revealed that a thesis in the greenhouse and open field conditions took place between 1-2 PM and 9-10AM respectively. No seed set of ginger during selfing or cross pollination was recorded. Meiotic studies revealed 30% to 40% of meiotic index in the studied cultivars of ginger. Failure of germination of pollen in artificial media was due to the absence of pollen germination pores and was then confirmed by Scanning Microscopic studies.

Results extracted from a study of floral biology of red ginger(*Zingiberales officinale* var. *rubra*) showed that commonly there was one of more than 20 spikelets in a spike anthesized per day. Final development stages were distinguishable from 6 or 7 am, where usually the Anthesis always began after 2pm and consisted of half and full Anthesis. Generally this variety of ginger has some negative floral characteristics based on fertility and fruit or seed setting ability.

2.3.4 Fruit development and seed set

Sexual reproduction is absent in ginger, making the recombinant breeding very impossible; thus, in vitro technology has become the preferred method, as it can be used for multiplication, conservation of the genetic material, and their utility in crop improvement of these crops.

2.4 ECOPHYSIOLOGY

Zingiber officinale varies a lot in its physiological appearance and processes. The chlorophyll and carotenoid contents of ginger leaves covered with a green, red, or blue film at the germination stage were marked higher than those which weren't covered during the growth period (RuiHua et al., 2007). Furthermore, the Carbon Assimilation and Photosynthesis Radioactive labeling studies (Zhao et al., 1987), showed that at the germination stage, assimilates are translocated mainly to the shoots and leaves. The main shoots contributed more to the rhizome formation, whilst secondary shoots were not so efficient and the youngest shoots contributed little to assimilation. During the growth stages of the rhizomes, carbon assimilation was mainly transported from the leaves to the rhizomes, thus becoming the main growth centers. All of these factors suggest that covering ginger leaves with colored plastic films alleviated photosynthetic depressions at noon without changing the diurnal variations in photosynthesis.

3 PROPAGATION AND MANAGEMENT

Zingiber officinale originates from India or Southeast Asia, and has been widely planted in tropical areas including a vast part of Asia, the Caribbean, Central and South America, Australia, and Africa (Flora of North America Editorial Committee, 2016; Royal Botanic Gardens Kew, 2016; Sutarno et al., 1999; Randall, 2012). Propagation of *Zingiber officinale* has commonly been through rhizomes, using them to sprout buds in semisolid soil. Various different methods including both traditional and in vitro propagation have resulted as great plant growth regulators and have similar outcomes (Shaik & Kanth G, 2014).

The management of *Zingiber officinale* is most expendeous in the initial stages due to its slow initial growth rate. As a result, it is invaded by a variety of weeds(Sah & Heisnam, 2017). A field experiment conducted under AICRP on Weed Management at College of Horticulture and Forestry, CAU, carried out during 2015-16 and 2016-17 identified alternatives to suppress weeds, enhance yield and income of small ginger producers of which more detail will be provided in a future section.

3.1 NATURAL REGENERATION

Natural regeneration of *Zingiber officinale* primarily requires a warm and humid climate with 2 to 5 hours of direct sunlight. The plant requires a minimum temperature of 15.5°C or around 60°F. *Zingiber officinale* rhizomes also require an average annual rainfall of 250-300cm for optimal growth, proposing additional irrigation in drier areas of the world(Nishina & Sato, 1992). Propagation of ginger also depends on a spot protected from strong winds (Texas A&M AgriLife Extension, 2019). Furthermore, optimal soil conditions include a semi loose soil with a balanced pH of 6.0-6.5, including high concentrations of organic matter, calcium, and nutrients. It should be free of weeds that could harbor cutworms, which attack young Zingiber shoots as they emerge, and are prone to cause future diseases within the organism. A successful crop of ginger is initiated with the use of a clean, good quality rhizome –Figure 6, below–, which should be treated with hot water at 50°C for 10 minutes to kill any undetected nematodes. About 2000 lb (907kg) of rhizomes are required to plant an acre of *Zingiber officinale* with the average conversion ratio of seed to crop 1:20.

Figure 6.

“Hand” of a mature ginger root that has been cured. (Nishina M., Sato D., Nishijima W., Mau R., 1992).



3.2 NURSERY PROPAGATION

Most recent testing and experimentation by scientists in the artificial or regulated propagation of ginger have evidenced very different results and ways to effectively grow *Zingiber officinale*. Abbas et al., (2011), established an efficient and promising protocol for *in vitro* propagation of the species via sprouting buds. These buds were sterilized and cultured onto MS (Murashige and Skoog)¹ medium supplemented with different growth regulators. The augmentation of these with 4.5 mg/L of benzylaminopurine(BAP)² recorded the highest percentages of shootlet multiplications. The maximum percentage of acclimatization, hardening and rhizomes production of *in vitro* derived plants in the greenhouse was 80-100%. Data tabulated in Table 1–below when also compared to Figure 7–below, clearly showed that between different treatments, the number produced multiple shoots/buds was significantly changed at the level of 5%. Conversely, the lowest number of shoots multiplication was

¹ Murashige and Skoog Medium (MS) provides all the essential macroelements and microelements to plants. The product is plant tissue culture tested but it is the sole responsibility of the user to ensure the suitability of the medium for individual species (Murashige & Skoog, 1962)

² Concentration of BAP significantly affected the average survival rate, shoot numbers, and shoot length per explant. In a study conducted by Khaskheli et al., (2016) these efficiencies were tested under *in vitro* conditions in which about 45 explants were cultured on each medium supplemented with different concentrations from 0.0-4.0 mg/L BAP.

recorded with MS free growth regulators (MC). The positive effects of MS medium along with BAP on increasing shoot numbers was also found by Balachandran et al., (1990), who reported an optimal concentration of 3.0mg/L BAP for *in vitro* multiplication of turmeric and ginger species. In agreement with the previous results, Muda et al., (2004) indicated that *in vitro* propagation of *Zingiber officinale* was successfully established on MS medium supplemented with a range of 1.0-3.0 mg/L BAP. Averages of three to five shoots per explant were successfully regenerated. All three varieties of *Zingiber officinale* showed that the rhizome yield from *in vitro* plantlets were higher than those from *in vivo* materials, in which the protocols developed suggest that they can be adopted for propagation and conservation purposes.

Table 2.

Effect of various growth regulators added to MS medium shootlets multiplication of Zingiber officinale after 4 weeks of cultivation. Extracted from Abbas et al., (2011).

Code	MS medium supplemented with	Number of shoots/ explant	Number of leaves/ shoots	Shoot length (cm)
MC	Free growth regulators	1.00	3.25	2.73
M1	1.5 mg/l BAP	4.25	10.50	3.18
M2	2.5 mg/l BAP	6.00	11.00	2.93
M3	3.5 mg/l BAP	6.25	12.00	3.85
M4	4.5 mg/l BAP	8.00	15.50	4.10
M5	0.4 mg/l BAP + 0.2 mg/l IAA	2.25	7.75	4.03
M6	0.6 mg/l BAP + 0.2 mg/l IAA	3.25	9.75	3.33
M7	0.8 mg/l BAP + 0.2 mg/l IAA	4.00	8.25	3.38
M8	1 mg/l BAP + 0.2 mg/l IAA	3.00	6.50	2.28
M9	1 mg/l Kin	4.19	11.25	4.10
M10	1 mg/l Kin + 1 mg/l NAA	3.75	10.25	3.63
M11	2 mg/l Kin + 1 mg/l NAA	4.00	11.00	4.18
M12	3 mg/l Kin + 1 mg/l NAA	4.75	12.75	4.58
M13	4 mg/l Kin + 1 mg/l NAA	5.00	13.75	4.03
LSD _{0.05}		2.08	5.23	1.10

Note: Each value is the average of five replicates.

Figure 7.

Multiple shootlets formation/bud of *Zingiber officinale* after 4 weeks of cultivation on MS medium.

Extracted from Abbas et al., (2011).



Note: Supplemented with, (A) 4.5 mg/L BAP, (B) 4.0 mg/L NAA³, (C) 3.5 mg/L BAP, (D) 1 mg/L BAP + 0.2 mg/L IAA⁴

³ Naphthaleneacetic acid(NAA; C₁₂H₁₀O₂) is a synthetic plant hormone and is an ingredient in many commercial plant rooting horticultural products; it is a rooting agent and used for the vegetative propagation of plants from stem and leaf cuttings.

⁴ Indole acetic acid is the most common naturally occurring plant hormone of the auxin class. This hormone is produced in cells in the apex and young leaves of plants. IAA plays a key role in root formation and bud growth.

3.2.1 Propagation from seed

Zingiber officinale has low genetic diversity due to its asexual reproduction via vegetative propagation in which new plants are created from the roots, stems or leaves of the parent plant. Rodger (2008), indicates that *Zingiber officinale* primarily reproduces from spreading rhizomes. The process of growing a successful crop is initiated with the use of a clean, good quality “seed” or rhizome. Nishina et al., (1992) indicates that the seed should be carefully treated with hot water at 50°C for 10 minutes to kill any undetected nematodes and to surface-sterilize the rhizomes. Furthermore, he goes into detail into the conservation of this temperature, as lower temperatures will not effectively control the nematodes and higher temperatures will damage the seed. The incorporation of a fungicide will help in reducing certain seed-borne diseases and prevent the decay of the seed after planting. Additionally, the seed should be planted immediately after treatment to minimize decontamination by aerial fungal organisms.

About 2000lb (907kg) of seed/rhizome is necessary to plant an acre of ginger. Seed size used in commercial production varies from 113-227 g, depending on the time of planting. The yield is not affected by the size of the seed when planting occurs in early spring; however, late plantings benefit greatly from larger seed size(Nishina et al., 1992).

3.2.1.1 Pre-preparation and implications for germination

Sharing ideas from the Texas A&M AgriLife Extension, before planting, the ginger rhizome should be cut into 1-1.5 inch pieces, and then be set aside for a few days to allow the cut surface area to heal and form a callus. Prior to planting in the early spring, each piece should be full of well-developed growth buds.

3.2.1.2 Sowing and germination process

A study performed by Jabborova, D et al., (2021), aimed to investigate the effects of biochar on seed germination, plant growth, root morphological characteristics, and physiological properties of *Zingiber officinale* and soil enzymatic activities led to the identification of several characteristics that can deeply affect the sowing and germination process of ginger. Pot experiments under greenhouse conditions at 24°C (day) and 16°C (night) showed six weeks later that biochar additions of 2% and 3% significantly increased seed germination, plant height, leaf lungs, leaf number, as well as shoot and root drum weights compared to the control. Root length increased by 30%, 47%, and 74%, with increasing biochar contents (1%, 2%, and 3%) compared to the control. The clear most effective treatment of 3% biochar application also significantly increased root dry weight, shoot dry weight, and root morphological characteristics. This treatment also had a pronounced, positive impact on soil enzyme activity, relative water content, chlorophyll content and carotenoid content as compared to all other treatments.

3.2.1.3 Storage

In an informal manner of storage of *Zingiber officinale*, the MasterClass team indicates three primary ways to store fresh ginger root depending on the use of ginger at home. First, if you are planning on using the entire root within a few days, it should be stored in a cool, dark place, such as a counter or a drawer. Second, Fridge; when properly stored, fresh ginger can last more than a month in the refrigerator. Peeled ginger will only last about two to three weeks. Third and final way proposed by the masterclass team is pickling. By peeling the ginger and slicing it thinly, one can then place it in a glass jar with equal parts vinegar, sugar and water. Stored pickled ginger can last in the refrigerator for up to two months.

Commercially, many different studies have been conducted regarding the storage stability of *Zingiber officinale*. In a thesis submitted to the School of Graduate Studies at the University Putra Malaysia in fulfillment of the degree of Master of Science, Rantawaty (2004), conducted a study to determine the physico-chemical characteristics of fresh ginger. Analyzed parameters were weight, length, diameter, pH, titratable acidity(TA), total soluble solids(TSS0, moisture content and crude fiber. This study used high performance liquid chromatography (HPLC) to determine the concentration of 6-gingerol, 8-gingerol and 10-gingerol. Results of the study showed that changes in physico-chemical characteristics and ginger oil content during storage showed that losses in gingerol content were very small during 12 weeks storage at 5°C as compared to storage at 28°C⁵.

3.2.2 Vegetative propagation

Vegetative propagation in *Zingiber officinale* happens via its roots, stems, and nodes as a vascular plant. *Zingiber officinale* grows out of modified roots called tubers, in ginger species, roots develop adventitious buds which then grow and form new plants/sprouts. These sprouts closely mimic the parent plant—thus the selection of the best candidates for parent plants is the main factor in the successful growth of ginger. Vegetative propagation in Zingiberales is known as Propagation by Roots as shown in figure 8—below.

⁵ During the study, the effect of adding carboxymethylcellulose(CMC) to the ginger drink was also carried out. The addition of the CMC slowed down the sedimentation process and the losses of gingerol content.

Figure 8.

Ginger shoots after a few weeks regularly watered (Skyer, 2014).



Figure 9.

Fully grown Zingiber officinale plant with over surface rhizomes. (UIOWA, 2022).



3.3 PLANTING

The first shoots of ginger appear 10-15 days after planting the rhizomes, and continually appear until about 4 weeks after planting. *Zingiber's* flowering is cultivar-dependent. Kaufman (2016) suggests that some cultivars flower rarely, others regularly, especially when grown undisturbed as perennials. Ginger fruits are seldom produced. Furthermore, ginger rhizomes normally only branch in the vertical plane (figure 9–above), so they are flat on the sides and stand upright in the soil. The crop must be planted in the tropics under warm, sunny conditions, though benefitting from shade during hot periods. Ginger is very sensitive to water logging, hence its growth must be closely monitored when growing in a pot and include plenty of drainage holes in the bottom.

3.4 MANAGEMENT

3.4.1 Tending

Weeds reduce crop yields and increase the total labor cost of agricultural production. Akobundu (1987) reported that weeds cause a 65% reduction in the yield of root and tuber crops and consume 25% of the total labor in production. In general, farmers start weeding late when the crops have suffered from weed competition or the ginger fields remain free of weeds for some time, and therefore the yield of ginger obtained by the farmers' fields has always been lower. under. Ginger is a long-lived crop (greater than 240 days), therefore pre-emergence herbicide application alone does not control weeds during the critical period of crop weed competition and requires integration of herbicide application. Post-emergence herbicides or intercropping operation in combination with Pre-emergence herbicide application.

This sparked a field experiment conducted during 2015 and 2016 at the College of Horticulture and Forestry with the objective to identify the approximate weed management method for optimum growth and yield of ginger in the North Eastern Region of India, the world's largest producer of *Zingiber officinale*. The experimental soil was sandy loam, acidic (pH 5.5), medium in available N (326 kg/ha), and high in available P (25.8 kg/ha) and K (276.4 kg/ha). Treatments consisted mainly of Pendimethalin⁶, Oxyfluorfen⁷, and Glyphosate⁸. The weed population data showed that grass and sedge population was high in the experimental field and it was observed that the maximum weed population was recorded in the weedless control plots. Maintaining weed-free plots for up to 60 days after planting significantly reduced

⁶ Pendimethalin is a herbicide used in preemergence and post emergence applications to control annual grasses and certain broadleaf weeds, preventing cell division and cell elongation at the growing points. It is mainly used in the spring in urban residential environments and has increasingly replaced bensulide and dacthal

⁷ Oxyfluorfen is a diphenyl-eter herbicide used for broad spectrum pre- and post emergent control of annual broadleaf and grassy weeds in a variety of tree fruit, nut, vides, and field crops.

⁸ Glyphosate is a widely used herbicide that controls broadleaf weeds and grasses. In 2007, glyphosate was the most used herbicide in the United States' agricultural sector.

the weed population. Oxyfluorfen application supplemented by hand weeding, 30 days after planting, fb mulch has also been shown to be an effective treatment for weed control, Table 3–below, during both harvest seasons. This may be due to the longer residence time of oxyfluorfen in the soil (Pillai et al., 2015). The effect on the crop growth parameters revealed that all the weed control treatments significantly influenced tillers per plant and plant height, Table 4– below.

Table 3.

Effect of integrated weed management practices on weed population (no./m²). (Dinesh Sah, 2017).

Treatments	Grassy and sedge weeds (no./m ²)		Broad leaved weeds(no./m ²)		Total weeds (no./m ²)		Weed dry matter (g/m ²)		WCE (%)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
T ₁	8.9 (80.3)	12.41 (153.7)	6.1 (36.7)	9.2 (84.7)	10.8 (117.1)	15.4 (238.3)	4.5 (19.7)	6.2 (34.8)	27.9	32.8
T ₂	8.6 (73.2)	11.58 (130)	5.8 (33.8)	6.7 (44.7)	10.3 (107)	13.2 (174.7)	4.2 (16.9)	5.3 (30.2)	38.2	50.8
T ₃	7.8 (61.3)	10.72 (112.3)	5.2 (27.7)	7.2 (52)	9.4 (88.9)	12.7 (164.3)	3.8 (14.3)	5.2 (26.6)	47.8	53.9
T ₄	7.2 (51.3)	8.29 (64.7)	4.4 (19.2)	5.4 (28.7)	8.4 (70.5)	10.4 (110.7)	3.4 (11.1)	4.0 (25.4)	59.4	72.9
T ₅	8.4 (71.2)	11.53 (128.7)	6.4 (41.1)	8.7 (76)	10.6 (112.3)	14.3 (204.7)	4.1 (16.1)	5.7 (33.5)	41.2	43.1
T ₆	8.3 (68.3)	11.29 (123.7)	6 (35.6)	7.7 (60.3)	10.2 (104)	13.6 (184)	4.0 (15.5)	5.5 (28.1)	43.4	48.2
T ₇	7.0 (59.2)	9.34 (83.3)	5.0 (25)	6.9 (47.3)	9.2 (84.2)	11.4 (130.7)	3.7 (13.2)	5.7 (26.3)	51.6	62.3
T ₈	5.5 (30.1)	7.79 (56.7)	4.3 (18.2)	4.3 (19.3)	6.9 (48.4)	8.5 (72)	2.7 (6.8)	3.6 (21.7)	75.2	77.6
T ₉	9.7 (93.3)	15.38 (232.7)	6.8 (46.4)	10.3 (105.7)	11.8 (139.7)	18.4 (338.3)	5.3 (27.4)	7.6 (35.9)	00	00
SEm±	0.11	0.47	0.10	0.39	0.10	0.60	0.03	0.19	0.55	3.17
LSD (P=0.05)	0.32	0.81	0.31	1.17	0.30	1.80	0.10	0.58	1.66	9.51

Note: Figures in the parentheses indicate the actual values, Transformed value= $\sqrt{(x+0.5)}$. T₁-Pendimethalin @ 1.5 kg/ha after planting, T₂-Oxyfluorfen @ 0.20kg/ha after planting, T₃-Pendimethalin @ 1.5 kg/ha after planting fb hand weeding 30 DAP but before mulching, T₄- Oxyfluorfen @ 0.20kg/ha after planting fb hand weeding 30 DAP but before mulching, T₅- Glyphosate @ 0.80 kg /ha before sprout emergence, T₆- Glyphosate @ 0.80 kg /ha plus Pendimethalin @ 1.5 kg/ha before sprout emergence, T₇- Glyphosate @ 0.80 kg /ha plus Oxyfluorfen @ 0.20 kg/ha before sprout emergence, T₈- Hand weeding 30 and 60 DAP, T₉- Un- weeded control.

Table 4.

Effect of integrated weed management practices on growth and yield attributes of ginger. (Dinesh Sah, 2017).

Treatments	No. of tillers/ plant		Plant height (cm)		Rhizome length (cm)		Rhizome width (cm)		No. of fingers/rhizome	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
T ₁	1.9	6.7	51.7	50.2	6.1	5.9	4.3	4.4	2.4	4.5
T ₂	2.8	6.3	50.2	48.8	7.2	6.6	4.9	5.0	3.0	5.2
T ₃	2.9	7.2	53.5	51.1	7.9	6.6	5.2	5.1	3.2	5.3
T ₄	2.6	5.7	48.2	46.5	6.6	6.8	4.7	5.3	2.9	5.5
T ₅	2.2	6.7	51.2	49.8	6.4	6.2	4.6	4.5	2.5	4.7
T ₆	2.5	7.2	52.5	50.7	6.5	6.2	4.7	4.6	2.8	5
T ₇	2.3	5.3	47.5	39.9	6.6	6.3	4.7	4.7	2.7	4.7
T ₈	3.2	7.5	56.2	52.3	8.4	6.9	5.5	5.7	3.4	4.2
T ₉	1.5	2.7	44.7	32	5.7	5.2	3.9	4.0	2.1	3.8
SEm±	0.07	1.19	3.1	4.7	0.31	0.53	0.24	0.28	0.19	0.38
LSD (P=0.05)	0.04	0.69	1.80	2.71	0.94	1.59	0.71	0.84	0.57	1.13

Note: Conditions regarding the treatments are shown in Table 3– above.

3.4.2 Pest and disease control

3.4.2.1 Bacterial Wilt

Bacterial wilt is the most devastating in ginger caused by *Ralstonia solanacearum*. Even though *Zingiber officinale* and mango ginger (*Curcuma amada*) are from the same family, *Zingiber officinale* is not resistant to the *R. Solanacearum* infection, figure 10–below. Studies conducted in the Ethiopian regions of Teppi and Jimma conducted by Guji et al. Agric & Food Secur. (2019) using both local and Boziab varieties of *Zingiber officinale*, demonstrated that interaction effects of variety by cultural management practices were highly and significantly ($P < 0.001$) different in growth parameters both at Teppi and Jimma, with the exception of plant height, which showed a no significant difference and number of tillers per plant, which was significant ($P < 0.05$) at Teppi. Jimma showed the maximum plant height of 70.2 cm, which was recorded from plots treated with integrated applications of lemon grass and soil solarization in both local and Boziab varieties (70.0 cm). In contrast, the lower plant height was recorded from untreated control plots, which included 55.9 cm in Local and 53.3 in Boziab variety, Table 5– below.

Figure 10.

Bacterial wilt of Zingiber officinale (Taylor, 2019).



Table 5.

*Interaction effects of cultural management practices and ginger varieties on bacterial wilt (*R. solanacearum*) initial and final mean disease incidence (%) at Teppi and Jimma, Ethiopia, during the 2017 main cropping season. Information amended from Guji et al., (2019).*

Treatment combination	Mean disease incidence (%) at Teppi				Mean disease incidence (%) at Jimma			
	Local		Boziab		Local		Boziab	
	PDi	PDIf	PDi	PDIf	PDi	PDIf	PDi	PDIf
Control	15.79	79.47	14.49	79.76	15.46	80.44	15.21	77.15
L	9.65	63.02	6.48	48.74	8.02	52.75	6.93	51.07
F	11.91	58.88	9.64	64.47	13.20	64.45	11.73	63.60
S	14.37	75.24	15.30	77.87	14.94	78.92	14.40	75.21
L+F	9.89	58.88	7.88	64.48	7.86	42.04	7.41	49.96
L+S	9.41	75.24	10.00	52.15	9.93	54.72	8.33	47.90
F+S	14.70	69.44	9.60	64.46	12.72	64.08	11.84	55.71
L+F+S	8.25	49.03	7.40	45.85	7.20	46.61	6.44	49.75
LSD (0.05)		2.19	1.02		ns	2.81		
CV (%)		2.20	7.84		8.93	2.80		

Note: L=lemon grass; F = fertilizer; S = soil solarization; L + F = lemon grass with fertilizer application; L + S = lemon grass with soil solarization; F + S = fertilizer application with soil solarization; and L + F + S = lemon grass with fertilizer application and soil solarization. PDi = percent mean disease incidence at 45 and 60 days after planting (DAP) at Teppi and Jimma, respectively, and PDIf = percent mean disease incidence at 150 DAP. ns=non significant.

Analysis of variance also revealed a highly significant variation ($P < 0.001$) for cultivating by cultural management practices in rhizome yield in both Teppi and Jimma as shown in Table 6– below. The highest rhizome yield (16.0 t ha^{-1} in Boziab and 14.6 t ha^{-1} in Local) was obtained through the integrated application of lemon grass with soil solarization and soil fertilization, followed by plots treated with a combined application of lemongrass and soil fertilization with which 13.5 and a yield of 13.1 t/ha of rhizome were achieved in the Boziab and Local varieties in Teppi. Similarly, the lowest rhizome yield was harvested from untreated plots, which was approximately $7.1\text{--}7.7 \text{ t ha}^{-1}$ for Teppi.

Table 6.

Interaction effects of ginger varieties by cultural management practices on number of fingers per rhizome and yield at Teppi and Jimma, Ethiopia, during the 2017 main cropping season. Amended from Guji et al., (2019).

Treatment combination	Ginger yield parameters at Teppi				Ginger yield parameters at Jimma			
	Fingers per rhizome		Yield (t ha^{-1})		Fingers per rhizome		Yield (t ha^{-1})	
	Local	Boziab	Local	Boziab	Local	Boziab	Local	Boziab
Control	5.1	5.0	7.1	7.7	3.2	3.3	8.3	8.4
L	6.1	6.6	11.2	11.7	5.9	7.4	11.3	14.0
F	5.9	4.4	11.3	11.4	5.4	5.0	9.0	11.4
S	4.6	5.5	8.3	8.6	3.6	3.4	9.1	9.1
L+F	5.9	6.7	13.1	13.5	5.4	6.6	13.7	14.5
L+S	5.5	6.5	11.5	13.2	5.2	6.5	11.1	14.1

Treatment combination	Ginger yield parameters at Teppi				Ginger yield parameters at Jimma			
	Fingers rhizome	per	Yield (t ha ⁻¹)		Fingers rhizome	per	Yield (t ha ⁻¹)	
	Local	Boziab	Local	Boziab	Local	Boziab	Local	Boziab
F+S	4.8	5.6	8.5	11.5	5.4	4.9	11.8	11.0
L+F+S	6.9	7.7	14.6	16.0	5.8	9.2	12.2	16.5
LSD (0.05)	0.74		0.59		0.59		0.96	
CV (%)	7.7		3.2		6.6		5.0	

Note: *L*=lemongrass; *F*=fertilizer; *S*=soil solarization; *L+F*=lemon grass with fertilizer application; *L+S*=lemongrass application with soil solarization; *F+S*=fertilizer application with soil solarization; and *L+F+S*=lemongrass application with fertilizer and soil solarization.

Symptoms of bacterial wilt include green leaves infected with the pathogen roll will turn yellow (figure 11– below), then necrotic; plants become stunted and die; rhizomes are discolored and water-soaked and may be rotten inside. Planting ginger in well draining soils where ginger had not been previously grown can help reduce contamination.

Figure 11.

Yellow ginger foliage caused by bacterial wilt (PlantVillage, 2014).



3.4.2.2 Dry rot

Dry rot (*Fusarium and Pratylenchus complex*) is caused by *Fusarium oxysporum f.sp. Zingiberi*. This fungus infects ginger and causes a wilt; however, in appearance it is similar to all other *Fusarium oxysporum* fungi, but the differences can be detected genetically (Jackson, 2010). Symptoms include discoloration of the rhizome surface by fungal mycelia accompanied by dry rotting.

3.4.2.3 Rhizome rot/Soft rot/Pythium rot

One of the most common needs for ginger are their culinary and medicinal properties, however, soft rot (Rhizome rot) is a common disease that affects the species caused by fungi. It is the most destructive disease of ginger, which can reduce the production by 50 to 90%. Rai (2018) suggests that the application of chemical fungicides is considered as an effective method to control soft rot; but extensive use of these fungicides pose serious risks to environmental and human health. This, Rai (2018) suggests that the development of eco-friendly and economically viable alternative approaches for effective management of soft rot of ginger such diseases is essentially required. So far, acceptable approaches in the investigation process involve nanotechnology, which could potentially control *Pythium* and *Fusarium*. Moreover,

possible antifungal mechanisms for chemical fungicides, biological agents and nanoparticles have also been discussed.

In a practice conducted by the N.D. University of Agriculture and Technology, A. K. Pandey et al., (2010) experimented with the management of the Rhizome Rot disease of ginger officinale var. Rose L. This study found that the chemical control of the *Pythium aphanidermatum* pathogen is not economical because of the high costs of the chemicals and other factors. They found that plant products may offer a practical and economical alternative to the issue, using *Boerhaavia diffusa* root extract. Rhizomes dipped overnight in the suspension on 10.00% crude root extract followed by 3 foliar sprays of the same proved effective in the management of the disease, showing results that indicated a gradual decrease in disease incidence with the corresponding increase in number of treatments. Carried out in India, 2009, the rhizomes were planted in a field at 25 x 15 cm spacing with three replications in randomized block design. The six treatments were applied in treated plots along with control specimens which were soaked and sprayed with water. As is shown in Table 7– below, results indicated a gradual decrease in disease incidence with the corresponding increase in number of sprays and rhizome treatment with *B. diffusa* root extract.

Table 7.

Effect of rhizome treatment and foliar spray with B. diffusa root extract on rhizome rot disease. Amended from Pandey et al., (2010).

Treatments	Disease incidence (%)	Disease reduction (%)
T1	28.33	67.08
T2	44.67	48.14
T3	40.67	52.96
T4	24.33	71.84
T5	18.00	79.19
T6	86.33	0.00
CD (0.05)	4.122	4.270

Note: T1- Rhizome treatment with B.D root extract @ 10% ; T2- Foliar spray with B.D. @ 5% (three foliar sprays) ; T3- Foliar spray with B.D. @ 10% (Three foliar sprays); T4- Rhizome treatment + 3 foliar sprays with B.D. @ 5% (T1+T2); T5- Rhizome treatment + 3 foliar sprays with B.D. @ 10% (T1+T3); T6- Control(Water spray).

These results indicated that the superiority of the rhizome treatment plus 3 foliar sprays @ 10% resulted in minimum disease incidence. The treatment resulted in production of good quality/quantity rhizomes of ginger.

3.4.4 Harvesting Procedure

Published by the Food and Agriculture Organization of the United Nations (FAO), Plotto (2002), assures that the time of harvest after planting depends on the end-use of the Zingiber. For fresh produce and preserves, rhizomes should be harvested while they are still tender, low in pungency and fiber content; it should be harvested before they are fully mature. Harvests for dried spices and oils are best at full maturity at the time the leaves turn yellow; leaving the rhizomes in the ground past that stage may reduce pungency and oil content; increasing oil content. Maximum oil and oleoresin contents are between 150 to 170 days after planting under Kerala's⁹ conditions.

In summary, best time for harvest depending on end-use is:

Fresh consumption:	5 months
Preserved ginger:	5-7 months
Dried ginger:	8-9 months, when leaves start yellowing
Essential oil:	8-9 months

Harvest is done by manually lifting rhizomes from the soil. In some countries such as Australia, harvest may be fully mechanized using special equipment; the crop must be planted in such a way that interspacing between rows is adapted to the equipment. Care should always be taken to assure the integrity of rhizomes during harvest and post-harvest handling.

⁹ Kerala, India— Located in south India, it's a small state stretching for about 580km along the Malabar Coast. Daily temperatures usually range from low 20s C to 27-32° C. It receives an annual precipitation of about 3,000mm with certain slopes receiving more than 5,000mm.

3.4.5 Quality control

Freshly harvested rhizomes should be washed, and cleaned from debris, shoots and roots. When available, pressure washing is preferred as it is more efficient and tends to reduce the microbial load. Usually, these organisms are killed in 10 min. immersion in boiling water (Pruthi, 1992), this also inactivates the enzymatic processes, then sun-dried (Sutarno, 1999 & Weiss, 2002). Plotto (2002) further suggests that another method is to scrape, peel, or slice rhizomes prior to drying. Peeling or scraping is advised for reducing drying time, thus minimizing mold growth and fermentation (Pruthi, 1992). However, while this process decreases the fiber content by removing the outside corky skin, it also tends to remove some of the oils constituents, as they are more concentrated in the peel, and therefore reduces some of the pungency.

3.4.5.1 Grading and packaging

Quality specifications are imposed by the importing country, and usually pertain to the cleanliness specification of the exporter rather than the quality of the spice (for specifications, see table 8 & 9– below). The proper care of *Zingiber* rhizomes must be taken into account to meet minimum requirements, otherwise it may lead to a lot needing further cleaning and/or disinfection with ethylene oxide or irradiation. Bulk rhizomes may be packed in jute sacks, wooden boxes or lined corrugated cardboard boxes for shipping (Weiss, 2002). Table 8– below shows the cleanliness specifications of the American Spice Trade Association, in agreement with the Food and Drug and Administration, while Table 9– below show specifications for EU-member countries. While some of these countries like the U.K, Germany and the Netherlands have their own specifications, the European Spice Association (ESA) has set a “quality minima for herbs and spices”, but has yet to finalize the cleanliness specification standards for spices.

Table 8

ASTA Cleanliness Specifications for Ginger. Amended from ASTA Cleanliness Specifications for Species, Seeds and Herbs, 1999.

Whole insects, dead	Excreta, Mammalian	Excreta, Other	Mold	Insect Defiled/Infested	Extraneous Foreign Matter ¹
by count	by mg/kg	by mg/kg	No more than 3% moldy pieces and/or insect infested pieces by weight		% by weight
4	6.6	6.6			1.00

Note: ¹ extraneous matter includes but is not limited to: stones, dirt, wire, string, stems, sticks, non toxic foreign seeds, excreta, manure, and animal contamination

Table 9

European Spice Association(ESA) Minimum Quality Standards for Zingiber officinale.

Total Ash(% w/w) max	<i>Acid Insoluble Ash(% w/w) max</i>	<i>Moisture(% w/w) max</i>	<i>Volatile oil(v/w) min</i>
<i>(ISO 928)</i>	<i>(ISO 930)</i>	<i>(ISO 939)</i>	<i>(ISO 6571)</i>
8.00 ^a	2 ^b	12 ^a	1.5 ^a

Note: *a: Indian Standards Institute ; b: European Spice Association*

4. ZINGIBER OFFICINALE COMMERCIAL IMPORTANCE

The commercial impact of *Zingiber officinale* has commonly been overlooked in most nation's agricultural reports. It is a very important spice for rural and urban communities; particularly in South East Asia, Africa, and South America (Deme, 2021). The tuber contains enormous medicinal and nutrition potential, with the possibility of contributing towards a qualitative improvement of the diet of consumers. Despite these many advantages, it has remained under-exploited due to insufficient knowledge of cultivation methods, cycle durations, and its water requirement. The preservation and improvement of ginger quality represent an important challenge for the various actors of this crop's industry. In India, it is a spice of great commercial importance, where Kerala is partly responsible for 33% of the total production in India. This has highlighted several uses of ginger, processing methods like drying, splitting/slicing, mechanical expression, and post-harvest operations and products like fresh, dried, preserved, pickled, crystallized and powdered or ground, essential oils and oleoresin processing and extraction methods. Various government schemes and export potential of ginger with respect to the Indian scenario have also been discussed (Bag, 2018).

4.1 EXPORTING AND IMPORTING OF THE PRODUCT

4.1.1 Exports

Ginger is the third most exported spice globally (ITC, 2018). In 2016, imports of ginger totaled more than \$757 million dollars globally. In major importing countries especially in the European Union and the United States, ginger exports for the manufacture of powdered ginger must be fibered free, while the products exported for the manufacture of ginger oil and oleoresins should have a high oil content.

4.1.1.1 India

Two important factors must be considered at the time of choosing ginger rhizomes for further processing or for development of secondary products from ginger rhizomes: Maturity stage at the time of harvest and the native properties of the type grown (Bag, 2018). The global ginger processing market was valued at \$2.16 billion dollars in 2019 proliferating at a CAGR of 6.6% (India Business and Trade). Out of this, Indian exports were valued at US\$ 44.5 million. An analysis performed at the 3rd International Conference on Global Initiatives in Agricultural, Forestry and Applied Sciences, Gohain et al., (2021) used the Markov Chain Analysis¹⁰ through a linear programming method to assess the transitional

¹⁰ A Markov Chain or Markov process is a stochastic model which describes a sequence of possible events in which the probability of each event depends only on the state attained in the previous state. It's a mathematical system that transitions from one state to the other according to a given set of probabilistic rules.

probabilities for the major ginger markets. Results showed that India stood fifth in terms of global ginger exports in 2019 and trade surplus for the country during the study period. The major Indian ginger export markets were categorized as stable market (UK) and unstable market (Bangladesh) based on the magnitude of transitional probabilities. The holistic conclusion led to the need of an emphasis on productivity, enhancing research measures to stabilize existing markets and tapping other market sections for improvement in this sector. India has seen a stable growth in its ginger exports as it industrializes its agricultural sector, but saw a steep increase between 2019 and 2020. Table 10 —below, shows exports between 2000-2020. In an article published by GlobalTrade on July 9th, 2021, analysts believe that the acceleration of growth in 2020 was due to the wake of the pandemic, as demand for foods with a reputation for immunity system health soared to unprecedented heights.

Table 10

Exports of Ginger in India. Amended from the Food and Agriculture Organization of the United Nations (FAOSTAT, 2020)

Year	Export quantity (tonnes)
2010	20,384
2011	29,747
2012	32,821
2013	25,912
2014	46,393
2015	31,341
2016	19,191
2017	24,416
2018	20,723
2019	26,864
2020	105,117

4.1.1.2 Netherlands

The amount of ginger sold by the Netherlands in 2020 was 68,980 tonnes. It is the largest exporter of ginger in Europe, improving by 30% in comparison to 2019 (Wamucii, 2020). In 2019, the Netherlands supplied ginger costing 106.01 million USD, increasing 2.67% from 2018. The Netherlands top export markets are Germany, France, Poland, Italy and Sweden. In 2020, they exported just over 35 million dollars worth of ginger to Germany and Spain. Overall, *Zingiber officinale* is the most exported spice in the Netherlands just after Chillies and Peppers (FAO, 2021).

4.1.1.3 China (mainland)

China accounted for 32% of crushed ginger exports in 2020, selling the highest value of this mode of ginger, selling 33.4 million USD of crushed ginger. Furthermore, China is also the top exporter of raw ginger, accounting for 55% of non-crushed ginger valued at 685.1 million USD. Totalling at 704.8 million USD (World Integrated Trade Solutions, 2020). China's primary export destination is the Netherlands, who receives 57,100 tonnes of ginger; the United States– second largest, with 56,200 tonnes of ginger. Among the countries importing ginger from China in 2021, the Netherlands, the United States, Pakistan, the United Arab Emirates, Malaysia, Bangladesh, Vietnam, Saudi Arabia, Japan, and the United Kingdom were the top ten (Fresh Plaza, 2022).

4.1.2 Imports

4.1.2.1 Japan

Japan is the fourth largest importer of ginger, known for their vast consumption of various spices and use of ginger in foods like sushi or cookies. The Japanese islands imported a total of 90.1 million USD in 2020, increasing by 0.7% in comparison to the previous year, taking up 7.1% of the global market. More than two thirds of the whole ginger brought into the island nation comes from China, importing 65.57 million USD worth of whole ginger. The next largest exporters to Japan are Thailand and Taiwan, tallying at 15.2 and 7.7 million USD respectively.

4.1.3 Peru

Zingiber officinale, better known as kion in Peru, has become a key export for Peruvian agriculture making it a steady exportable good for the nation. Peru was the fourth largest exporter globally, with 23.4 thousand tonnes and 41.5 million USD, making it the largest exporter and producer in Latin-America(Cisneros-Santos, 2021). According to Tridge Fulfillment Solutions (2020), Peru was the

third largest exporter of whole ginger in 2020, exporting 118.4 million USD worth of ginger, growing by 168.13% over the course of one year. Cisneros-Santos (2021) further indicates that exportation of *Zingiber Officinale* began initially in 2005 to Chile, being labeled as a commodity rather than agricultural produce. From 2006, an organic production has begun that is exported to the United States, exporting 44.53 million USD in 2020 (Tridge, 2020). Ever since, ginger has shown a continuous growth that has given it an important position in the international market. The evolution of ginger exportation annually and monthly in this decade is shown in Figure 11 and 12 respectively–below.

Figure 11.

Annual Exportation of Ginger (2010-2020). Extracted from UNHEVAL(Universidad Nacional Hermilio Valdizan), 2021.

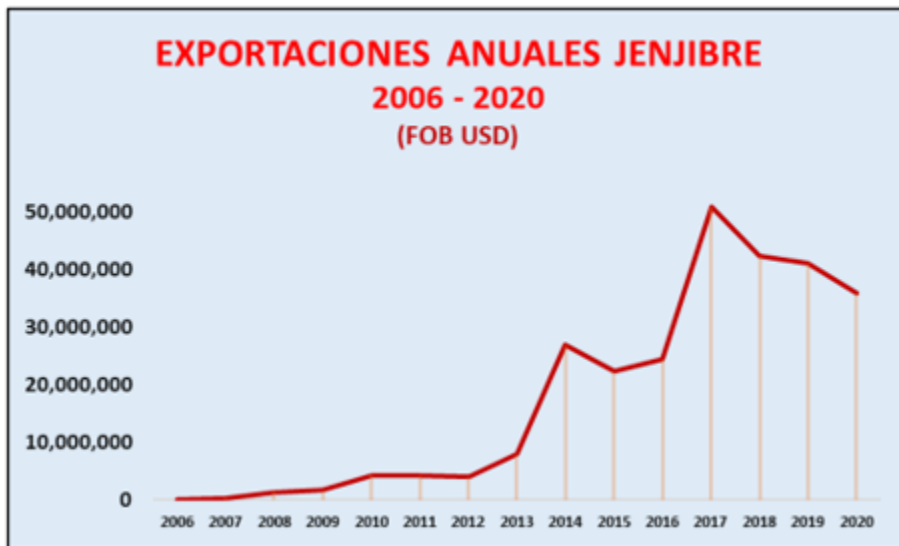
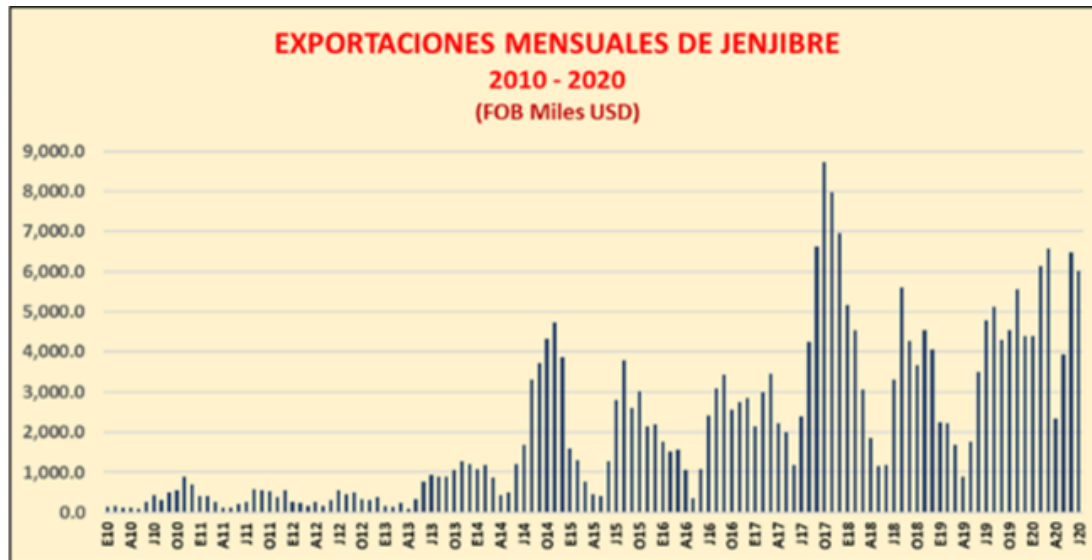


Figure 12

Monthly Exportation of Ginger (2010-2020). Extracted from UNHEVAL(Universidad Nacional Hermilio Valdizan), 2021.



Note: Monetary values are measured in *thousands of USD*

Peru incremented its ginger exports by 6.75 times between 2010 and 2014 due to reductions and constrictions from Chinese exports. This increment is further visualized in Figure 11—above, where in between 2010 and 2019, exports increased by 9.5 times. Finalizing, Cisneros-Santos(2021) further indicates that the small nation has placed a massive emphasis on keeping its current markets, particularly the United States and the Netherlands, which make up 80% of their exports. Regardless, Cisneros-Santos(2021) indicates that PROMPEX has been conducting market research and consolidating present markets like Germany, Italy and the UAE.

4.2 COMMERCIAL PRODUCTION AND USES

4.2.1 FOOD USES

The first record of ginger being used dates back to 500 BCE. *Zingiber officinale* is commonly pickled in sweet vinegar, turning it into a pink colored vinegar often used in sushi. Ginger harvested 8 to 9 months after planting have tough skins which must be peeled. This type of ginger is mainly used for cookies, cakes, and curry mixes. Candied or crystallized ginger is cooked in sugar syrup and coated with granulated sugar (Bode, 2011). The fresh rhizome, green ginger, is used in cooking being named a staple of Asian, Indian and Caribbean cuisines. By boiling the peeled rhizomes into syrup, they can be stored. Ginger tea also offers health benefits, especially if looking for relief from inflammatory conditions or nausea. Slices of ginger are eaten between courses or meals in Japan and overseas to cleanse the palette

(Britannica, 2022). Zaleska (2022), suggests that ginger can be used in cooking in several ways, among these in vegetables, stir-fries, chicken dishes, soups, curries, sauces for main dishes, salad dressings, desserts, smoothies and even pancakes and tea. According to a 2018 study (Nikkhah, 2018), ginger's effects on the gasses that develop in the digestive system during digestion have been studied in various research. According to this study, ginger enzymes can help break up and eliminate this gas, offering relief from any pain. Furthermore, studies suggest that ginger may aid in the flow of food through the digestive tract, implying that it may help treat or avoid constipation. The enzyme pancreatic lipase, which assists digestion in the small intestine, also appears to benefit from ginger.

4.2.2 MEDICAL USES

Zingiber officinale is commonly referred to as one of the healthiest spices on the planet (Leech, 2021). Ginger has a very long historical use in various forms of traditional and alternative medicine, usually known to reduce nausea, aid digestion, and fight the common cold/flu. It does all of these things via gingerol, which has powerful medicinal properties. According to Leech (2021), gingerol has powerful anti-inflammatory and antioxidant effects, collectively known as 6-Gingerol. It's been found to possess several beneficial activities via its impact on a variety of biological systems. Due to its efficacy and regulation of multiple targets, 6-gingerol has received considerable interest as a potential therapeutic agent for the prevention and treatment of various diseases (Wang, 2014). Procedures performed by the School of Nutrition and Food Science at Isfahan University, led by Mashhadi (2012), found several studies regarding anti-oxidative stress effects, along with anti-inflammatory, anti-diabetic, and anticancer effects of ginger, being eventually brought to the conclusion that the anticancer potential of ginger is well documented and its functional ingredients like gingerol s are valuable ingredients which can prevent various cancers. One of the studies analyzed showed that an ethanol extract of *Zingiber officinale* in combination with vitamin E partially improved cisplatin-induced nephrotoxicity, while other studies analyzed evidenced a protective effect of ginger extracts on the liver, indicating that *Zingiber officinale* could be useful in preventing acute liver injury by acetaminophen-induced liver damage. Mashhadi (2012) further found that gingerol and other substances within ginger inhibit prostaglandin¹¹ and leukotriene¹² biosynthesis. Which are known to be anti-inflammatory agents. Because of potent

¹¹ Prostaglandins are compounds in the body made of fats that have hormone-like effects. They're interesting because they can have different effects depending on the receptors where they attach, they influence reactions in the body when they're present in certain tissues(Nall, 2020).

¹² a group of compounds derived from unsaturated fatty acids, primarily arachidonic acid, that are extremely potent mediators of immediate hypersensitivity reactions and inflammation, producing smooth muscle contraction, especially bronchoconstriction, increased vascular permeability, and migration of leukocytes to areas of inflammation. (*Leukotriene*, 2007)

compounds within the ginger rhizome for inhibiting allergic reactions, it may be useful for the treatment and further prevention of allergic diseases. It can reduce the previously mentioned TNF-alpha and the elevated expression of NF-κB¹³. The activation of the aforementioned chemical is linked to a variety of inflammatory diseases including cancer, diabetes, asthma, arthritis, Crohn's disease, Alzheimer's and AIDS (Mashhadi, 2012).

Anticancer effects of ginger work on the basis of a chemo preventive spice which remains a matter of conflict among researchers. Base ingredients like gingerol s, ahógalos, and parasols exhibit antitumorigenic properties. They are effective in controlling the extent of colorectal, gastric, ovarian, liver, skin, breast, and prostate cancers (Mashhadi, 2012). Furthermore, the administration of zerumbone¹⁴ orally in mouse models showed a sharp inhibition in multiplicity of colonic adenocarcinomas via the suppression of colon inflammation. Additionally, the presence of 6-gingerol has shown to have drastic effects on the regulation of cancer. In gastric cancer, Ishiguro *et al.* (2007) observed that 6-gingerol inhibits TRAIL-induced NF-κB activation by impairing the nuclear translocation of NF-κB, suppresses cIAP1 expression, and increases TRAIL-induced caspase-3/7 activation. Furthermore, Mashhadi *et al.* (2012) suggested that 6-gingerol can inhibit both proliferation and invasion of hepatoma cells.

Various research studies have further proved the effectiveness of ginger against diabetes and its complications. Weidner and Sigwart (2000), conducted experimental studies on rats, and the effects of a ginger extract on many different variables. They found that ginger extracts with high contents of gingerol s and ahógalos did not induce significant changes in blood glucose, blood coagulation, blood pressure and heart rates in rat models. Furthermore, Mashhadi *et al.* (2012) showed that ethanol is an extract of *Zingiber officinale* fed orally for 20 days produced a significant antihyperglycemic effect in diabetic rats.

Further studies have been considered *Zingiber officinale* as a potential plant against Rheumatoid Arthritis. Zingiber has traditionally been used for the treatment of RA in alternative medicines. In depth analysis can be found in Al-Nahain *et al.*, (2014)

¹³ The transcription factor NF-κB regulates multiple aspects of innate and adaptive immune functions and serves as a pivotal mediator of inflammatory responses. (Liu, 2017).

¹⁴ Zerumbone derived from *Zingiber zerumbet*, can reduce the level of pro-inflammatory cytokines such as TNF-α and decrease the upregulated protein level for possessing the anti-inflammatory activities.

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