NIGERIAN AGRICULTURAL JOURNAL
ISSN: 0300-368X
Volume 53 Number 1, April 2022 Pg. 357-362
Available online at: http://www.ajol.info/index.php/naj
https://www.naj.asn.org.ng

Physiology and Agronomy of Ginger (*Zingiber officinale*): An Empirical review

Adiele, J.G.

National Root Crops Research Institute, Umudike,
Km 8 Ikot Ekpene Road, PMB 7006, Umuahia, Abia State, Nigeria
Corresponding Author's email: joyadiele@yahoo.com

Abstract

Ginger is commonly grown for its edible rhizome which is used as spice for food and drinks. It is also known for its medicinal values; however, attaining optimum yield of this important crop is one of the major interests of farmers and researchers. This study aims to provide more insight on the physiology of ginger, aid innovative technologies and agronomic practices that will increase its productivity and production efficiency. The information and data on ginger were collected from sources like research activity reports of National Root Crops Research Institute, Umudike, Nigeria, Google Scholar, Science Direct, Research Gate and FAOSTAT. The productivity of ginger in Nigeria is poor, hence, increasing the yield sustainably will boost food and nutrition security, provide raw material for pharmaceutical and food industries, and contribute meaningfully to economic growth through foreign exchange. However, poor crop management and limited access to viable seed, credit, unreliable rainfall pattern, diseases and pests and post-harvest losses impede ginger production and productivity. The study suggests that in-depth understanding of the crop's physiology and sustainable solutions to the constraints will inform better agronomic practices and guide technological breakthrough that will result in increased yield and seed quality.

Keywords: Ginger physiology, nutrition security, quality yield, ginger rhizome

Introduction

Considering the rate of food and nutrition insecurity in Nigeria, the goal of many farmers is to produce not only enough food, but essential food types to combat hunger, malnutrition and prevent diseases (Osabohien *et al*., 2019). Evidently, the current state of agricultural technology will not suffice to meet the production challenges ahead, unless innovative technologies have to be exploited in order to enable sufficient food availability in the future. In this context, an understanding of the physiology of crops offers promising approach to increase productivity and production efficiency. Evolving technologies such as biotechnology and crop modeling require basic information on crop functions and behavior, in order to improve crop growth and yield. One of such crops that are lagging behind in productivity is Ginger (*Zingiber Officinale*). Ginger is an important horticultural crop, grown for its scented rhizome and majorly used in the pharmaceuticals, food and beverage industries, especially as a cooking spice and flavouring agent (Gong *et al*., 1989). The history of ginger dates back over 5000 years ago. Originally, it is a native of South East Asia but over centuries has been introduced to various parts of the world including Africa. Its medicinal uses were first documented in Asia. As a high valued crop, only second to pepper, a pound of ginger was exchanged for a sheep (GHH, 2017; Nair. 2019a). It is an effective antioxidant and has been used to help alleviate all sorts of nausea, especially those associated with motion sickness, pregnancy, surgery and nausea following chemotherapy (Ryan *et al*., 2012; Prasad and Tyagi, 2015). Ginger became popular in Nigeria around 1927 and was cultivated in large-scale in the southern part of Zaria (Nair, 2019a). Nigeria is the third largest producer of ginger, with average (2010 – 2019) annual production of about 508,160 metric tons of fresh produce (Fig. 1a), from a total area of 7872 hectares (Fig. 1b). The increase in production is mainly achieved by expansion of the area cultivated. Average fresh yield of ginger from the farmers field between 2010 and 2019 ranged from 3 to 9 t ha^{-1} (Fig. 1c) (FAOSTAT, 2021), much below its potential productivity of about 29 t ha^{-1} (Nair, 2019c). In addition to the nutritional and medicinal benefits of ginger, it is an economic crop that can contribute meaningfully to the economic growth and development in Nigeria (Omeni, 2014; GHH, 2017). Ginger can be cultivated on any available arable land, except stony and water logged or marshy land. Stony farmland does not allow ginger to grow wide tubers while water logged farmlands rotten the ginger rhizomes (Arnhold *et al*., 2014). The crop thrives best in well drained soils like sandy loam, clay loam, red loam or lateritic loam which encourage better rhizome shape and size. A friable loam rich in humus is ideal, soil moisture is critical at the time of planting and sufficient amount of water is required for optimum growth and yield. However, too much water can create conducive environment for diseases to thrive and can also wash away or leach nutrients from the soil. Ginger requires mildly acidic soils for healthy growth and rhizome production, maintaining the soil pH between 5.5 and 6.5 is ideal (Nair, 2019a). In southern Kaduna where ginger is extensively grown in Nigeria, beds are preferred for rainfed ginger production while planting on ridges is recommended for irrigated ginger (Dauda *et al*., 2006). Ginger is cultivated as rainfed crop in areas with 5 – 7 months rainfall distribution and irrigated crop in areas with less rainfall. The crop requires 1300 – 1500 mm of water during its growth period. When grown under irrigation, the critical stages for water supply are during germination, rhizome initiation - about 90 days after planting (DAP) and rhizome development (135 DAP). The recommended planting depth is between 5 – 10 cm with spacing of 20 by 20 cm to give a plant population of 250,000 ha^{-1} (Sati and Bala, 2017).Weeding is done manually just before fertilizer application and mulching and about 2 – 3 times depending on the intensity of weed growth or by using chemicals (herbicides). Earthing up is essential to prevent exposure of rhizomes and provide sufficient soil volume to enhance development of the rhizomes. It is done at 45 and 90 DAP, immediately after weeding and application of fertilizers. Mulching among other benefits is practiced to conserve soil moisture and control soil erosion. Although ginger may be harvested at any stage at maturity, harvesting at about 8 – 10 months after planting (MAP) is ideal. In this review, we aimed to understand the growth and development pattern of ginger under rainfed production system in Nigeria, including the nutrient requirement and management for improved agronomic practices. It is expected that both yield and the resource use efficiency strongly improves, production risk decreases, and that the financial risk for farmers are effectively reduced.

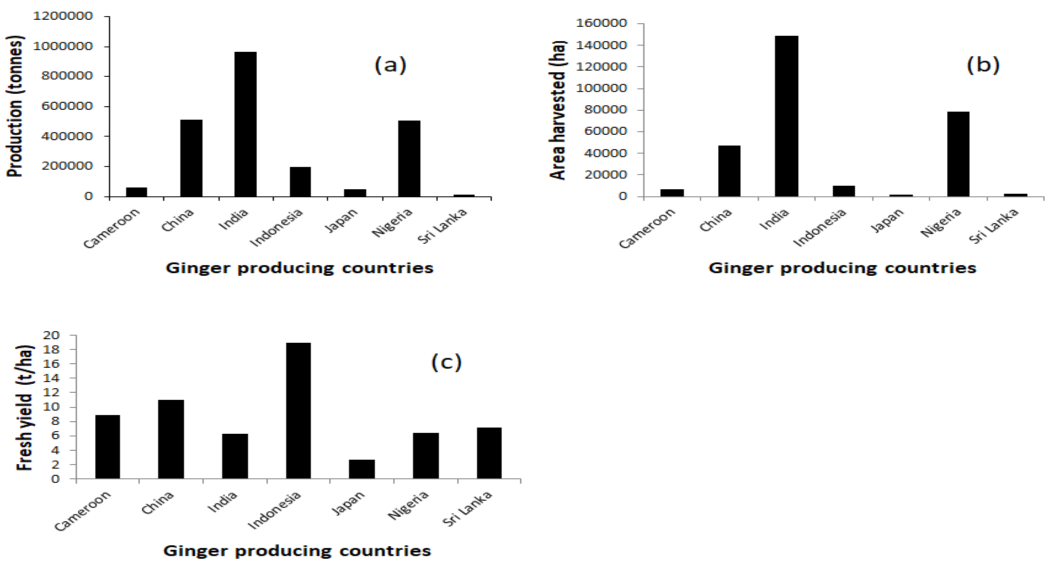

Fig. 1: Average annual production (a), total area (b) and fresh yield per unit land area (c) of ginger between 2010 and 2019 from selected countries

Botany and physiology of ginger

Ginger belongs to the family Zingiberaceae which includes about 85 species of herbs known to exist worldwide. It grows well in tropical and humid climates. It is an erect herbaceous perennial that grows to a height of approximately 60 – 120 cm. The outer skin of the rhizome is brownish while the inner flesh depending on the variety may be red, yellow or white. The leaves are simple, alternate, linear – lanceolate aerial shoots (pseudo stem), 2 – 3 cm broad with sheathing bases that grow from the branched rhizome. It has a club-like spike of yellowish, purple-lipped flowers. However, the flowers are usually sterile and rarely set seed (Aleem *et al*., 2020). The stem is surrounded by the sheathing bases of two-ranked leaves. Ginger has an underground stem known as rhizome. The aromatic rhizome is much branched; somewhat resembling the palm of a hand with fingers, a mature ginger rhizome is fibrous and has a striated texture. Except for the first few nodes of ginger, all the nodes have axillary buds. The fibrous roots grow from these nodes (Stewart *et al*., 1991). Several cultivars of ginger are named after their localities (FAO, 2004). Two major varieties of ginger are grown in Nigeria and are differentiated by the colour of the rhizomes; namely, the reddish and yellow varieties. The yellow variety known as UG1 is widely cultivated and more common in the market than the reddish variety (UG2) (Chukwu and Emehuite, 2003; Tridge, 2020). The UG1 (locally called *Tafin Giwa* meaning Elephant's foot type) is high yielding (about 15 t ha^{-1}). It yields higher and is more pungent than UG2 (*Yatsun Biri* meaning monkey's finger type), which yields about 11 – 12 t ha^{-1} in the farmers field. Ginger has a narrow genetic base and the constraint in breeding of improved varieties of the crop is that it does not produce viable seed that can form the template on which further breeding research activities can be built (Kure, 2007). Ginger is an intermediate to long duration crop, it takes about 10 months from planting to harvesting (Sharma *et al*., 2021). There are four stages of growth identified in ginger. Namely; the germinating stage – this stage begins when the bud starts to sprout, revealing the first leaf, at about 50 DAP. This is followed by the seedling stage which starts from the first leaf appearance to when the plant develops two tillers and this occurs at about 60 to 70 DAP. Then, there is the active vegetative growth (90–120 DAP), slow vegetative growth (120–180 DAP) and senescence (180 DAP), while the rhizome development continues until harvest. The shoot growth and development is prioritized against rhizome growth during the active vegetative growth stage, while the rhizomes dominate growth during the final growth phase and assimilates are mainly transported from the leaves to the rhizomes (Anderson, 1991). Xu *et al*. (2004) observed that at the seedling stage, about 80.7 % of the carbon (C) produced was translocated to the shoots. Later, C partitioning to the rhizome increased, while the distribution rate for shoots decreased with the plant age. The chlorophyll content and photosynthetic rate of ginger leaves increased with leaf expansion, reaches a peak at about 15^{th} day of leaf age and subsequently declines (Xu *et al*., 2004). Nair (2019b) reported that Leaf stomatal conductance of ginger decreased with increasing shade levels, and were highest when grown under open conditions. On the other hand, stomatal resistance increased with increasing shade levels. Also, photosynthetic rate and transpiration decreased with increasing shade levels when ginger was grown under open conditions. Leaf area index and dry matter yield peaked with 20 % shading and decreased with higher shade levels (Sreekala and Jayachandran, 2001).

Ginger nutrition

Physiological activities of plants, including growth and development are influenced by the availability of nutrients, and this in turn depends on the availability in the soil (Gowariker *et al*., 2009). Nutrient recommendation based on crop nutrient requirement and environmental condition should form the basis for manure and fertilizer application that optimizes economic returns while protecting water quality and the environment. Ginger rhizomes are mainly nitrogen (N) and potassium (K) exhausting, while it makes intermediate use of phosphorus (P) and magnesium (Mg) (Nair, 2019c). Ginger accumulates macronutrients in the decreasing order of N > K > Ca > Mg > S > P and micronutrients in the order of Fe > Mn > B > Cu (Haag et al., 1990). However, uptake of these nutrients varies with the crop variety, soil type, climatic conditions, nutrient levels in the soil, etc. A study by Govender *et al*. (2009) reported that soil quality influenced the distribution of elements within the ginger rhizome and the plant tends to control the amount of elements absorbed. Most especially, nitrogen uptake and utilization in ginger follows similar pattern of carbon assimilate distribution. About 48.41% of the N absorbed from fertilizer applied at seedling stage was distributed to the shoots, while 65.43% of N derived from fertilizer applied at active growth of rhizome was distributed to the rhizomes; only 32.04% was distributed to shoots (Nair, 2019c). The results indicated that the rate of N utilization increased when application synchronized with active growth stages. For the calculation of nutrient requirement of ginger, Johnson (1978) recommended a sample of the fifth pair of leaf within 90 – 120 DAP for foliage diagnosis of NPK.

Nutrient requirement and management

Ginger like other crops performs well when supplied with adequate nutrients. Organic matter from various sources e.g. mulches, green and organic manure enhances ginger growth and development. In most cases, basal application of organic manures is encouraged. It can also be applied after emergence of the crop, as mulch. Nair (2019c) reported a recommended dose of 25 – 30 t ha^{-1} of farm yard manure and 30 t ha^{-1} of green leaf mulch applied in three splits during the growing season. The application of inorganic N with neem cake containing 50 % N, poultry manure (25 % N), and groundnut cake (50 % N) increased ginger yield up to 29 t ha^{-1} (Nair, 2019c). Also, NPK application at 75:50:50 kg ha^{-1}, with neem cake at 2 t ha^{-1} increased the yield of ginger and reduced the rhizome rot incidence in Kerala, India (Nair, 2019c). Gradual release of nutrients from decomposing organics tend to synchronize with the nutrient uptake dynamics during the growth phases and this may contribute to the observed better growth and yield, when organic manure or the mixture with inorganic is used. Equal split mulch application of 10 – 30 t ha^{-1} applied twice or thrice (at planting, 45 DAP and 90 DAP), can increase yield considerably and add to the soil organic matter content, control weed, conserve soil moisture, reduce soil temperature and improve soil physical properties (Nair, 2019c; Ibrahim, 2018). There are many mulch materials, they include; coconut leaves, banana leaves, green and dry forest leaves, sugarcane trash residues, straws, cleared weeds, etc. Intercrops such as soybean, cowpea, French beans and many others can serve as live mulch and used latter for mulching from 45 to 60 DAP (Kandiannan *et al*., 1996). Nwaogu and Muogbo (2015) reported that ginger intercropped with grain legume crops performed well, with the highest responses in terms of ginger leafiness, tiller formation and fresh rhizome yield obtained from mung-bean/ginger intercrop. A study on improving ginger/maize intercrop (a common practice in southern Kaduna, Nigeria) showed that ginger (250,000 plants ha^{-1}) intercropped with maize (24,074 plants ha^{-1}) produced ginger rhizome yield of 10.8 t ha^{-1}, almost comparable with rhizomes yields of 14.1 t ha^{-1} obtained in sole ginger crop (Lyocks *et al*., 2013). The growth and yield attributes of ginger are significantly influenced by the nature of organic manures. Maximum plant height, tiller number, leaf number, clump weight and length and yield of 29.7 t ha^{-1} was obtained when ¼ of N was applied through poultry manure and ¾ of N as urea (Roy and Hore, 2007). It is economical to discontinue the application of complete fertilizer when ginger plants begin to flower and then amend with a potassium fertilizer as the plants mature. It increases the production of plump rhizomes (Thankamani *et al*., 2018).

Factors affecting ginger cultivation in Nigeria

The constraints of ginger production in Nigeria include: limited access to viable seeds, unreliable rainfall pattern, diseases and pests, inadequate fertilizers, post-harvest losses, market glut, lack of credit facilities and limited access to international market by ginger farmers (Sharma *et al*., 2021). Generally, ginger farmers, especially the smallholder farmers hardly acquire sufficient quantity of healthy planting material as they harvest and sell their produces before maturity, for quick returns. Hence, the immature ginger rhizome results in lower seed quality available for replanting. Intensified efforts on ginger seed sector development, including innovation of advanced scientific method of seed production such as hydroponics, will ensure that clean and viable planting materials are made available to farmers. Unreliable and low rainfall amount affects the yield of ginger. Farmers try to overcome this situation by shifting to alternative crops such as sorghum or maize, and by reducing the amount of ginger cultivation during the season. On the other hand, if the drought occurs at the mid part or towards the end of the wet season, the commonly adopted strategy is to delay harvest until the next planting season (Shehu *et al*., 2013). Diseases such as soft rot, bacteria wilt and leaf spot, including pests (nematode, shoot borer) affect ginger productivity. Soft rot is the most destructive disease of ginger which results in total loss of affected clumps. It could cause more than 50 % loss of the seed vegetation and about 30 % yield losses (Sharma *et al*., 2021). The disease is soil-borne and is caused by Pythium specie. The fungus multiplies with buildup of soil moisture, with the younger sprouts most susceptible to the pathogen. In order to prevent ginger soft rot, clean seed rhizomes from disease free farms are advised. Treatment of seed rhizomes with mancozeb 0.3 % or metalaxyl mancozeb 0.125 % for 30 minutes before storage, and once again before planting reduces the disease incidence (Sharma *et al*., 2021). Also, selection of well drained soils for planting limits the disease proliferation. At the early growth stage of ginger, the soil is exposed to erosion, thereby enhancing land degradation. Soil conservation measures and improved crop management technologies are required. Fertilizer, both organic and inorganic, is a major need of ginger farmers in Nigeria (Nwaogu and Muogbo, 2015). Unfortunately, this need is not always being met with ease. In order to overcome this challenge, farmers adopt management practices like crop rotation, mulching and application of organic manure, derived from several sources, such as ginger residues, burnt or decomposed domestic waste, animal or farmyard manure etc. In order to ensure that soil fertility of ginger farms are well managed, ginger is mono cropped and adequately mulched (Kantiok, 2007). This strategy, according to the farmers, helps in reducing competition on the available nutrients, allowing the ginger plant to grow well. In addition, crop rotation is commonly practiced. As such, the site where ginger has been cultivated for a year or two is being rotated with another different crop in the subsequent year, such as sorghum, cowpea, groundnuts or maize. This strategy of crop rotation enables the farmlands to relatively regain its fertility. The occurrence of market glut, a concept whereby ginger is in excess supply as against the demand for it, often happens, especially when the price of ginger rises, it entices ginger farmers to increase ginger production in the subsequent growing season which in most cases result in over production in relation to its market demand (Yakubu, 2007). When such situation is expected, those that are yet to harvest their products pause harvest until a favourable period, when there is a high demand for fresh ginger. This strategy helps ginger farmers break even. Nevertheless, improved post-harvest storage technologies can reduce losses due to market glut. On the other hand, drudgery makes ginger processing unpleasant and encourages post-harvest losses. There is need to develop a ginger processing technology for production of ginger flakes for variety of uses and storage. It comprises a washing, slicing and drying unit. This technology encourages large scale production, reduces post-harvest loss, enables value addition and increases farmer's income. Lack of credit facilities and direct access to international market are serious impediments to ginger farming; as inadequate funds limit farmers to small scale production, while limitedaccess to international market, keeps them from reaping favourable price returns. Unless these constraints are addressed, ginger production in Nigeria will remain retarded.

Discussion

Tremendous losses are incurred each year by ginger farmers who fail to plant, mulch, weed, fertilize and harvest at the appropriate time and with the appropriate methods. This review throws more light on the physiology and practicable agronomical approaches that could spur focused research towards improving the yield of ginger per unit land area. Research should be targeted towards enhancing the pungency, aroma/flavour and oleoresin content in ginger, in order to increase the demand and value of ginger from Nigeria in the international market. Another shortcoming of ginger production is the very narrow gene pool. Farmers have relied only on the two cultivars (UG1 and UG2), this should be improved by introducing cultivars from other ginger producing countries e.g. India and China. For instance, Indian ginger variety (Cochin) is a high quality variety with a unique lemon-like flavour and does not contain fiber. On the other hand, Chinese ginger is high yielding with large rhizome size (Tridge, 2020). These distinct varieties can be crossed with local varieties for better yield and nutritional quality. Nigeria is among the highest producers of ginger in the world, but backward in exportation. A breakthrough on the processing and storage techniques for better quality could improve the competitive power and earn more foreign exchange for the country. Comprehensive research on the supply and distribution channels of ginger is required in order to allow farmers have leverage in determining prices. The use of biotechnology in the improvement of some important plant species has not been fully harnessed and practiced by farmers and researchers. To increase the production of ginger, various techniques of biotechnology and improved production methods should be implemented. For instance, large scale greenhouse production for this sensitive crop will help produce more viable seeds and improve production.

Conclusion

Ginger is a beneficial crop with its potentials unharnessed, both in yield per unit land area and economics in Nigeria. The need for studies in sustainable cultivation, processing, storage, value addition and trade has become important. Research should focus on introducing cultivars that are high yielding, disease and flood-tolerant in Nigeria, such that could withstand problems associated in waterlogged areas, as done in rice.

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