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Interplay of Light Intensity and Nutrients on Ginger Responses Related to Growth, Yield and Quality of Ginger in Various Cropping Systems: A Retrospective Analysis

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Authors' contributions

This work was carried out in collaboration between both authors. Author HT did planning, conceptualized the study and wrote the manuscript. Author VK did planning and revised the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Ginger is an important crop belonging to the Zingiberaceae family. It is grown for its rhizomes, which are vitally important in the food and spice sectors as well as in the pharmaceutical and perfumery industries as a therapeutic herb. Its cultivation has been greatly expanded in several nations, particularly India, as it is a lucrative crop. The majority of ginger is produced and exported from India. Since ginger can withstand partial shade, it is a good choice for intercropping in several

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cropping systems, mainly for agroforestry systems. The effect of light intensity, as well as how they interact with nutrients to affect crop performance in terms of growth and development, production and quality is crucial for achieving maximum yield. However, the relationship between the growing environment and nutrient management which affect the elements that govern its growth, development and quality is not well understood. It is crucial to comprehend the proper amount of nutrients to apply in an intercropping system in order to minimise wastage since the intercrop may potentially interact with the main crop for nutrients and other inputs. Therefore, it is worthwhile to undertake the current literature study to learn how ginger responds to the stimulus of nutrients and varying light intensities in diverse cropping systems. From this, it can be inferred that ginger grown under partial shade in various cropping systems, can be a very profitable spice crop with superior yield and quality rhizomes.

Keywords: Ginger; cropping system; light intensity; nutrients; interaction; growth.

1. INTRODUCTION

Ginger (*Zingiber officinale* Roscoe) is an important spice crop grown throughout the world. It is well known for the medicinal values imparted by unique phytochemical compounds. There are more than 400 different chemical compounds present in ginger. Major constituents of rhizome include carbohydrates (50–70%), lipids (3–8%), terpenes (zingiberene, β-bisabolene, α-farnesene, β-sesquiphellandrene, and α-curcumene), and phenolic compounds (gingerol, paradols, and shogaol) [1]. In India, rhizomes of ginger are used for cooking with vegetables and for adding aroma and flavour to food. In some of the countries like Thailand, leaves of ginger are also used as salad. It is also used as a carminative relieving flatulence [2]. It is a traditional medication that has been used to treat a wide range of ailments, including sickness and confinement in women, as well as headaches, motion sickness, nausea, dyspepsia, and a reduction in colic and gas.

Increasing attention in ginger as spice, food ingredient, medicine and industrial component led to increased cultivation in many countries. Most of the ginger (78.3 %) is grown in Asian countries like India, China, Japan, Thailand, Indonesia and Taiwan; about 19.8 percent is cultivated in some African countries like Nigeria, Mauritius, Sierra Leone, Ghana;1.7 per cent in some parts of North and South America and only 0.3 % in Oceania. India is the largest producer and exporter of the ginger; it produces 1,844,000 tonnes of ginger from an area of 1,72,000 hectare [3]. Most of the ginger is produced in Madhya Pradesh, Karnataka, Assam, Maharashtra, West Bengal, Gujarat, Kerala and North-Eastern states.

Ginger can tolerate partial shade conditions and therefore it is well suited as intercrop in agricultural, horticultural and agroforestry systems, although it is also grown as a stand-alone crop. In southern states of India, it is grown under plantation crops such as coconut and arecanut. Growing ginger under the shade of fruit crops like guava, aonla, citrus etc. is a common practice in sub-Himalayan region. In sub-tropical areas, it is frequently interplanted in forest trees such as between rows of *Populus*, *Ailanthus*, *Luceana*, etc. [4]. The purpose of planting vegetable crops in these production systems is to utilize every inch of land as the available land for agriculture is decreasing at an alarming rate. In silviculture system a lot of land remain unutilized and a large proportion of land goes wasted. Moreover, there is less utilization of inputs like fertilizers and irrigation water. However, it is possible to grow more crops on the same piece of land in a given amount of time by using the land wisely in terms of time and space.

Intercrop selection is a crucial planning in agricultural, horticultural, and agroforestry systems. The intercrop should be selected in such a way that it should be complementary with the main crop, there should not be any competition for light, water and nutrients between the crops and most importantly the cropping system should be profitable [5]. Ginger is one of the best crops which fits into this system because of its tolerance to partial shade and high economic value of ginger rhizomes which are in continuous demand in global trade. It is important to note that light intensity plays a crucial role in the photosynthetic process as well as plant growth and development. Also, the intercrop may potentially interact with the main crop for nutrients and other inputs, it is important to understand the appropriate amount of nutrients to apply in an intercropping system to prevent wastage of fertilizers. There are several conflicting reports on the performance of ginger yields when grown in the open as well as in shades with varying light intensity [6,7,8,9, 10,11,12,13]. Therefore, to ascertain how ginger responds to the stimulus of nutrients, and various intensities of light in different cropping systems it is worthwhile to conduct the current literature study.

2. GINGER UNDER DIFFERENT CROPPING SYSTEMS

The foremost objective of agriculturists and farmers is to enhance the crop productivity, by increasing production per unit area with the expansion of cultivated land. However, the arable land is decreasing, so there is a need to analyse the role of multiple cropping as a method of crop production to enhance the agricultural production [14]. The success of multiple cropping system lies in the fact that the intercrop uses space and labour more efficiently [15]. Moreover, well-consumption of climatic factors, higher and more stable yields under varying environmental conditions, soil conservation, and the extent of inputs and outputs and their contribution to the stabilisation of household food supply [16] are some of the other factors contributing to its increased trend. An intercrop combination is considered best when it provides greater yield per unit area and is more competent to use resources than would otherwise be the case if each crop was grown as a monoculture [17]. Ginger, being a long-duration crop and having partial tolerance to shade, is well suited for multiple cropping in agriculture, horticulture and agroforestry systems. Intercrop of ginger in larger spacing of poplar (5 × 4 m) resulted in increased plant height, a greater number of tillers and leaves per plant. Additionally, the intercropped ginger had greater length and width of rhizome and yield per plant than monoculture [18]. Shade plays an important role in productivity of ginger, while growing as an intercrop in an agroforestry system. It was observed that ginger grows well with mango at 50 ± 5% shade and yielded 2.45-fold better than the least yield i.e., 5.07 t/ha in ginger-guava cultivation with 70 ± 5% shade [19]. In another study based on intercropping of ginger in different fruit trees, the yield of ginger was highest in coconut + guava-based system with 70-80 % PAR [20]. Intercropping of high fertilizer requiring crops can lead to reduced yields of both crops as compared to sole cropping. The reduction in the number of ears of sweet maize by 17.35 %, ear weight by 8.07 % and decreased number of ginger branches (5.12 to 6.47 %) and rhizome weight (5.64 to 16.43 %) was also reported [21]. However, higher comprehensive economic benefits were reported in ginger-sweet maize intercropping than sole cropping. The qualities of the soil and its microbial microecological environment are altered over time by the continuous cultivation of one crop on the same piece of land, which limits the development of the medicinal plant business by lowering the chemical components of medicinal plants. The intercropping of ginger with *Pogostemon cablin* improved the abundance and diversity of soil microbes and community structure by enhancing the number of dominant bacteria and activities of soil enzymes, which ultimately led to an increase in the active ingredient in *Pogostemon cablin* [22]. Similarly, Table 1 shows how intercropped ginger performed with different crops and its effect on various aspects of crop production.

Table 1. Features of intercropping ginger in different crops

S. No.	Intercrop/ Mixed crop	Effect of intercropping	Location	Reference
1	Sapota- Jatropha	Higher fresh rhizome yield and increased morphological traits like number of fingers, plant height, length and width of rhizome.	Gujarat, India	[23]
2	Maize at varying row spacing	Higher ginger yield, increased gross return and margin and benefit cost ratio when maize was planted on 3rd, 4th and 5th ginger row with 100 % ginger	Chapainawabganj, Bangladesh	[24]
3	*Paulownia elongata*	Ginger gave high yield as compared to maize and beans	*Buckingham, China*	[25]
4	Two bamboo species: (*Dendrocalamus*	Increase in yield by 10.5–15.6% as compared to open field Maximum returns (3,595.67 US$	Himachal Pradesh, India	[26]

S. No.	Intercrop/ Mixed crop	Effect of intercropping	Location	Reference
	asper Dendrocalamus hamiltonii)	ha^{-1} yr^{-1}) when ginger grown under the canopy of *D. asper*		
5	Spinach, cauliflower, bitter gourd	Sole crop of ginger lead to highest yield The benefit cost ratio of Ginger + spinach was best	Jharkhand, India	[27]
6	Popular	Increase in yield, plant height, number of tillers/plants, rhizome length and width at 5 X 4 m spacing of poplar.	Himachal Pradesh, India	[18]
7	Sweet maize	Decreased number of branches and rhizome weight per plant and increased income in intercropping	Jinan, China	[21]
8	Cowpea, soybean, mungbean, lablab	Enhanced growth, rhizome yield and other yield traits in intercropping with legume crops; highest yield was attained when ginger was intercropped with mung bean; yield was maximum when one row of ginger was planted with two rows of legume crops	Abuja, Nigeria	[28]
9	Ginger + Maize-Soybean	Increased total land output (2% higher than ginger sole cropping) and increased potential economic return by 6%).	Pokhara, Nepal	[29]
10	*Pogostemon cablin*	Improved soil microbial abundance, diversity and community structure, modification of soil physical and chemical properties	Guangzhou, China	[22]
11	Maize, French bean, Soybean, pumpkin, groundnut	Ginger + maize + French bean + pumpkin system recorded 15.20%, higher than sole ginger crop yield The intercropping of ginger + groundnut recorded highest benefit cost ratio (3.42)	Meghalaya, India	[30]
12	Maize	At 24074 maize plants/ha, the production of intercropped ginger (250000 plants/ha) was noticeably comparable to the yield of ginger grown as a solitary crop. At this plant population, the production of maize grains was likewise maximum.	Zaria, Nigeria	[31]
13	Teak	Intercropping of pruned teak and application of fertilizer in ginger increased the net weight of ginger	Karangduwet, Indonesia	[32]
14	Pigeon pea and Maize	Increased yield and reduces rhizome rot incidence	Assam, India	[33]

3. EFFECT OF SHADE AND LIGHT INTENSITIES ON GROWTH AND YIELD OF GINGER

Light intensity is a crucial element in plant growth and development. It is defined as the amount of visible light emitted in one unit of time per unit of solid angle. It is also the main component of photosynthesis and food production by plants. Accordingly, increasing light intensity will increase the photosynthetic capacity and also have a positive impact on plant growth [34,35]. Since ginger prefers shade, the amount of light that it receives in a cropping system will affect its growth characteristics and yield. Numerous research studies demonstrated an increase in ginger yield and contributing attributes with various levels of photosynthetic active radiation (PAR) under natural and artificial systems of shade [6,7,8,9,10]. In contrast to these studies, it was found that solitary cropping of ginger at 29200 lux was considerably more productive than intercropping with cashew plantations at 25774 lux in terms of fresh weight of rhizome, quantity of secondary rhizomes, and clump size [13]. According to Wilson and Ovid [36], ginger intercropped with okra (*Abelmoschus esculentus* L.), corn, and peas had more plant height, number of tillers, and rhizome yield than corn alone and in the absence of shade. Studying the impact of shade levels on ginger growth and yield, it was reported that plant height and tiller count were higher in 50% shade levels, while fresh rhizome weight, dry weight, and total yield were higher in 30% shade levels [37]. Ginger can also be successfully cultivated under the partial shade of multipurpose trees in a forest. Another study [38] reported higher rhizome weight and yield under the partial shade of guava trees (180 cm × 180 cm) than planting with the dense shade of gamar trees (90 cm × 90 cm). Moreover, it is also observed that ginger grown in shade remained greener and physiologically active for longer periods of time [4]. Pruning is an important practice in fruit crops to maintain a balance between reproductive and vegetative growth. Pruning of branches will lead to decreased interception of PAR by the fruit crops, allowing more light to reach the intercrop. Ginger, while growing as an intercrop with oranges, responded well to pruning, and authors reported an increase of 70 and 50 percent in growth and yield, respectively with pruning compared to unpruned orange trees [39]. Similarly, in an agroforestry system, pruning of teak trees resulted in increase in rhizome yield of *Zingiber officinale* var. *amarum* [32]. Comparing the efficiency of light authors reported that green light was less efficient wave length and it can only lead to increase in plant height as compared to white light treatment [40]. Later, it was found that supplementing green light under strong sunlight had a positive impact on the growth characteristics of ginger, leading to a higher number of shoots, increased crown density, and greater crown volume [41]. Intercropping ginger with pigeon pea and maize led to attenuation of total PAR (1688.1 μ mol s^{-1} m^{-2}) by 79.5 and 69.2%, respectively, leading to decreased rhizome rot incidence and increased yield due to unfavourable soil and air temperatures and soil moisture for the spread of disease [33].

4. EFFECT OF LIGHT INTENSITY ON BIOACTIVE COMPOUNDS AND QUALITY OF GINGER

Besides being used as a spice and flavouring compound, ginger is widely grown as a medicinal herb throughout the world, especially in Asia. The species *Z. officinale* is known for its wide range of bioactive compounds and phytochemical antioxidants, which have many health-promoting benefits [42]. Similar to other herbs that are used as flavouring agents in food, ginger is also a good source of phenolic and flavonoid compounds [43]. Quality control becomes an important issue while growing ginger for medicinal purposes, the altered concentrations of the bioactive compounds can be harmful to consumers. The concentration of phenolics and bioactive compounds in plants is highly influenced by environmental conditions such as light intensity, temperature, and other biotic and abiotic factors [43,44]. Furthermore, the concentration of phenolics and flavonoids may vary among different plant parts while grown in different light intensities. The flavonoid content was higher in the leaves in 60 percent shade, while phenolics were favouring the rhizomes in zero percent shade. Caffeic acid was only detected in ginger grown under zero per cent shade, while tannic acid only accumulated in the leaves of ginger grown under 60% shade level [45]. The synthesis of phenolic compounds and flavonoids in ginger, *viz*., quercetin, rutin, catechin, epicatechin, and naringenin, was high in plants grown at low light intensities. The antioxidant activities in leaves also increased with increasing flavonoid concentration at low light intensities (310 μmol $m^{-2}s^{-1}$). The ferric reducing activity of the rhizomes was higher than that of the leaves in 310 μmol $m^{-2}s^{-1}$ of sun light [43]. The growth and development of ginger are also affected by the function of the green light. The chlorophyll metabolism gene was upregulated, and the amount of chlorophyll-a was increased when green light was added with intense sunshine. The expression of photosynthetic genes and the rate of photosynthesis were both efficiently boosted by the enhancement of green light radiation [41].

In India, ginger is either eaten raw or dried, and in the importing nations, it is used to make oleoresin and essential oils. Dry ginger is necessary to command a higher price in the market, and ginger's essential oils, oleoresin, starch, protein, and dietary fibre are crucial qualities [46]. These traits are highly influenced by light intensity. According to a study, the dry ginger yield, non-volatile ether extract, starch content and crude fibre content increased at 20 and 40 percent shade as compared to 60 and 80 percent shade and volatile oil content increased with the increase in shade level [47].

5. INTERACTION OF NUTRIENTS AND SHADE AFFECTS GINGER'S GROWTH

The availability of nutrients is an essential factor in the growth and development of ginger, thus choosing the right fertilizer type and rate of application to get the best yield is important. In *Zingiberaceae*, which includes plants like ginger (*Z. officinale*) and turmeric (*Curcuma longa*) increasing fertilizer rates greatly increases the rhizome production [47,48]. Ginger is grouped as an exhaustive crop which responds greatly to manure application [49]. Ginger prefers shade, and the relationship between shade and fertiliser type and its rate of application impacts the crop's development and output. The interaction between shade levels and NPK fertilizers in *Zingiber zerumbet* (L.), reported an increase in yield with the increase in NPK fertilizer doses and shade levels [37]. The best plant growth and maximum rhizome yield was produced at 30 % shade level and N: P: K at 120:140:230 kg/ha/year. Ginger cultivated in shaded conditions can result in increased N and K uptake, necessitating a 150% increase in fertiliser dose [50]. Therefore, it was recommended that a fertiliser dose of 150 kg N: 100 kg P_2O_5: 100 kg K_2O ha^{-1} be used to increase ginger yield when grown under coconut trees [47]. Crop growth and productivity in an agro-forestry system are regulated by the interaction of crop canopy, soil nutrient content, soil temperature and moisture, etc. It was revealed that dense canopy and increased leaf litter of bamboo species (*D. asper*), and application of FYM improved the soil's physical, chemical, and moisture qualities, which in turn led to better development of ginger and an increase in rhizome production [26]. Similar to this, when teak and ginger were intercropped, pruning of teak increased light transmission, which together with fertilizer application resulted in heavier clumps of ginger as opposed to fertilized and non-fertilized treatments under open conditions [7, 32]. The grain legume crops like cowpea, soybean, mung bean and lablab as a sole crop or as an intercrop improve the nutrient status of the soil. Ginger intercropped with legume crops lead to enhanced rhizome growth and yield variables as compared to sole crops. However, growth variables of ginger can be reduced due to intercrop competition and reduced PAR due to excess shading brought about by the crop canopy. A ginger-to-legume planting ratio higher or lower than 1:2 may lead to under or overutilization of growth resources such as soil nutrients, light, and moisture by the component crops in the mixture [28]. Another study discovered a substantial interaction effect between light intensity and vermicompost on ginger's fresh rhizome yield. According to reports, vermicompost alone produced yields comparable to those of recommended dose under normal lighting conditions [51]. The fact that ginger accumulates more dry matter and absorbs more nutrients in the shade can be highlighted here. This suggests that if ginger is grown in an intercropped scenario with low light intensities, the fertilizer dose may need to be increased to get the best yield.

6. MECHANISMS INVOLVED IN GINGER'S REACTION TO LIGHT AND NUTRIENTS

Light and nutrients are the most crucial components for successful plant growth when environmental considerations are taken into account. Photosynthesis, a complicated process for producing biomass that involves the synthesis of pigments, the Calvin cycle, and electron transport, requires functional light [52]. Along with influencing plant growth and yield potential, light quality and intensity also have an impact on the architecture and mechanism of the photosynthetic apparatus [53,54]. A certain amount of light is required by plants for growth; light levels that are too high or too low may affect photosynthesis adversely. Light also affects the environmental conditions like soil and air temperature, humidity, carbon dioxide concentrations around the plant [55]. In addition to light, balanced nutrients must also be provided to meet the needs of plant for growth and development, as deficiencies in nitrogen, phosphorus, potassium and other essential nutrients can hinder plant growth and development, photosynthesis, and reduce leaf area [56,57,58]. Finding a balance between lighting and fertilization based on regional circumstances is crucial for greater quality and higher yields. For instance, different nitrogen rates, as well as red-blue LED light intensities, had an impact on lettuce development. Higher light intensities and lower nitrogen contents enhanced photosynthesis and lettuce output [59]. The following is a description of some potential reasons that could explain how nutrients, light, and their interactions affect ginger's growth and quality.

6.1 Probable Causes of the Varying Effects of Light on Ginger Growth and Yield

Ginger, being a shade-loving plant, can carry out its physiological processes appropriately at reduced light intensities [60]; however, the effectiveness of relative light intensity may vary with the geographical region, season, day length, intensity of light, humidity, temperature and cultivar. Ginger as an intercrop intercepted less PAR with a lower reflection coefficient as compared to a sole crop, indicating efficient use of PAR (Fig. 1). Here, the higher rhizome yield and increased value for other morphological parameters of the plant may be attributed to the low light intensity and shade-loving nature of the crop. It was reported that ginger grows more rapidly when light transmission is reduced and air temperatures and relative humidity (RH) are raised [6,9,18,61]. As a matter of fact, relative humidity drops as the temperature rises if no additional moisture is supplied to the air [62,63,64]. Therefore, the inadequate combination of light, temperature, and humidity may be the cause of the lower growth parameters in open field conditions. Additionally, high light intensity may cause damage to shade-loving plants by reducing the leaf area due to high radiation level causing damage to photosynthetic pigment [37]. On the other side, more photosynthates accumulated under shadowed conditions due to higher leaf area values, which in turn enhanced bulking rate, net assimilation rate, and crop growth rate, increasing rhizome output. In addition, increased weight of rhizomes results from early bulking and progressive accumulation of photosynthates even during the latter phases of plant growth [65]. Similarly, increasing the shade level was reported to produce a higher biomass in turmeric [66,67]. Growing ginger as intercrop with crops like maize and pigeon pea provided congenial microclimate which led to optimum growth and high yield of ginger and reduced incidence of rhizome rot disease [33]. Contrastingly, there are reports of increased rhizome yield in open conditions as compared to shading. Authors have suggested high light interception, less competition for nutrient and moisture in sole crop [11,12,13] and competition for light, source and sink relationship in plant and mobilisation of assimilates from the source to primary and secondary rhizomes for decreased yield in partial shade [68,69]. The allelopathic nature of *Tectona grandis,* competition for essential nutrients and inadequate light intensity for the poor tiller production by ginger grown in the teak was also reported [7].

6.2 Reasons for Differential Effect of Light Intensity on Bioactive Compounds and Ginger Quality

During growth and development, plants have to interact with the biotic and abiotic factors of their ecological environment. Among abiotic factors, *viz*., water, light, temperature, soil, etc., light is the most crucial of all; extremes of it cause stress, which leads to variation in the synthesis of secondary metabolites [70]. The phenolic and flavonoid content of the same plant may vary depending on the ecological type it is domesticated into. It has been reported in ginger and many other crops that low light levels are ideal for producing the most flavonoids, but high light levels were ideal for phenolic acid production [45,71,72,73]. This is because UV and blue light at zero per cent shade level inhibits the activity of the enzyme chalcone synthase, which is crucial for the flavonoid pathway [74,75].

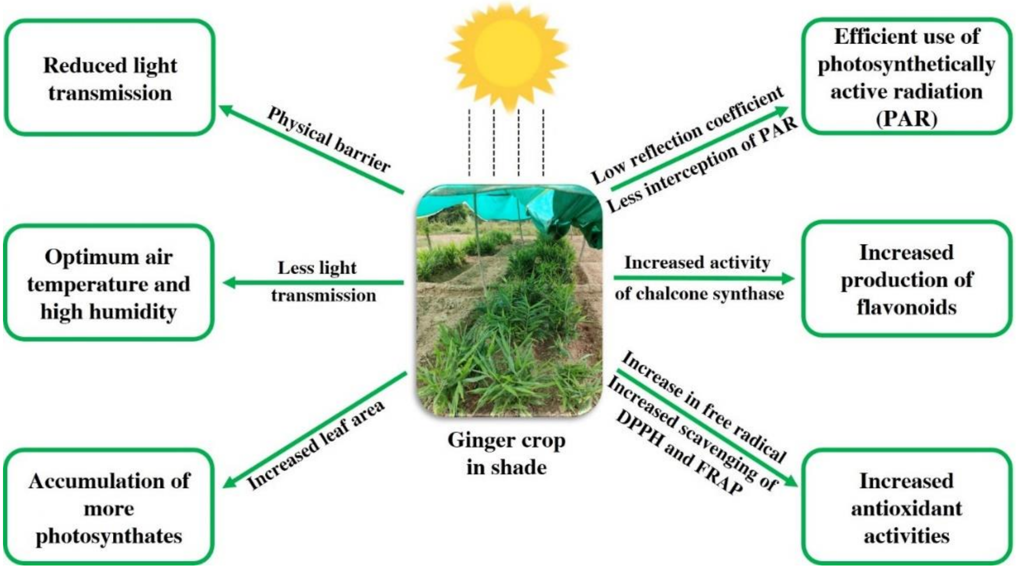

Fig. 1. Flowchart showing factors responsible for improved performance of ginger under shade

While the increased phenolic compounds in high light intensity is due to increased activity of Phenylalanine ammonialyase (PAL) enzyme under high light intensity and UV (Fig. 1) [76]. Additionally, different shade levels had a substantial impact on the synthesis, accumulation, and partitioning of flavonoids and phenolic acids in different parts of ginger and different genotypes had a variable concentration of flavonoids and phenolic acids. The strong positive relationships between total flavonoids contents and antioxidant activity were reported in other studies also [43,77]. Therefore, antioxidant activities were also higher at low light intensities due to increased free radical scavenging power, which rose along with the increase in total flavonoids, suggesting that flavonoids had a greater impact on free radical scavenging than phenolics [43]. The antioxidant activities are in general higher in leaves than the rhizomes in most of the studies [42,78,79]. The most abundant flavonoid in ginger is quercetin and apigenin. Recent studies on the potential carcinogenicity of quercetin have also looked at its potential as a cancer preventative. The synthesis of quercetin content in leaves and rhizomes increased in low light intensity, suggesting that medical power of ginger can be improved by growing it in low light intensity.

7. CONCLUSION

Ginger is able to effectively utilise low light intensities, suggesting that the growth performance of ginger can be improved under partially shaded conditions. Ginger is an excellent intercrop because in shaded conditions it uses PAR efficiently and has low light reflection. As a result, it accumulates more photosynthates under shaded conditions because of its larger leaf area values. This increases the crop's bulking rate, net assimilation rate, and growth rate, all of which increase the production of rhizomes. On the other side, in open conditions, high light intensity can cause damage to the plant pigments, which leads to reduced leaf area and ultimately reduced photosynthesis and poor growth of the plant. However, it is well known that too much shade can lead to reduced yields. Here, it is crucial to emphasise that the efficiency of relative light intensity may vary depending on the geographical region, season, length of the day, light intensity, humidity, temperature, and cultivar. Therefore, with the proper management of light intensity and nutrition, ginger can be accommodated as an intercrop in agricultural, horticultural, and agroforestry systems. The tall crops of these systems can modify the microclimate by providing shade during sprouting and rhizome development stages. Nevertheless, by including ginger as an intercrop in various systems, farmers' income per unit area can be increased.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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