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Agronomic Advances and Challenges of Chia Production in Kenya: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Chia (*Salvia hispanica* L.) is an annual tropical plant belonging to the Lamiaceae family. In Kenya, Chia has gained significant attention in recent years due to its nutritional benefits and increasing demand in the local and global market. This review aims to explore the potential of chia production in Kenya as a source of income for farmers. The review highlights the agronomic requirements of chia, including soil, water, and climate conditions, as well as practices necessary for successful cultivation. Chia production is becoming a favorite enterprise for most farmers in Kenya due to its ease of management and short growth period. However, a seamless production has been encountered by several challenges, including scarce information regarding its agronomic management practices, poor yielding varieties, emerging pests and diseases, and poor harvesting and post-harvesting techniques. The growing demand for chia globally presents an opportunity for Kenyan farmers to tap into this market and generate income through export. Chia, has the potential to become a new golden crop for Kenyan farmers, contributing to food security, poverty reduction,

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and sustainable development. However, to realize this potential, there is a need for investment in research, extension services, and market linkages to support chia production, improve agronomic practices, and create a sustainable market for the crop.

Keywords: Production practices; crop management; harvesting; insect pests; crop nutrition; varieties.

1. INTRODUCTION

Chia (*Salvia hispanica L.)* is an annual tropical plant belonging to Lamiaceae and the genus Salvia. Chia seeds are considered a rich source of omega-3 compared to other plants due to the high content of alpha-linolenic fatty acids. Chia production in Kenya is slowly gaining momentum due to the popularity of the nutritional benefits of the seeds and leaves. Different authors have referred to it as the sleeping beauty [1] and the golden crop of the 21st century [2].

However, the expansion of Chia production in Kenya is encountering challenges in terms of organization and efficiency, largely attributed to the limited availability of comprehensive information [3]. Existing studies in Kenya have predominantly focused on investigating the physical and chemical properties of Chia seeds, while crucial aspects related to its cultivation have been overlooked. Thus, the primary objective of this review is to bridge this knowledge gap and provide a thorough understanding of Chia production in Kenya. By exploring cultivation practices and uncovering its agricultural potential, the review aims to pave the way for maximizing the benefits of this nutritional treasure within the Kenyan agricultural landscape.

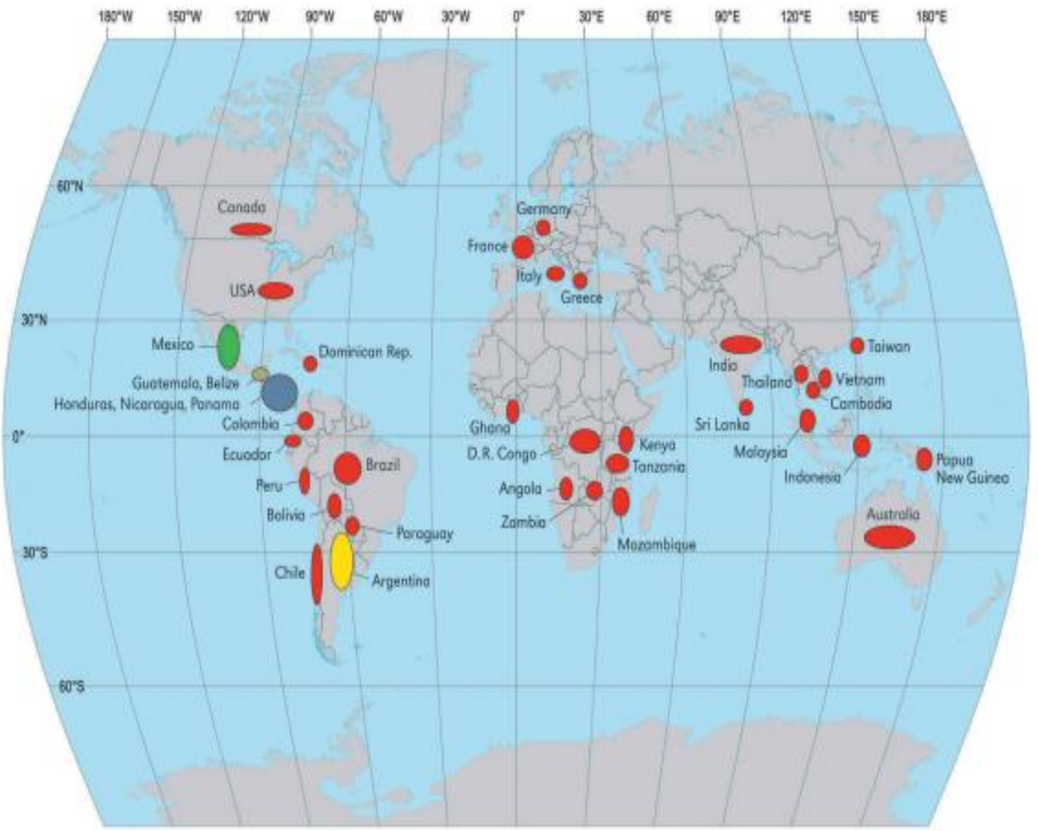

Fig. 1. Historical widespread of Chia globally. The agricultural areas shaded green, blue, yellow, and red represent the area of Chia cultivated on Early pre-Columbian times (3500 BC-1000 AC); Late pre-Columbian time (1000AC-1500 AC); Post Columbian time (1500 AC- 2000 AC); and Modern time (2010 until this date) [4]

1.1 Chia Production Globally

Chia, amaranth, corn, and bean were the main staple food for the Mexicans during the pre-Columbian times (Ayerza & Coates, 2005). The arrival of the Spanish in southern Mexico and Guatemala led to the disappearance of Chia as it was related to Mexican traditional medicine. In the 90s, it was revitalized by Acatic jalison farmers who had secretly retained the use of Chia [5]. Chia was classified by a botanist known as Carl Von Linneo, who named it Salvia (cure) hispanica (Spanish) (Sosa et al., 2016). However, the name *Salvia hispanica* gained a lot of controversies since its origin was Mexico and not Spain.

The spread of Chia production to other countries (Fig. 1) was ignited by researchers' findings from Argentina and the USA (Fonseca, 2016). They found out that Chia seeds and leaves had high omega 3s and poly-unsaturated fatty acids. Due to its multiple uses for both man and animals, there has been an increase in demand for Chia [6], leading to Chia's integration into modern agriculture, hence an increase in production.

The major producers of Chia globally are Mexico, Bolivia, Australia, the USA, Guatemala, Argentina, and Peru (Fig. 1) [7]. Today chia production has expanded to many regions of the world, covering about 370,000 hectares from 500 hectares in the 1990s. Bolivia, one of the major producing countries globally, increased its cultivation from 50,000 hectares producing 18,000 tonnes per hectare, to 80,000 hectares producing 30,000 tonnes [2]. Chia was introduced to Kenya by NGOs in 2014 (Fig. 1), with the crops entering through the Kenyan-Ugandan border [8]. The introduction of Chia aimed to play a pivotal role in alleviating malnutrition in the region, highlighting its potential as a nutritional resource and demonstrating the ongoing efforts to improve food security and health through innovative agricultural practices.

The ideal growing zones for Chia are found between latitudes 25° 55’N and 25° 05’S. In regions with higher latitudes, such as 38° 00’N (USA), Chia plants are unable to produce seeds as frost destroys them before flowers can set [9]. Countries outside this optimal latitude range often face challenges with relatively low nutritional quality and seed yield, sometimes resulting in no seed yield at all. To address this issue, these countries are focusing on producing Chia varieties or cultivars that can better adapt to their specific climates. An example of such a variety is Sahi Alba 914, which exhibits photoperiodic independence, making it suitable for cultivation in regions with high latitudes [9].

Modern plant breeding efforts for Chia have been limited, and improved cultivars have mostly been developed through the selection of lines from mixed germplasm sources, particularly landraces (Sosa et al., 2016). The dominant domesticated variety "Pinta" is widely cultivated (Cahill, 2005). However, efforts have been made to develop better cultivars, including Sahi Alba 911, Sahi Alba 912, and Sahi Alba 914 (Table 1), which are white seed lines resulting from mass selection. Additionally, "Omega 3," a variety developed in Florida USA through mass selection from a mixed population, likely derived from "Pinta," variety (Sosa et al., 2016).

Countries like the USA and Argentina are utilizing plant breeding to develop Chia cultivars that can adapt to varying day durations and climatic conditions. For instance, the Hearthland variety was developed in the USA through gamma radiation-induced mutation and is available with both white and black seeds. Argentina has seen significant success in genetic improvement, resulting in the establishment of large Chia cultivation areas in a short period. The seed yield in Argentina ranges between 150 and 1,200kg per hectare, with a national average of 350 kg per hectare [10]. In contrast, Chia cultivation in some agricultural zones in the USA has been less successful, with a limited increase in the land area dedicated to Chia and a low average seed yield of only 290 kg per hectare [11]. Chile and Italy are conducting research to identify the best planting date for Chia, but the seed yield in these countries remains below 400 kg per hectare.

However, tropical regions such as Mexico, Ghana, and Kenya have demonstrated promising results, achieving high yields of Chia seeds ranging from 1305 to 2605 kg per hectare, especially with proper irrigation (Sosa et al., 2016) [12]. The low seed yields observed in some countries are often associated with water stress due to inadequate irrigation practices (Sosa et al., 2016).

Table 1. Chia Varieties Globally

Cultivar/Genotype/Variety / Abbreviation	Country of Origin	
G8	USA	(Grimes et al., 2020) [13]
"CHIA"mpion W-83	India	(Mohanty et al., 2021) [14]
06815BOL, 06915ARG, 07015ARG	Bolivia and Argentina	(Mack et al., 2017) [15]
UGA	Uganda	(Grimes et al., 2020) [13]
Sachia White, Sachia Black	Mexico	(Grimes et al., 2020) [13]
KOL, BOL	Columbia and Bolivia	(Grimes et al., 2020) [13]
Sahi Alba 911, Sahi Alba 912,	Peru	(Bochicchio et al., 2015) [10]
Sahi Alba 914	Argentina	(Mack et al., 2017) [15]
W13.1	USA	(Mack et al., 2017) [15]
SALVA 66	Spain	(Grimes et al., 2020) [13]
Pinta White, Negra Puebla	Mexico	(Sosa-Baldivia et al., 2018) [1]
Tzotzol	Mexico	(Ayerza, 2019) [16]
Chia Nigra	Spain	(Grimes et al., 2020) [13]
Oruro©	France	(Kuznetcova et al., 2020) [17]
Heartland	USA	(Sosa-Baldivia et al., 2018) [1]

In Africa, Chia is produced in various countries, including Uganda, Tanzania, Egypt, Mozambique, Zambia, Angola, Ghana, the Democratic Republic of Congo, and Kenya. Ghana, lying between latitudes 23° 30'N and 23° 30'S, has achieved higher seed yields ranging from 1300-2600 kg/ha under suitable agronomic management practices, surpassing those of native Chia countries [18]. Uganda is the only country in Africa known to have developed a Chia variety called UGA (Table 1). However, in Kenya, studies indicate that there is limited information concerning different Chia varieties, particularly among farmers, resulting in the production of unknown and unimproved germplasm [19]. Given the commercial importance of Chia, it is essential for all stakeholders to consider future production through breeding. Breeding high-yielding varieties adaptable to the Kenyan environment is necessary, considering the ongoing breeding efforts in other countries (Table 1).

1.2 Chia production In Kenya

Chia in Kenya is believed to have been introduced by community health organizations in 2014, through the Kenyan Ugandan border to improve and manage lifestyle diseases [8]. Kenya's agricultural zone lies on the equator, which is between the latitude for Chia production. With recent research, Kenya has shown a great potential to produce more than the countries of origin. A study conducted in Meru, Kenya, on the influence of Nitrogen reported that the seed yield ranged as high as 2000-3000kg/ha [3]. A kilogram of Chia seeds in Kenya fetches around 1,500- 2000 Kenyan shillings, and with the current literature of 2000kg/ha, this would translate to 3-4 million Kenyan shillings per hectare. However, the price of Chia is believed to fluctuate according to demand, quality and quantity produced.

Kenyan farmers have gained a lot of interest, resulting in to spread of Chia production to different counties such as Nyeri, Busia, Machakos, Nakuru, Trans-Nzoia [19], and Meru. Due to its nutritional and financial benefit, farmers substitute common crops such as maize and potatoes for Chia. Commercial Production of Chia may lead to the diversification and stabilization of the local economy. However, in a survey conducted by Gitau et al. [8], in Nyeri County, Kenya, only 18% of Kenyan farmers knew about Chia while 82% had not had about chia plant. Nevertheless, the survey also found that 88% of the farmers were willing to produce Chia on their farms. Information on the agronomic management of Chia in Kenya is still scarce. This could be why only a small percentage of farmers in Kenya know about the crop. Gitau et al. [8] recommend the sensitization of the importance of Chia production to the farmers in Kenya.

2. EFFECTS OF ECOLOGICAL FACTORS ON CHIA PRODUCTION

2.1 Growing Temperature

The optimum growing temperature of Chia ranges between 15-36^{0}C. In addition, Chia seed

Table 2. Maximum and minimum temperature for chia producing Counties in Kenya

County	Average Minimum Temperature (^{0}C)	Average Maximum Temperature (^{0}C)
Nakuru	16	19.4
Busia	20.9	23.4
Trans Nzoia	16.5	20.7
Meru	18.9	21.4
Machakos	17.2	20.5
Nyeri	13.9	17

germination occurs under a constant temperature of 20^{0}C [10]. Chia producing Counties have a varying minimum and maximum temperature as shown in Table 2. The minimum average temperature is experienced in the month of July while the maximum average temperature is experienced in the months of February and March. The average temperatures fall under the recommended chia producing range, however with temperatures varying across counties and months, there exist limited information on the influence of temperatures on the yield of Chia.

Various studies have reported a higher germination rate of above 80% when seeds were germinated under 20, 25, and 30^{o}C [20]. However, poor germination rate of chia seeds has been observed under extreme temperatures. Banginsky et al. [21] reported a lower germination rate when seeds were germinated under temperatures above 30^{0}C. This is in agreement with Cabrera-Santos et al. [22] who also recorded a low germination rate when seeds were grown at temperatures above 30^{o}C and below 20^{o}C. The same study also revealed a 2-day germination delay on seeds placed at 10^{o}C, which was characterized by reduced metabolic rates. Extreme temperature has also an effect on the reproductive phase of Chia. Dead flower buds were recorded when temperatures were lowered below 10^{0}C [23]. Similarly, high temperatures led to an extension of the leaf formation periods, thus leading to increased vegetative growth at the expense of grain production [21].

2.2 Soils

Chia grows well in moderately saline, well-drained soils with a pH of 6.5-9 [18]. Different authors have related salinity when growing chia seeds to leading to reduced oil in chia seeds [24]. Chia can be grown in different textural classes, provided the soils are not too wet. However, Chia is moderately tolerant to acidic soils and drought [25].

Soils types in Chia growing areas in Kenya vary however, but they are considered to be conducive for Chia production given that Chia grows in all soil textural classes. However, soil studies have revealed that soils in Kenya are generally acidic with a pH ranging from 4.53 to 7.12 [26]. Acidic soils are known to affect the availability of nutrients in the soil either by decreasing nutrients and causing deficiency or increasing and resulting to toxicity. Acidic soils have been reported to affect growth of Chia thus subsequently leading to low yields [27].

3. INFLUENCE OF CHIA PRODUCTION ON DIFFERENT AGRONOMIC PRACTICES

3.1 Nutrient Management

Nutrient management is very critical in both environmental and economic terms. This helps increase the yields of crops and, at the same time, reduces nutrient losses to the environment. There has been a misleading theory of Chia being a low nutrient requirement crop which is on the contrary of the findings of Mary et al. [28], who reported application of 90:60:75 NPK/ha resulted in an increased yield of 623kg/ha as compared to the lower fertilizer level of 30:20:25 NPK/ha producing 477.95 kg/ha. These results were in harmony with Salman et al. [29], who recorded a higher plant growth after application of 3g/l of NPK (two portions) with the addition of a biofertilizer. Low nutrition to the plant has been found to interfere with the size of all external parts of the Chia plant, for example, reduced panicle sizes and grain weight, while high fertilizer application results in high vegetative growth [30].

3.1.1 Nitrogen fertilization

Chia plant, nitrogen fertilizer application is currently recommended at a rate of 15-51kg/ha [31,10]. However, a higher amount of nitrogen has been proposed, such as Sosa-Balvidia et al. [1] applied 150 N kg/ha. Nitrogen is the nutrient applied more frequently and in higher quantities than phosphorus and potassium, thus being referred to as the engine of plant growth. Its supplement results in a four per cent increase in the biomass of the plant. A good supply of Nitrogen is critical for the absorption of other nutrients and it is requirement in the soil is believed to change according to the soil type and the region of production [32].

Nitrogen is essential in plant growth since it is a critical element of the structure of enzymes, protein, by-product molecules, and amino acids involved in the plant's growth and development. The addition of Nitrogen fertilizer to chia plant has had a positive impact on both growth and development. Salman et al. [29] found that Chia plants grown in Brazil increased when 125kg of Nitrogen per hectare was used compared to plants that did not receive any nitrogen fertilizer. The plant height of Chia was 60.03cm in 125N kg/ha compared to 37.33cm in 0 N kg/ha; these results agree with Busilachi et al. (2014), who found a higher height of 70-112cm. The number of leaves also increases with an increase in Nitrogen content. Salman et al. [29] observed 18 leaves at higher nitrogen fertilization and 16 leaves on a plant that did not receive nitrogen fertilizer.

Salman et al. [29] also found an increase in dry biomass due to increased nitrogen fertilization resulting in a weight of 8.06g per plant at a fertilizer rate of 2125 N kg/ha and lower biomass of 3.52g per plant in 0 N kg/ha. However, Bochichio et al. [10] found contradictory results, where they observed unresponsive plants towards nitrogen fertilizer. Sosa-Baldivia et al. [1] assumed that Chia recovers 80% of the nitrogen applied, and thus each kilogram of Nitrogen used produces 16.7 kg of seed. Soils in Kenya do not fully meet the demand for Nitrogen [33] hence, it is essential to complement it with other nitrogenous fertilizers. Nevertheless, nitrogen application requires care in respect to the quantity and time of application since high nitrogen levels could result in lodging, making it difficult to harvest and, as a result, lead to low yields.

3.1.2 Phosphorus fertilization

The recommended phosphorus fertilization application on Chia plants is 43 P_2O_5 kg/ha [10]. Phosphorus is the most limiting factor in plant nutrition due to its low concentration in the soil and the fact that it binds to soil colloids, thus affecting its availability in the soil [34]. Phosphorus nutrient is essential at the beginning of the vegetative stage, and the unavailability of this nutrient could result in developmental constraints, which could make the plant not recover even after providing adequate nutrients [29]. Low phosphorus content in the plant could lead to slow cell growth due to the accumulation of soluble nitrogen components in the tissue [10]. The slow growth of cells could eventually lead to decreased plant height, reduced root development, and low seed yield [29].

Various literature reports the influence of phosphorus nutrients on the growth of Chia, Salman et al. [29] observed a higher plant height of 22.49cm at a phosphorus fertilization rate of 100kg/ha and also a higher number of leaves per plant as compared to no phosphorus fertilization. The absence of phosphorus could lead to reduced biochemical function in the plant physiology resulting in lower heights [35]. Higher plant biomass on phosphorus application has been reported [35], this is as a result of increased photosynthesis from the higher number of leaves produced by the plant, thus increased production of the photoassimilates. This was also in agreement with Korkmaz et al. [31], who recorded a sixfold increase in dry matter compared to plants with no phosphorus fertilization.

Da Silva et al. [35], reported a high number of inflorescence when 76kg/ha of phosphatic fertilizer was applied. The findings also showed a decreased plant height, leaf area, and inflorescence production in plants denied phosphorus fertilizer. This may be attributed to phosphorus promoting photoassimilates production in the development of leaves and inflorescence. In other studies, the Chia plant has shown poor response to very high and low doses of phosphatic fertilizer; this results from a similar residue effect in the soil [35]. The poor response of Chia to both low and high doses of phosphorus has been attributed to the loss of genetic variability during the domestication process of Chia [35]. Low mobility of Phosphorus in the soil and its easy adsorption rates by clay oxides and minerals, applying phosphorus fertilizer to the plant is necessary, especially during the early stages of growth. Understanding the characteristics of Phosphorus accumulation, remobilization, and partitioning is important for developing practices and strategies to improve Phosphorus use efficiency in the production of Chia in Kenya.

3.1.3 Potassium fertilization

The recommended pottasium fertilization application on Chia plants is 60 K_2O kg/ha [10]. To date, Potassium fertilization on Chia receives less attention than nitrogen and phosphorus [10]. After harvest, potassium is lost more than what is returned to the soil [29]. Potassium is the cation required in greater quantity by plants, regardless of the nutrient management philosophy. High amounts of K are needed to maintain plant health and vigour. K's specific roles include; osmoregulation, an internal balance of cations and anions, activation of enzymes, proper use of water, translocation of photosynthesized products. Since Potassium is needed for most biological processes of the plant, its deficiency has been reported to reduce crop development [29].

Plant height of Chia is reduced under low potassium doses, and this was reported by Salman et al. [29], who found a significant difference in the height of Chia under 0 kg/ha and 100 kg/ha of phosphorus. At 100kg/ha, Chia grew to a maximum height of 60.30cm and a minimum height of 37.33cm in 0 kg/ha. The study also recorded a significant difference in the number of leaves, inflorescence, and dry matter under different rates of potassium. A higher number of leaves (16), inflorescence number (8), and dry biomass per plant (5g) were recorded under 100kg/ha of potassium fertilizer as compared to 0 kg/ha. To date, no studies have been done in Kenya on the response of the Chia plant to different doses of potassium fertilizer.

Chia farmers in Kenya are currently using organic fertilizer to improve production, while others are not incorporating any nutrients. The composition in the organic fertilizer is usually based on the compost and green manures, liquid or solid manure, and crop rotation [36,37]. The release of the usable nitrogen in the soil is usually slow, and factors such as adequate soil temperature and soil moisture affect the mineralization process [38]. Knowledge of the benefits of different nutrient compositions such as Nitrogen, Phosphorus, and Potassium is necessary to increase the current production of Chia in their farms.

3.2 Plant Spacing

Chia seed rate is recommended at 5-6kg/ha with a row spacing of 70-80 cm [10]. Crop spacing has been reported to be one of the main challenges facing field crop growers worldwide [39]. The interception of radiant energy to crops in different spacing has a critical role on plant secondary metabolites and growth [40]. The number of plants in a field is an essential factor that affects the volatile oil and yield of Chia plants [41]. Wider spacing allows plants to have sufficient light, water, air, and nutrients, while a narrow spacing allows plants to have restricted exposure to resources [21]. Chia growth and yield is affected markedly by how closely plants are spaced in a plantation field, Rasha et al. [40], reported plant spacing influenced the growth of chia plant in terms of height and number of branches.

At a narrow row spacing of 30cm, chia plants were taller (70cm) and with a lower branch number [40]. These results resemble those findings in Kenya, where at plant spacing of 30cm x 15 cm, the plants were taller in size than plants with wider spacing of 50cm x 50cm [12]. In other studies, increased plant spacing has been accompanied by increased branching and increased stem length. However, the increase in stem length and branching did not compensate for the fewer plants per meter squared. An increase in biomass accumulation has been recorded in a wider spacing. Rasha et al. [40] recorded an increased biomass accumulation in a wider row spacing of 40cm. The increase in stem length and branching in a wider spacing, which also led to increased biomass, has been directly attributed to the exploitation of the active photosynthetic radiation and available nutrients used for plant growth compared to plants in narrow spacing.

Grimmes et al. [42] found no significant difference in yield and a thousand seed mass of Chia seeds planted under different row spacing arrangements. However, a higher seed yield of 1171 kg/ ha was obtained in a narrow spacing of 35cm. The results are in agreement with Yeboah et al. [18] and Rasha et al. [40], where they obtained a higher seed yield of 3208kg/ha at a narrow spacing of 0.5cm x 0.5cm and 250 kg/ha on a row spacing of 30cm respectively. Contrary, Chia yield and growth is influenced by the number of plants planted in an area of land is according to the results of Mary et al. [28], who found out that a larger spacing of 60cm x 45cm resulted in a yield of 597kg/ha as compared to a spacing of 60cm x2 2.5cm which had a maximum output of 489.15kg/ha. Based on the results from different studies, Grimmes et al. [42] advocate for a narrow plant spacing arrangement in high-yielding environmental conditions. Information on the performance of Chia under different spacing arrangements in different agroecological zones in Kenya is limited.

3.3 Water Management

Chia can be grown on irrigated fields or under rain-fed conditions. Rainfall requirements range from 300 to 1000 mm throughout the growing period [1]. Optimal rainfall is needed during propagation and vegetative growth, thereafter drier conditions are required until maturity (Aryeza, 2016). Drought is one of the abiotic factors that is known to limit the production potential of most plants. Change in rainfall distribution has caused low water availability to the plant, water availability for farming purposes is likely to reduce in the coming years. The use of water in the plants corresponds directly to biomass and yields [43]. The plant response to water scarcity is dependent on the stage in which the deficit was applied [15]. Water availability affects the Germination of Chia seeds, and germination cannot occur below a certain point [12].

Chia has the characteristic of producing mucilage during the hydration period [44]. Mucilage produced seals the seed, thus protecting the seed from drying [45]. In other studies, the mucilage has been reported to slow the germination rate but increase its capacity to survive in stressful conditions [46]. However, the myxocarpic characteristic can be overruled due to the inability of the seedling to penetrate the hard soil crust [47]. This is in agreement with reports of a low germination rate in chia seeds grown in Kenya [3]. Chia seed germination is also affected by excessive watering; this is in accordance with the reports published by Nadtochi et al. [20], where 4ml of water in a petri dish of 100 seeds resulted in a 30% germination rate as compared to 2ml, which resulted in over 80%. These results were related to the low oxygen diffusion to the embryo due to the mucilage seal.

After germination, the leaf area has been reported to decrease in water scarcity conditions and automatically leading to a decrease in total dry matter [47]. This result has been attributed to the reduced photosynthetic activity caused by the reduced leaf size. Lovelli et al. [48] found out that the total dry matter of leaf to stem ratio decreased with increased irrigation. The study also found out that in a 100% water availability, there was a fifty percent increase in leaf area as compared to plants that received only 40%. In another study, water scarcity on grown chia fields led to reduced growth, thereby reducing the foliar area to forty-three percent and a fifty-four percent reduction in the total dry-matter as compared to the well-watered plants [23]. The decrease has been associated with the capacity of the Chia plant to endure water scarcity through a plastic morphogenetic reaction [1]. Besides the morphogenetic reaction, Chia plants have the ability for osmotic adjustment and thereby maintaining the cellular turgor, which is usually associated with the plant's growth [23].

The stomata have also been reported to close partially in water-stressed plants, thus reducing the rate at which the plant loses water [48]. This result was also confirmed by Silva et al. [23], who reported decreased transpiration rate in water-stressed plants, and the results were attributed to the ability of chia leaves to produce mucilaginous plugs [49]. Observed an increased efficiency in water use and CO_2 absorption when there was partial opening of the stomata. A study conducted in Kenya found that plants subjected to water scarcity at different growth stages had a smaller number of leaves than those plants that were well-watered [12]. The reduced number of leaves tends to decrease the amount of water lost through the leaves; however, the lesser the leaves, the lower the rate of photosynthesis.

Water scarcity has been found to affect the rate of photosynthesis due to decreased CO_2 in the chloroplasts [50]. These results are in agreement with Escobar et al. (2017), who reported a higher seed yield of 1154kg/ha in 100% irrigation as compared to 787.17kg/ha in 40% irrigation. Silva et al. (2021) also recorded a low grain yield (114kg/ha) as a response to water reduction to the plant; however, the study reported heavier seeds compensating for the loss in yields. This reflecting a more portioning of assimilates to the grains over the other parts of the plant. Kenya is endowed with arid and semi-arid zones where water is a limiting factor, and Chia production may be an attractive enterprise. However, more research needs to be conducted on the performance of different varieties in arid and semi-arid lands (ASALs) in Kenya.

3.4 Weed Management

The main weeds interfering Chia production in Kenya include blackjack (*Bidens pilosa*), Kikuyu grass (*Pennisetum clandestinum*), macdonald eye (*Galinsoga parviflora*), thorn apple (*Datura stramonium*), and couch grass (*Elymus repens*). Weeds are the main limiting factor to crop production. Weed interference can lead to low seed yield and subsequently lower the quality of the yields [51]. Forty-five days after Chia shoot emergence is considered the most critical period for competition [52]. However, the crop forms a canopy at the latter days of growth, thus providing shade for the soil and eventually limiting the growth of weeds. Therefore, it is important that during the commercial production of Chia, weeds should be controlled at the early stages of growths to evade serious economic losses.

Weeds control is done mechanically or chemically using herbicides with active ingredients such as metribuzin, hosphonothy (pre-emergent), and haloxyfop Methyl (post-emergent) [52]. These herbicides are recommended in situations very extreme since these herbicides can cause phytotoxicity in plants [42]. Farmers in Kenya today use hand hoeing methods in managing weeds. This method is cumbersome, costly, and time-consuming. Chemical control of weeds is considered a better method of managing weeds in the commercial production of crops. To date, there are no registered herbicides for the management of weeds in a chia field crop.

A study by karkanis et al. [53] reported pre-emergence herbicides (oxyfluorfen, pendimethalin, and linuron) significantly affected seedling emergence. However, Chia plants were not markedly affected by the post-emergence herbicides (bentazon and fluazifopp-butyl) although, there was a foliar injury in bentazon treated plots. This is in agreement with de Goes Maciel et al. [52], who reported pre-emergence herbicides such as oxyfluorfen, flumioxazin, and s-metolachlor affected the growth and yield of Chia.

Under different doses, the herbicides were not selective for the pre-emergence in chia planting. Sulfentrazone at 100g/ha was the only selective pre-emergence herbicide for the production of Chia. However, Chia plants were not affected significantly by the post-emergence herbicides (bentazon and fluazifopp-butyl) although, there was a foliar injury in bentazon treated plots. Grimmes et al. [42] recommend evaluation of the selective post-emergence herbicides on different soil types and different application doses to make safe proposals on chemical control. In Kenya, no studies have been conducted on the efficacy of selective herbicides related to the mint family on the different weeds of the Chia crop.

4. INSECT PESTS

The common insect pests in Chia production are caterpillars, foliage beetles, coreid bugs, whiteflies, and aphids [18]. Chia has been characterized to produce insect pest repellant substances that act as a defensive mechanism [54]. However, some insect pests have been reported by different researchers and farmers. Some insect pests have been found to feed on the leaves of the plants, which caused wilting and dying of the leaves, although it is common during the early stages of plant growth. Caterpillars and leafhoppers have been reported to feed on Chia leaf from the edges (Fig. 4) to the midrib, although the study found a low pest incidence [55]. Lacewings, whiteflies, and aphids have been reported to occur in all plant developmental stages [56]. In addition, these sucking insects could also produce honeydew, which later forms a black sooty substance on the leaves, interfering with photosynthesis [57]. During Chia production in Kenya, root mealybugs were found on the roots of the dead Chia plant (Fig. 2). Currently, there exists no literature on pest infestation on the flower part. To date, there is no documentation of any failure of crops due to insect pest damage. However, there is a need to develop best-integrated pest management practices to manage this pest's species affecting Chia.

Although Insect pest infestation decrease as the crop grows, there is a need to review the pest status before adopting any control strategies. Different reports have reported pest infestation to be below the required economic threshold; thus, no crop protection management methods were applied [55,42]. However, Grimmes et al. [13] used a neonicotinoid type of pesticide at a rate of 300ml/ha^{-1} to control both sucking and biting insects. Nevertheless, the use of the neonicotinoid class of pesticide has been discouraged by various agronomists due to the harmful effects on pollinators and human beings. With the production of Chia in Kenya gaining momentum, there is a need to develop strategies and techniques to control and manage new emerging pests that could become a production threat in the future.

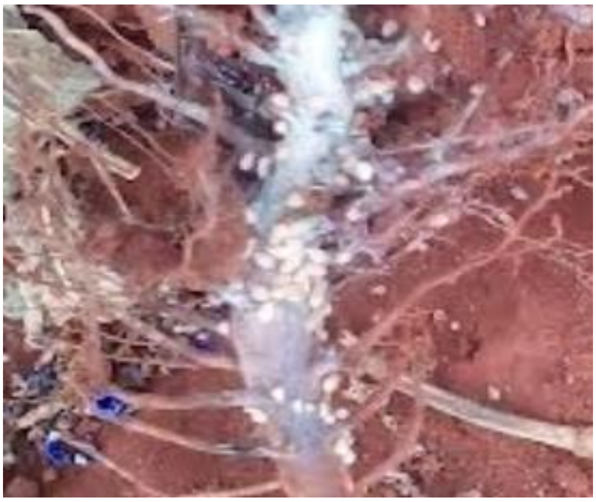

Fig. 2. Root mealy bugs (own)

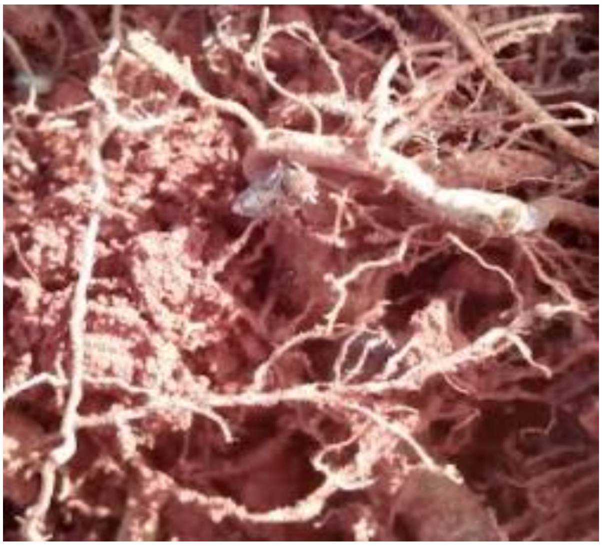

Fig. 3. Insect pests on roots

Fig. 4. Leaf damaged by chewing insects (images: own)

Fig. 5. Viral symptoms: leaf curling, chlorosis, wilting (images: own)

5. DISEASES

Diseases in Chia are a rare occurrence in most producing countries (Win et al., 2019). However, some countries such as Argentina, Ghana have reported diseases in Chia. In Argentina, there has been a report of 3 diseases causing virus that is Tomato yellow spot virus, sida mosaic virus [56], and cowpea mild mottle virus (CPMMV) [58]. Tomato yellow spot virus and the sida mosaic virus are categorized under the genus begomovirus, while cowpea mild mottle virus under carlavirus. The plants identified with the two begomoviruses showed deformed, chlorotic leaves and dwarf plants. These symptoms were reported to be severe thus considered as a threat to Chia production line.

Plants infected with Cowpea mild mottle virus had yellow-spotted and scorched leaves, with deformed stem, leaves, and reduced internodes. The three viruses have been reported to be transmitted mechanically by the whitefly (*Bemisia tabaci*). The virus was also associated with virally infected seeds during planting, hence an increased infestation in the Argentinian fields [58]. Yeboah et al. [18] reported fusarium wilt in chia field in Ghana, some of the Fusarium species identified were *Rhizopus, Pallidoroseum*, and *Fusarium solani*. Plants with similar symptoms as those in Argentina have been reported in Kenya (Fig. 5), although the cases were insignificant [12]. The few incidences of disease must be considered a risk to Chia's production since the presence of pests such as *Bemisia tabaci* is present in many agricultural farms in Kenya. With new viral infections in Kenyan farms, there is a need for more research on the causes and the influences of viral diseases on the growth and yield of Chia.

6. HARVESTING

Harvesting should be carried out when 80% of the foliage has turned brown or lost all its leaves. Farmers In Kenya use different ways to assess the harvesting time for Chia; these include observing the spikes' colour change or the leaves and chewing seeds. Chia seeds selected before harvest maturity tend to shrink and turn brown hence lowering the oil content [8]. However, delay in harvesting could lead to shuttering of the spikes or mould infection and eventually lead to a loss in yields [59]. Mould infection was reported in chia seeds harvested in Kenya, which was attributed to the humid conditions experienced during harvesting [19]. Harvesting techniques are also a factor that could also lead to mould infection. After harvest, chia seeds are placed on gunny bags on the ground, could also lead to mould infection.

The most common mould found in chia seeds in Kenya belong to the species *Rhizopus*. Since chia seeds are either taken raw or processed, the quality is more critical; thus, farmers need to ensure that the seeds are harvested in time, using proper techniques, and stored using the correct procedures [19]. Chia seeds are obtained by pounding the dry spikes using sticks then winnowed manually. This process is regarded as expensive by most Chia farmers in Kenya; hence there is a need to develop equipment that will reduce the cost involved during harvest. Chia leaves are considered nutritious due to the high content of Omega-3 [19]; some Kenyan farmers have taken this opportunity to cultivate Chia as a vegetable. However, scarce information on the time and frequency of harvesting leaves and the performance of the crop in terms of the leaf and seed yield should be considered as a limiting factor.

7. POST- HARVEST HANDLING

Chia seeds need proper preservation after harvesting; poor preservation and packaging could undergo several physiochemical reactions, leading to losses in yield and low quality [60]. The physiological changes could lead to oxidation during storage, thus lowering the nutritional quality and the shelf life of chia seeds [59]. Post-handling activities such as drying, packaging, and storage have to be controlled and managed to ensure quality and quantity are not affected. High moisture content in the seeds during storage can lead to mould formation, thus lowering the quality of the seeds [19].

Different researchers have proposed different temperatures that can be used to dry chia seeds after harvest. Oliveira-Alves et al. [60] used temperatures 40, 50, and 60 degrees centigrade to attain moisture of 2.3 %. Thermodynamical properties of chia seeds have been reported by different researchers who attributed them to different drying temperatures. Temperatures used should aim to reduce the moisture content, preserve the nutritional content, and extend the shelf life of the seeds. Seeds with low moisture content prevent microbial infection [59]. In Kenya, farmers store their seeds in gunny bags or package them in different materials such as polythene bags, plastic containers, or khaki papers. The seeds are either stored or packed immediately after harvest or after drying. Most farmers sun-dry their seeds after harvest since it is cheap and accessible; however, the seeds are usually subjected to long time drying, which leads to low-quality products and contamination of seeds to other substances such as toxic fungi [19]. In Kenya, there is scarce information about the best drying temperatures and the shelf life of chia seeds.

8. OPPORTUNITIES AND CHALLENGES OF CHIA PRODUCTION IN KENYA

Kenya has a high potential for Chia production as any country near the equator. Chia production has the potential to expand to new areas across Kenya since it has unique growth characteristics and almost 20% of the country's land is arable [33]. Currently, chia production occupies below 1% of the country's arable land, indicating a low level of exploitation [8]. Most agricultural lands lie at an altitude of 1000-2500 meters above sea level and receive an annual rainfall of 800-2000mm [33], which is suitable for the production of Chia [21]. Chia production in Kenya would ultimately fulfil the increasing demand for environmentally sustainable and healthy food products. In addition, Chia production creates opportunities for policymakers, researchers to develop policies and technologies to increase and improve production.

The low production of Chia per acreage has been attributed to several factors, including unavailability of certified seeds, poor agronomic practices, scarce information on the production process [3], lack of suitable harvesting and post-harvesting techniques. Poor agronomic practices are one of the major barriers to the high production of Chia [12]. Gitau et al. [8] reported over 80% of Chia farmers had encountered challenges during the cultivation and production of Chia.

Different farmers across the country have also reported crop failure or failure of the seeds to germinate. In a study conducted in Nyeri County, Kenya, 37% of the farmers reported total crop failure [8], thus attributing to the low acreage of chia farming in Kenya. Extension services on Chia production are minimal, Gitau et al. [8] reported only 5.4% of farmers had received information about Chia production from Extension officers. However, the low extension advice could be due to the low ratio of the extension officers to farmers.

Seed shattering is also a problem facing farmers, and this has led to high losses of seeds. Seed shattering is commonly caused by wind, rain, and birds. Increased shattering has also been associated with un-uniform maturation of the Chia spikes [61]. The central chia spike tends to mature before the lateral spikes leading to an extended period of mature spikes in the field [13,62-67].

9. CONCLUSION

Kenya has a suitable climatic condition for Chia production and proper management of Chia can lead to increased growth and subsequently higher yields. As the production of Chia in the country is gaining momentum, knowledge on its agronomic management is critical in attaining its yield potential. However, farmers in Kenya lack crucial information in regards to high yielding varieties and suitable Chia plant management techniques. Lack of information serves as a limiting factor in the production of Chia. Unavailability of information in regards to the different chia varieties has led to farmers sowing uncertified and poor yielding varieties. Chia being an important food crop, increase in its production in future needs promising consideration from all concerned stakeholders. Farmers need to be provided with high-yielding varieties from other countries as well as locally bred varieties since this may significantly increase the yields. In addition, the performance of high-yielding Chia varieties needs to be assessed in regards to different management practices, to provide necessary production information to farmers in Kenya.

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 manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sosa-Baldivia A, Ruiz-Ibarra G, De la Torre RRR, López RR, López AM. The chia (*Salvia hispanica*): Past, present and future of an ancient Mexican crop. Australian Journal of Crop Science. 2018;12(10):1626-1632.
2. Orona-Tamayo D, Valverde ME, Paredes-L´ opez O. Chapter 17 - chia—the new golden seed for the 21st century: Nutraceutical Properties and Technological Uses. In Nadathur SR, Wanasundara JPD, Scanlin L. (Eds.), Sustainable Protein Sources. San Diego: Academic Press; 2017.
   Available:https://doi.org/10.1016/B978-0-12-802778-3.00017-2
3. Njoka M, Masinde P, Mwenda CM. Influence of nitrogen and spacing on growth and yield of Chia (*Salvia hispanica L*.) in Meru County, Kenya. International Journal of Agricultural Education and Extension. 2022;8(1):442-451.
4. Šilc U, Dakskobler I, Küzmič F, Vreš B. Salvia hispanica (Chia)–from nutritional additive to potential invasive species. Botany Letters. 2020;167(2):255-264.
5. Kazydub NG, Pinkal AV, Chernov RV, Nadtochii LA. Possibilities for the introduction and breeding of chia (*Salvia hispanica L*.) In the southern forest-steppe of western Siberia. Siberian Journal of Life Sciences and Agriculture. 2022;14(4):354-369.
6. Mohd Ali N, Yeap SK, Ho WY, Beh BK, Tan SW, Tan SG. The promising future of chia, *Salvia hispanica L*. BioMed Research International; 2012.
   Available:https://doi.org/10.1155/2012/171956
7. Wojahn RE, Bortolotto RP, Zamberlan JF, Koefender J, Tragnago JL, Camera JN, Damiani F. Agronomic feasibility of growing Chia in northwestern Rio grande do sul. Holos. 2018;3:112-122.
8. Gitau DM, Mburu MW, Kiarie DM. The economic, health and nutritional benefits of Chia (*Salvia hispanica L*.) Farming In Nyeri County, Kenya– Baseline survey analysis. Journal of Agriculture and Veterinary Science. 2019;12(4):34-46.
9. Sosa-Baldivia A, Ruiz-Ibarra G, Johnson F, Robles-de la Torre RR, Robles-Lopez MR, Sharma M, Liu X. A historical review of the scientific and common nomenclature associated with chia: From Salvia hispanica to Salvia mexicana and chian to salba. Agric Sci Technol. 2018;18(1):556047.
10. Bochicchio R, Rossi R, Labella R, Bitella G, Perniola M, Amato M. Effect of sowing density and nitrogen top-dress fertilization on growth and yield of Chia (*Salvia hispanica L.)* in a Mediterranean environment: first results. Italian Journal of Agronomy. 2015;10(3):163-166.
11. Bochicchio R, Philips TD, Lovelli S, Labella R, Galgano F, Di Marisco A, Perniola M, Amato M. Innovative crop productions for healthy food: The case of chia (*Salvia hispanica L*.). The sustainability of agro-food and natural resource systems in the Mediterranean basin. 2015;29-45.

12. Muriithi MN, Masinde P, Mwenda CM. Influence of varying soil moisture on growth and yield of Chia (*Salvia hispanica L*.) in Meru County, Kenya. African Journal of Science, Technology and Social Sciences. 2022;1(2):26-35.
13. Grimes SJ, Capezzone F, Nkebiwe PM, Graeff-Hönninger S. Characterization and evaluation of *Salvia Hispanica L.* and *Salvia columbariae Benth.* Varieties for Their Cultivation in Southwestern Germany. Agronomy. 2020;10(12): 2012.
14. Mohanty P, Umesha C, Sarangi DR, Kumarsanodiya L. Impact of Spacing and Nitrogen Levels on growth and Yield of Chia (*Sylvia hispanica L*.). Biological Forum – An International Journal. 2021;13(1):148-153.
15. Mack L, Capezzone F, Munz S, Piepho HP, Claupein W, Phillips T, Graeff-Hönninger S. Nondestructive leaf area estimation for Chia. Agronomy Journal. 2017;109(5):1960-1969.
16. Ayerza R. Antioxidants, protein, oil content, and fatty acids profiles of chia seeds (*Salvia hispanica L.*) genotype Tzotzol growing in three tropical ecosystems of Bolivia, Ecuador, and Paraguay. International Journal of Agriculture Environment and Food Sciences. 2019;3(3):191-196.
17. Kuznetcova DV, Linder M, Jeandel C, Paris C, Desor F, Baranenko DA, Yen FT. Nanoliposomes and nanoemulsions based on chia seed lipids: Preparation and characterization. International Journal of Molecular Sciences. 2020;21(23):9079.
18. Yeboah S, Owusu Danquah E, Lamptey JNL, Mochiah MB, Lamptey S, Oteng-Darko P, Agyeman K. Influence of planting methods and density on the performance of Chia (*Salvia hispanica*) and its suitability as an oilseed plant. Journal of Agricultural Sciences. 2014;2(4):14-26.
19. Njeri V, Mburu MW, Koskei K. Mould characterization and mycotoxin quantification of Chia Seeds (*Salvia hispanica L.)* Grown in Kenya. Journal of Food Research. 2019;8(6):119-128.
20. Nadtochii LA, Kuznetcova DV, Proskura AV, Apalko AD, Nazarova VV, Srinivasan M. Investigation of various factors on the germination of chia seeds sprouts (*Salvia hispanica L.*). Agronomy Research. 2019;17(2):1390–1400.
21. Baginsky C, Arenas J, Escobar H, Garrido M, Valero N, Tello D, Silva H. Growth and yield of Chia (*Salvia hispanica L*.) in the Mediterranean and desert climates of Chile. Chilean Journal of Agricultural Research. 2016;76(3):255-264.
22. Cabrera-Santos D, Ordoñez-Salanueva CA, Sampayo-Maldonado S, Campos JE, Orozco-Segovia A, Flores-Ortiz CM. Chia (*Salvia hispanica L.*) Seed Soaking, Germination, and Fatty Acid behavior at different temperatures. Agriculture. 2021;11(6):498.
23. Silva H, Arriagada C, Campos-Saez S, Baginsky C, Castellaro-Galdames G, Morales-Salinas L. Effect of sowing date and water availability on the growth of plants of Chia (*Salvia hispanica L*) established in Chile. Plos One. 2018;13(9):e0203116.
24. Heuer B, Yaniv Z, Ravina I. Effect of late salinization of chia (*Salvia hispanica*), stock (*Matthiola tricuspidata*) and evening primrose (*Oenothera biennis*) on their oil content and quality. Industrial Crops and Products. 2002;15(2):163-167.
25. Herman S, Marco G, Cecilia B, Alfonso V, Luis M, Cristián V, Sebastián A. Effect of water availability on growth, water use efficiency, and omega 3 (ALA) content in two phenotypes of Chia (*Salvia hispanica L*.) established in the arid Mediterranean zone of Chile. Agricultural Water Management. 2016;173:67-75.
26. Bakari R, Mungai N, Thuita M, Masso C. Impact of soil acidity and liming on soybean (Glycine max) nodulation and nitrogen fixation in Kenyan soils. Acta Agriculturae Scandinavica, Section B—Soil and Plant Science. 2020;70(8):667-678.
27. Ouzounidou G, Skiada V, Papadopoulou KK, Stamatis N, Kavvadias V, Eleftheriadis E, Gaitis F. Effects of soil pH and arbuscular mycorrhiza (AM) inoculation on growth and chemical composition of chia (*Salvia hispanica L*.) leaves. Brazilian Journal of Botany. 2015;38:487-495.

28. Mary J, Veeranna HK, Girijesh GK, Sreedhar RV, Dhananjaya BC, Gangaprasad S. Effect of spacing and fertilizer levels on yield parameters, yield, and quality of Chia (*Salvia hispanica L.*). International Journal of Pure and Applied Bioscience. 2018;6:259-263.
29. Salman AM, Omer EA, Hussein MS, Sewedan E, Osman AR. Influence of foliar fertilization on the growth and yield of Chia (*Salvia hispanica*) plant. Egyptian Pharmaceutical Journal. 2019;18(3):263.
30. Bordin-Rodrigues JC, Da Silva TRB, Soares DFDM, Stracieri J, Ducheski RLP, Da Silva GD. Bean and Chia development in accordance with fertilization management. Heliyon. 2021;e07316.
31. Ayerza R. The seed's protein and oil content, fatty acid composition, and growing cycle length of a single genotype of chia (*Salvia hispanica L.*) as affected by environmental factors. Journal of Oleo Science. 2009;58(7):347-354.
32. Rossi R, Bochicchio R, Labella R, Bitella G, Amato M. Fodder yield, quality and growth of Chia (*Salvia hispanica L.)* as affected by sowing density and top-dressing nitrogen fertilization. Agronomy. 2020;10(12):1980.
33. Wanyama D, Mighty M, Sim S, Koti F. A spatial assessment of land suitability for maize farming in Kenya. Geocarto International. 2019;1-18.
34. El-Sheshtawy AA, Hager MA, Shawer SS. Effect of bio-fertilizer, Phosphorus source and humic substances on yield, yield components and nutrients uptake by barley plant. Journal of. Biological Chemistry and Environmental Science. 2019;14(1):279-300.
35. Da Silva TRB, De Melo SC, Nascimento AB, Ambrosano L, Bordin JC, Alves CZ, Da Silva GD. Response of Chia (*Salvia hispanica*) to sowing times and phosphorus rates over two crop cycles. Heliyon. 2020;6(9):e05051.
36. Korkmaz K, Akgün M, Özcan MM, Özkutlu F, Kara ŞM. Interaction effects of phosphorus (P) and zinc (Zn) on dry matter, concentration, and uptake of P and Zn in Chia. Journal of Plant Nutrition. 2021;44(5):755-764.
37. Muleta HD, Aga MC. Role of nitrogen on potato production: A review. Journal of Plant Sciences. 2019;7(2):36-42.
38. Zhang TA, Chen HY, Ruan H. Global negative effects of nitrogen deposition on soil microbes. The ISME Journal. 2018;12(7):1817-1825.
39. Casini P, Biancofiore G. Influence of row spacing on canopy and seed production in grain amaranth (*Amaranthus cruentus L.).* Agronomy Research. 2020;18(1):53–62.
40. Rasha S, El-Sheshtawy AA, Ali HE. Phenology, architecture, yield, and fatty acid content of Chia in response to sowing date and plant spacing. Fayoum Journal of Agricultural Research and Development. 2020;34(1):314-331.
41. De Freitas TF, Rissato BB, Muller AL, Brustolin DB, Coltro-Roncato S, Dildey ODF, Mendonca-Muller HFC. Development and production of Chia (*Salvia hispanica L.*) in different space arrangements. African Journal of Agricultural Research. 2016;11(43):4384-4388.
42. Grimes SJ, Phillips TD, Capezzone F, Graeff-Hönninger S. Impact of row spacing, sowing density, and nitrogen fertilization on yield and quality traits of Chia (*Salvia Hispanica L.*) cultivated in Southwestern Germany. Agronomy. 2019;9(3):136.
43. Escobar H, Solís Ovando LD, Contreras D, Baginsky C, Arenas J, Silva H. Effect of irrigation water availability on gas exchange, sees yield, biomass, and water use efficiency in two chia phenotypes established in Azapa valley, Arica, Chile. Interciencia. 2018;43(1):55-61.
44. Fernandes SS, De las Mercedes Salas-Mellado M. Addition of chia seed mucilage for reduction of fat content in bread and cakes. Food Chemistry. 2017;227:237-244.
45. Geneve RL, Hildebrand DF, Phillips TD, AL-Amery M, Kester ST. Stress influences seed germination in mucilage-producing Chia. Crop Science. 2017;57(4):2160-2169.
46. Amato M, Bochicchio R, Mele G, Labella R, Rossi R. Soil structure and stability in the spermosphere of myxosdiaspore Chia

(*Salvia hispanica L.).* Soil Research. 2018;57(6):546-558.

47. Jamshidi AM, Ahmadi A, Karimi M, Motesharezadeh B. Evaluation of some growth and physiological responses of Chia (*Salvia hispanica L*.) to various moisture regimes. Iranian Journal of Field Crop Science. 2020;50(4):99-110.
48. Lovelli S, Valerio M, Phillips TD, Amato M. Water use efficiency, photosynthesis and plant growth of Chia (*Salvia hispanica L*.): A glasshouse experiment. Acta Physiologiae Plantarum. 2019;41(1):1-7.
49. Lawson T, Vialet-Chabrand S. Speedy stomata, photosynthesis, and plant water use efficiency. New Phytologist. 2019;221(1):93-98.
50. Yan W, Zhong Y, Shangguan Z. Responses of different physiological parameter thresholds to soil water availability in four plant species during prolonged drought. Agricultural and Forest Meteorology. 2017;247:311-319.
51. Finch-Savage WE. Influence of seed quality on crop establishment, growth, and yield. In Seed Quality. CRC Press. 2020;361-384.
52. De Goes Maciel CD, Vidal LHI, Jadoski SO, Iuchemin CEL, Helvig EO, Da Silva AAP, Inoue MH. Selectivity of herbicides applied in pre-emergence in chia crop. Revista Brasileira de Ciências Agrárias. 2019;14(1):1-7.
53. Karkanis AC, Kontopoulou CK, Lykas C, Kakabouki I, Petropoulos SA, Bilalis D. Efficacy and selectivity of pre-and post-emergence herbicides in Chia (*Salvia hispanica L.)* under Mediterranean semi-arid conditions. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 2018;46(1):183-189.
54. Chen Y, Luo J, Zhang N, Yu W, Jiang J, Dai G. Insecticidal activities of *Salvia hispanica L*. essential oil and combinations of their main compounds against the beet armyworm Spodoptera exigua. Industrial Crops and Products. 2021;162:113271.
55. Win AN, Xue Y, Chen B, Liao F, Chen F, Yin N, Chai Y. Chia (*Salvia hispanica*) experiment at a 30˚ N site in Sichuan Basin, China. Ciência Rural. 2018;48(9):8.
56. Celli MG, Perotto MC, Martino JA, Flores CR, Conci VC, Pardina PR. Detection and identification of the first viruses in Chia (*Salvia hispanica*). Viruses. 2014;6(9):3450-3457.
57. Borkar S, Matcha N, Ponnusamy D, Reddy MSP. Sucking pests of oilseed crops. In sucking pests of crops. Springer, Singapore. 2020;153-185.
58. Celli MG, Perotto MC, Merino MC, Nome CF, Flores CR, Conci VC. First report of Cowpea mild mottle virus in Chia (*Salvia hispanica*). Crop Protection. 2016;89:1-5.
59. Katunzi-Kilewela A, Rweyemamu L, Kibazohi O, Kaale L. Effects of drying, packaging conditions, and storage time on proximate composition of Chia Seeds (*Salvia hispanica*). Tanzania Journal of Science. 2021;47(1):258-267.
60. Oliveira-Alves SC, Vendramini-Costa DB, Cazarin CBB, Júnior MRM, Ferreira JPB, Silva AB, Bronze MR. Characterization of phenolic compounds in chia (*Salvia hispanica L*.) seeds, fiber flour and oil. Food Chemistry. 2017;232:295-305.
61. Maity A, Lamichaney A, Joshi DC, Bajwa A, Subramanian N, Walsh M, Bagavathiannan M. Seed shattering: A trait of evolutionary importance in plants. Frontiers in Plant Science, (2021). 12, 1180.
62. Baldivia AS, Ibarra GR, De la Torre RRR, Lopez RR. The Chia (*Salvia hispanica*): Past, Present, and future of an ancient Mexican crop. Australian Journal of Crop Science. 2018;12(10):1626-1632.
63. Bilalis D, Tabaxi I, Zervas G, Tsiplakou E, Travlos IS, Kakabouki I, Tsioros S. Chia (*Salvia hispanica*) fodder yield and quality as affected by sowing rates and organic fertilization. Communications in Soil Science and Plant Analysis. 2016;47(15):1764-1770.
64. Grimes S, Phillips T, Claupein W, Graeff-Hönninger S. Chiaˆ4: Is a new tetraploid chia (*Salvia hispanica L*.) genotype able to revolutionize European agriculture. The Food System Approach: New Challenges for Education, Research and Industry; ISEKI Food Association: Stuttgart, Germany. 2018;79.
65. Mack L, Boote KJ, Munz S, Phillips TD, Graeff-Hönninger S. Adapting the CROPGRO model to simulate chia growth and yield. Agronomy Journal. 2020;112(5):3859-3877.
66. Mohammed SA, Fallah RQ. Climate change indicators in Alsheikh-Badr Basin

(Syria). Geography, Environment, Sustainability. 2019;12(2):87-96.

67. Das MK, Dash S, Pattnaik S, Mohapatra D. Growth and Instability in Agriculture Production in Odisha, India. Asian Res. J. Agric. 2024;17(2):184-95. Available:https://journalarja.com/index.php/ARJA/article/view/436

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