DETERMINATION OF CRITICAL PERIOD OF WEED CONTROL ON GINGER (*Zingiber officinale* Roscoe) AT SELAM, SOUTH WEST ETHIOPIA

MSc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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A THESIS SUBMITTED TO THE DEPARTMENT OF PLANT AND HORTICULTURAL SCIENCES, COLLEGE OF AGRICULTURE, SCHOOL OF GRADUATE STUDIES

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ADVISORS' APPROVAL SHEET

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This is to certify that the thesis entitled: "Determination of Critical Period of Weed Control on Ginger (*Zingiber officinale* Roscoe) at Selam, South West Ethiopia" is submitted in partial fulfillment of the requirements for the degree of Master's with specialization in crop-protection to the Graduate Program of the Department/School of plant and Horticultural Sciences and has been carried out by **Muluken Asfaw** ID. Nº. **GPCrPrR/0005/14**, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned members of the Board of Examiners of the final open defense by **Muluken Asfaw Wolde**, have read and evaluated his thesis : "Determination of Critical Period of Weed Control on Ginger (*Zingiber officinale* Roscoe) at Selam, South West Ethiopia" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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DEDICATION

This thesis is dedicated to all my family including my wife, who have never stopped believing in me and helped me in any way they could with my educational achievements.

STATEMENT OF AUTHOR

First and foremost, I hereby state that this thesis is entirely my creation and that all sources of information used in it have been properly acknowledged. The Hawassa University College of Agriculture has accepted this thesis as a partial fulfillment of the requirements for a progressive MSc degree. I certify that this thesis has not been submitted to any other organization, anywhere, to receive a diploma, certificate, or academic degree.

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Place: Hawassa University, Ethiopia

Date of Submission: ______________

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LIST OF ABBREVIATION

ANOVA	Analysis of Variance
BoA	Bureau of Agricultural
CPWC	Critical periods of Weed Competition
EIAR	Ethiopian Institute of Agricultural Research
IWM	Integrated Weed Management
LSD	Least Significant Difference
SNNPR	Southern Nations Nationality and People Region
SWR	South Western Region

Determination of Critical Period of Weed Control on Ginger (*Zingiber officinale* Roscoe) at Selam, South West Ethiopia

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ABSTRACT

Ginger is an important spice and cash crop in Ethiopia. However, its production is constrained by different abiotic and biotic factors; weed is one of the most important biotic factors which reduces yield of ginger. Therefore, this study was conducted in 2023 main cropping season at Yeki, South Western Ethiopia to determine the critical period of weed competition and yield loss. The trial had twenty *treatments in two sets, namely weedy set and weed-free set, each sets comprising weed competition durations of* 15, 30, 45, 60, 75, 90, 105, 120 and 135 days after *crop emergence and weedy control as well as weed-free plot throughout crop life cycle. The trial was laid out as a randomized complete block design with three replications and the treatments were assigned randomly to experimental units within a block. The weed and crop data were collected and subjected to analysis of variance by using SAS software. The most dominant species was Bidens pilosa L. (Asteraceae family) with density and relative density of 73 m^{-2} and 18.4%, respectively. Weed density, weed dry biomass, yield components and yield of ginger were significantly affected by weed competition durations. Uncontrolled weed growth reduced the yield of ginger by 93%. The beginning of CPWC (Critical period of weed control) based on 10% AYL (acceptable yield loss level) occurred at 180 GDD (Growth degree days), which was corresponded to 26 DAE (Days after emergence). The end of the CPWC at 10% AYL occurred by 1150 GDD or 143 DAE. To prevent more than 10% yield loss, the efficient weed control period for ginger at Selam area could be accomplished by keeping the crop weed free between 26 to 143 DAE. Further research in different physiographic, edaphic and climatic conditions is recommended.*

Keywords: Ginger, critical period; weed; weed-crop competition; yield loss.

1. INTRODUCTION

Ginger (*Zingiber officinale* Roscoe) is monocotyledonous, herbaceous, tropical plant belonging to the family *Zingiberaceae.* It is a perennial plant, but is usually grown as an annual crop for harvesting as a spice. Ginger is native to South East Asia, and now it is grown commercially in most tropical regions (Abeykera *et al.*, 2005). It has a long and well - documented history of both culinary and medicinal use throughout world history, especially in Chinese, Indian and Japanese medicinal care. The Arabs, in the 13th century brought ginger from India to East Africa (Jansen, 1981; Girma *et al*., 2008; Endrias and Asfaw, 2011). Ginger had perhaps been known since then in Ethiopia, and predominantly grown in the wetter parts of the former Southern Nations, Nationalities and Peoples" Regional State (SNNPRS) (Girma *et al*., 2008).

Ginger production to a lesser extent, has been also extended to some parts of Western Oromia and Northern Amhara. Large-scale commercial production of ginger by farmers in SNNPRS is practiced with the administrative districts of Kacha Bira and Hadaro-Tunto (both are located in Kambata-Tambaro Zone), Boloso Bombe and Boloso Sorie (both are located in Wolaita Zone), and part of western Badawacho (Hadiya Zone) taking the leading position in the region as well as in the country (Endrias Geta and Asfaw Kifle, 2011). The statistical information from the Ministry of Agriculture and Rural Development indicates that 99% of the crop's production was in SNNPRS (Geta and Kifle, 2011). The standard of living of the farmers cultivating ginger in this region is by far better than those farmers whose livelihood is based on any other crop. Its contribution to the national economy has also been considerable. Ginger (*Zingeber officinale* Rosccoe) is one of the leading exported spice crop in Ethiopia, for instance in 5years (2005/06-2009/10), the country exported 47180 tons of dry ginger and generated $ 38.1 million and this accounted for the lion share of 71% of the total four major spices exported followed by turmeric (8.3%), and cumin (7.9%) and fenugreek, coriander and pepper taking the rest (MasreshaYimer, 2010).

In Ethiopia, ginger has been used as a flavoring agent, carminative and stimulant and it has become the most important spice for the local as well as the export market. The underground rhizome of this crop is also valued throughout the world as a spice of flavoring agent for its two major classes of constituents, such as essential oils and oleoresins (Baladin *et al.* 1998). The more volatile essential oil consists of monoterpenes and sesquiterpenes, which contribute to the characteristics flavor of ginger, and oleoresins which is responsible for the pungent flavor, which is also a source of antioxidants (Sanwal *et al*., 2010). The principal compounds responsible for the pungency of ginger are gingerols and shagols. Ginger is commercially available in various forms, such as green ginger, dry ginger, ginger powder, ginger oil, ginger oleoresin and preserved ginger (Kizhakkayi and Sasikumar, 2009).

The area under ginger cultivation in the world was estimated to be 314350 hectares in 2011, with a total production of 2025571 tones, out of which the share of Ethiopia was 7746 tones, that is about 0.38 %(MasreshaYimer, 2010).

. Ginger yield on farmers field is very low i.e., 15.87 t ha^{-1}, which is far less than the crops potential, which have averagely 25 tone fresh ginger per hectare (Hailemichael *et al*., 2008). This is attributed to several factors of which shortage of improved varieties, poor agronomic practices and poor soil fertility are the most important ones (Hailemichael *et al*., 2008). The top five ginger producer countries are India, China, Nepal, Nigeria, and Thailand. India is the largest producer of ginger accounting for more than 34% of the world production in 2011 followed by China. For the past five consecutive years (2006-2011), Ethiopia stood 10^{th} and 14^{th} position in terms of area harvested and total production of ginger, respectively among the 36 countries engaged in ginger production globally (FAO, 2013).

1.1. Statement of the Problem

Ginger is one of the important spice crops which is /will be helpful in income generation. Nevertheless, the yield of the crop is limited by many biotic and abiotic factors among which weeds are the major constraints. Weeds cause reduction in crop yield and require extra cost in the total labor use in crop production. Akobunda (1987) reported that weeds result in 65% reduction in yield of root and tuber crops and takes 25% of total labor use in production. The CPWC is the period of crop life cycle during which weeds must be controlled to prevent unacceptable or economic yield loss **(**Evans *et al*, 1980 and Zimdahl *et al*., 2003)**.** The magnitude of yield loss on ginger is affected by many agronomic and environmental factors, but most importantly by the weed density and time of emergence relative to the crop. As a general rule, an average weed infestation may be expected to reduce yields by 10 - 15% on ginger (Woolley *et al*., 1993).

This study is initiated because farmers in the study area practice of ginger production specially weeding practice and over all weed management activities. Farmers understand that weeds can cause significant yield loss on their crop but the economical time period to control weed at the specific period in which we can reduce yield loss because of weed is not known.

As the crop is slow germinating and growing yield loss as a result of weed competition is expected to be high. The environmental condition of southwest Ethiopia is characterized by high temperature and high rainfall which is highly conducive for year round emergence and growth of highly competitive perennial and annual weed species such as *Cynodon* spp., *Cyprus* spp., *Digitaria* spp., *Commelina* spp., *Bidens pilosa, Gyzotia scabra,* and *Ageratum conyzoides* (Tadesse *et al*, 1998).

Weed competition has also been identified as a constraint to root and tuber production (Unamma, 1984). In the study area farmers weed ginger late after the crop has suffered weed competition or sometimes ginger fields may be left unwedded. Therefore, this experiment is designed with the following objectives.

1.2. Objectives

1.2.1. General objectives

To enhance the productivity of ginger (*Zingeber officinale* Rosccoe) by identification of major weeds and proper time of weeding at Selam South West Ethiopia.

1.2.2. Specific objectives

- To assess and quantify the weed species which exist in the experimental plots, at Selam South West of Ethiopia.
- To quantify the yield loss of Ginger (*Zingeber officinale* Rosccoe*)* due to weeds at Selam South West of Ethiopia.
- To determine the critical period of weed competition on Ginger crop (*Zingeber officinale* Rosccoe*)* at Selam South West of Ethiopia.

Hypothesis

Ho: Weed competition duration with Ginger cannot cause significant yield reduction.

HA: Weed competition duration with Ginger can cause significant yield reduction.

2. LITERATURE REVIEW

2.1. Descriptions of Ginger

Ginger (*Zingiber officinale* Rosccoe) is monocotyledonous, herbaceous, tropical plant belonging to the family *Zingiberaceae.* It is a perennial plant, but is usually grown as an annual crop for harvesting as a spice. Ginger is native to South East Asia, and now it is grown commercially in most tropical regions (Abeykera *et al.,* 2005). It has a long and well - documented history of both culinary and medicinal use throughout world history, especially in Chinese, Indian and Japanese medicinal care.

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The more volatile essential oil consists of monoterpenes and sesquiterpenes, which contribute to the characteristics flavor of ginger, and oleoresins which is responsible for the pungent flavor, which is also a source of antioxidants (Sanwal *et al*., 2010). The principal compounds responsible for the pungency of ginger are gingerols and shagols. Ginger is commercially available in various forms, such as green ginger, dry ginger, ginger powder, ginger oil, ginger oleoresin and preserved ginger (Kizhakkayi and Sasikumar, 2009).

The ginger plant is an erect, perennial herb with thick, hard laterally compressed, often palmately branched rhizomes, covered with small scale leaves and fine fibrous roots.

Rhizome is pale yellow in cross section. The stems are erect and vertical, generally sterile, covered with leaf sheaths, and reaches up to 1.5 m height. It is a perennial reed like plant with annual leafy stems. Leaves are alternate, sessile, distichous, linear, lanceolate, acuminate, lamina 15-20 cm long and 2-3 cm wide, continuing into a transparent sheath on the stem. Ginger produces clusters of white and pink flower buds that bloom into yellow flowers. In ginger, fruit capsule are with three loculi and fruits are very rarely found. Seeds are angular, small, black, arillated and they develop very rarely. Because of its aesthetic appeal and the adaptation of the plant to warm climates, ginger is often used as landscaping around subtropical homes (Abeykera *et al.*, 2005).

2.2. Production Status of Ginger

Ginger (*Zingiber officinale* Rosc.) is one of the oldest known spice, has been used by man since several centuries not only as a spice but also as medicine. Ginger is indigenous to tropical India and South East Asia, Australia and Japan, with the main center of diversity in Indo- Malaysia (Jansen, 1981). In India, ginger in its fresh and/or dried form has innumerable uses in culinary and medicinal preparations. India and China are the world's largest producers and exporters of ginger. Other important producers are Jamaica, Nigeria, Sierra Leone, Thailand, and Australia (Yiljep *et al*., 2005).

Ginger is known to be introduced to Ethiopia as early as the 13th century and perhaps its cultivation has also been started since then (Jansen, 1981). The statistical information from the Ministry of Agriculture and Rural Development indicated that 99 % of ginger production was from the Southern Nations, Nationalities and Peoples Regional State (SNNPRS) and about 1 % was from the Oromia National Regional State. The productivity of fresh rhizome ginger is about 11,522 kg/ha in the SNNPRS, 2615 kg/ha in the Oromia National Regional State and 7050 kg/ha nationally (MOA, 2003).Despite, the increasing demand for ginger the current production capacity of ginger was very low when compared to its immense potential of the crop is not as such encouraging. The primary reason is due to outbreaks of bacterial wilt, which affect quality and yield of ginger in major producing area.

Bacterial wilt (BW) is one of the most important, widespread and lethal bacterial diseases of plants (Singh, 1978). reported that more than 55 crops and wild species are affected by R. *solanacearum* crops such as potato, tobacco, tomato, eggplant, banana, chili, bell pepper and peanut are highly susceptible to the disease. It is common in tropical, subtropical and warm tempera-true regions where temperature and moisture conditions are favorable for its development (Singh, 1978). The bacterium may also be present in cooler climates such as relatively high elevation in the tropics or higher latitudes.

Some ancient literature's claim that, in Wolaita (Jansen, 1981) and in the neighboring – areas of Kambata-Tambaro, SNNPRS ginger has been cultivated long ago applying some modern agronomic management practices. In Ethiopia, ginger is cultivated under sub-optimal rain- fed conditions with the rain fall often less than 1500 mm per annum and at lower temperatures (Jansen, 1981). However, reasonable yields, i.e., as high as 30 tons of fresh rhizome yield per hectare has been recorded in some parts of the country, mainly in SNNPRS under farmers" management condition (Geta and Kifle, 2011). However, the average yield reported for ginger in the region was only 16 tons/ha –according to the report of BoA (2008).

Ginger production in Ethiopia was restricted to a home garden using local cultivars at the level of small-holder farmers to be used for household consumption and/or for small local trading. Nowadays, farmers in some parts of SNNPRS have been engaged in large scale commercial production covering more than ten hectares of land using newly introduced relatively high yielding cultivars, especially at Boloso Bombe, at Wolaita Zone, SNNPRS. Moreover, the level of ginger production in Ethiopia has also been -advanced to the level of large scale commercial farms at the level of big investors (MOA, 2003).

2.3. Argo ecology of ginger

Ginger has wider adaptability for different climatic requirements. It prefers brilliant sunshine, heavy rain fall and high amount of relative humidity for a promising yield. Dry spells during land preparation and before harvesting are required for large scale cultivation. Ginger prefers warm and humid climate, with moist soils that have proper water holding capacity and aeration. The crop is sensitive to water logging, frost and salinity and is also tolerant to wind and drought. Steep slopes in hilly areas are not recommended for cultivation as it leads to soil erosion during heavy rainfall because rhizome yield is negatively correlated with slope. Ginger is cultivated in the tropics from sea level up to 1500 m altitude, but partial shade also increases its yield.

2.3.1. Temperature

The base temperature requirement for ginger is 13^0C and the upper limit is 32^0C/27^0C (day/night), whereas the favorable range is 19-28^0C. The optimum soil temperature for germination is between 25-26^0C, and for growth it needs 27.5^0C. A temperature in excess of 32^0C can cause sunburn; on the other hand, low temperatures induce dormancy. The day and night length does not have significant variation in Ethiopia; however, in other ginger growing countries as day length increase from 10 to 16 hours, the vegetative growth was enhanced, while it was inhibited and rhizome swelling promoted as the day length was decreased from

16 to 10 hours. Nevertheless, further increase in day length above 16 hour did not promote rhizome swelling.

2.3.2. Soil Requirement for ginger production

Ginger prefers soils that mostly have proper water holding capacity and aeration. It also prefers deep, sandy loam soils. The upper layer needs to be permeable. For higher yield, the soil should be loose, friable and offer minimum resistance to rhizome development.

Well drained soil with at least 30 cm depth is essential. As depth of soil increases, its suitability for cultivation of the ginger increases. In heavy clay soils, deep plowing allows better root penetration and free rhizome development. Stony and water logging soils need to be avoided for ginger production. Compact clay soils, which are subject to water logging or coarse, sands without water holding capacity, gravelly soils or those with hard pan are not conducive for the production of high yielding healthy plants. The most favorable soil pH is 6.0-6.5. Though ginger is grown on a wide variety of soils such as sandy loams, black rich clay soils and lateritic soils, for optimum yield it best prefers medium loam soils with a good supply of humus.

Most parts of ginger growing areas of the region are characterized by clay loam and sandy loam soils, which are suitable for the production of quality ginger.

2.3.3. Rainfall

Ginger is cultivated in the tropics with an annual rain fall of 1500 mm or more (up to3000 mm) (Purseglove, 1972). A rainfall of, well distributed in 8-10 months is ideal for ginger production. In Ethiopia, ginger is cultivated under sub optimal conditions with rain fall often less than 1500 mm per year (Jansen, 1981).

2.4. Importance of critical period of weed competition for crop growing

A concept of critical period of weed competition has been introduced for more than 40 years ago. The concept is based on the assumption that weeds are not equally harmful to a crop during the whole season and that there is a period in crop development in which weeds impact on the yield is the biggest. This period is called critical period of weed competition (CPWC), critical period of weed interference, or critical period of weed control. There is a difference in CPWC between crops, but CPWC for a certain crop can vary a lot because it depends on many factors which can affect the crop or weeds competition ability. The critical period of weed competition identification is essential for integrated weed control and precise planning of a weed control strategy as well as for rationale use of herbicides and other weed control measures.

2.5. Impacts of Weed on Growth and Yield of Ginger

Weeds are a major constraint in ginger production. Ginger was found very poor competitor of weeds that as weeding was delayed tremendous yield loss was incurred. When weeding was totally ignored yield loss amounted to 100%.The magnitude of yield loss is affected by many agronomic and environmental factors, but most importantly by the weed density, and time of emergence relative to the crop. As a general rule, an average weed infestation may be expected to reduce yields by 10 - 15% (Woolley *et al*., 1993).

2.6. Critical Periods of Weed Competition in Ginger

Critical period for weed control (CPWC) is defined as a period in the crop growth cycle during which weeds must be controlled to prevent yield losses (Knezevic *et al*., 2002), or it is the time interval between the maximum weed infested periods or the length of time that which emerge with the crop can remain uncontrolled before they begin to compete with crop must be free of weed after emergence.

Controlling weeds based on CPWC lead to reduce costs and risks of intensive weed control. It also reduces the number of herbicide treatments as a result of better timing and efficiency which it leads to decrease the potential environmental contamination and the selection pressure for herbicide resistant weeds and help to optimize weed control methods (Bystro *et al*., 2012).

Determination of CPWC is based on characterizing functional relationships between two separately measured competition components: crop yield as a function of the duration of weed interference to identify the beginning of CPWC and crop yield as a function of the duration of the weed-free period to identify the end of CPWC. In theory, weed competition before or after the CPWC will not reduce crop yield below acceptable levels (Williams, 2006). The length of the CPWC is dependent on site-specific factors, including climate variation; weed species composition and crop-specific production issues (Bystro *et al*., 2012). In a study which was conducted in Ethiopia 30 up to 45 DAP of ginger were found the critical period for weed competition; Hand weeding and apply mulch in between 30 and 45 DAP were found good weed management practice.

Generally critical period for weed control is the maximum period over which can be tolerated without affecting the final crop yield or the point after which weed growth does not affect the final yield.

Weeds compete with crops for environmental resources available in limited supply nutrient, water and light. Competition has been defined as the tendency of neighboring plants to utilize the same quantum of light, ions of mineral nutrient, molecules of water or volume space, as consequences weeds may significantly reduce the yield and impair crop quality, resulting in financial loss to the grower or farmer. Thus, has been estimated that global basis weeds considered being responsible for 10% reduction of crop (Bystro *et al*., 2012).

The critical useful in defining the crop growth stages most vulnerable to weed competition. In practice, the critical weed competition defined as a number of weeks after crop emergence during which a crop must be weed free in order to prevent yield loss less than 5 percent (AK Jha and Shrivastava, 2013).The beginning of the critical period was also defined as the crop stage or day after crop emergence when weed interference reduces the yield by a pre-determined level.

The end of critical period defined as the crop stage or days after emergence until the crop must be free of weed in order to prevent a pre-determined level of yield loss. The length of critical period of weed competition varied between years and levels of chosen yield loss (Found, 2002).

The critical period of weed competition is not necessarily the time of the most intense interference. Therefore, it may be better to use the term critical period for weed control instead of critical period of weed competition. The length of the critical period of weed control may vary depending on the acceptable yield loss (Bystro *et al*., 2012).

All noxious and important weed species were abundantly growing in the experimental site and the surrounding. The classifications as noxious and important was based on the species competitive ability and time and money spent for their control. The noxious species are highly competitive for essential growth requirements and are also too difficult to control once they are established in the field. The *Cynodon* spp, *Cyperus* spp and *Digitaria* are those growth nature are perennial and their economic importance were noxious while *Guizotia scabra* and *Commelina benghalensis* were annual growth nature. In another way *Bidens pilosa, Ageratum conyzoides* and *Plantago lanceolate* were annual growth nature and their economic importance were important (Habetewold *et al*., 2015; Tadesse *et al*., 2015).

Mulching ginger at planting followed by two hand weeding at 60 and 90 days after planting or hand weeding ginger at 30 and 60 days followed by mulching or weeding ginger at 45 and 75 days after planting is recommended for good weed control and high Yield of ginger (Tadesse *et al*., 2015).

Understanding the critical period for weed control (CPWC) can be a tool for effective weed control and reducing the impacts of weeds (Weaver and Tan, 1987). It is an integral part of integrated weed management (IWM) and can be considered the first step to design weed control strategy (Zimdahl, 2004). The CPWC is the period of crop life cycle during which weeds must be controlled to prevent unacceptable or economic yield loss **(**Evans *et al*, 1980)**.** The length of the critical period of weed control may vary depending on the acceptable yield loss first proposed in corn (Hall *et al*., 1992), and later in soybean and white bean (*Phaseolus* *vulgaris* L.) (Woolley *et al*., 1993). The critical period of weed control for canola is around the 4-leaf stage, or 17-38 days after crop emergence (Martin *et al*., 2001). For pea varied between sites but began as early as 2 weeks after emergence (Harker *et al*., 2001). For a more competitive crop such as barley the timing of weed removal is not as clear cut (O'Donovan *et al*., 2005). For corn, the critical period depends on nitrogen availability, with the critical period becoming shorter with increased fertilizer rates.

Critical period was determined as 7–49 days after seeding in off-season and 7–53 days in main season to achieve 95% of weed-free yield, and 23–40 days in off-season and 21–43 days in main season to achieve 90% of weed-free yield in Turmeric (Williams, 2006). Turmeric should be kept weed free between 7 days and 85 days after transplanting to avoid yield losses in excess of 5%. Many findings suggested that critical time of weed competition vary from crop to crop and area to area.

2.7. Method of Weed Control in Ginger

As the crop receives a high amount of external nutrition coupled with initial slow growth, conditions. Favor weed emergence which later compete with the crop for moisture, nutrition, space and sunlight. Identification of major weeds of ginger was conducted in different sites in Southwestern Ethiopia. All noxious and important weed species were abundantly growing in the experimental site and the surrounding. The classification as noxious and important was based on the species competitive ability and time and money spent for their control. The noxious species are highly competitive for essential growth requirements and are also too difficult to control once they are established in the field (Swanton *et al.,* 2008).

2.7.1. Mechanical method

Tillage is one management strategy that can impact the diversity of weed species present. The type of tillage practiced can affect crop and weed development (Hendrix *et al.,* 2004). Intensive tillage can be an effective weed management tool but may contribute to a decline in soil quality (Gallandt, 2006; Hobbs, 2007). Germination of weed seeds can be promoted or diminished by tillage events (Gallandt, 2006). For example, shallow tillage promoted the emergence of four broad-leaf species, reduced the germination of a grass and did not affect the emergence of three other broad-leaf species (Swanton *et al.,* 2008). When compared to other forms of tillage (disk, rotary tiller and chisel plow) moldboard ploughing had a greater tendency to bring weed seeds to the soil surface as well as to bury weed seeds present on the soil surface. For this reason, moldboard ploughing could serve as a useful method for the control of weed species with a short survival time in the soil (Thomas, 2002). There is a tendency for a shift to biennial and perennial weed species under reduced tillage systems (Swanton *et al.,* 2008). The shifts in weed populations under reduced tillage populations are a form of natural succession (Thomas, 2002).

Species diversity can also be influenced by tillage, no-till tends to promote the highest species diversity and moldboard plow the lowest. The weed species diversity seen in the chisel plow treatments was intermediate to that of conventional and no-tillage. (Swanton *et al.,* 2008). Mulches stop weed growth by restricting the penetration of sunlight to the soil surface and in the case of surface mulches of cover crops has the potential to release inhibitory (allelopathic) chemicals in to the soil environment that inhabit weed seedling growth. There has been considerable research investigating the use of living plants that are suppressed or kill with herbicide and then used as mulch prior to crop emergence.

2.7.2. Biological method

Biological control of weeds involves the use of any organisms or management practice using an organism to reduce, or eliminate the potential detrimental effects of weed population (Thomas, 2002). Classical biological control is associated with the use of insect, pathogens, herbivores or parasites that naturally attach weeds. There are two approaches used in the introduction of classical biological control agents in to a system. First one is inoculative approach which dispersion its own inhabit with the target weed. The second in undeceiver augmentative referred to as a bio herbicide or mycoherbicide which is used where an abundant supply of the agent is applied (Thomas, 2002). Plant attaching insects are currently the most widely used biological control agent for weed control. They have a specific host range; can be mobile (which promotes their dispersion) and can destroy both vegetative and reproductive portion of weeds. Insect attacks can also predispose weed to attack by other factor such as disease, in fact researcher investigating a combination approach of insect as a disease vector for biological control *(*Knezevic*et al*., 2002).

The inoculums and inundactive are used for employing plant pathogens, primarily fungi, for biological control weeds. The mycoherbicide approach offers the best potential for extension of biological control weed control in to nontraditional disturbed areas. Extensive research is being conducted on many fungal pathogens and bacterial bio control agents as summarized by *(*Knezevic*et al*., 2002).

2.7.3. Chemical method

Chemical control is the last option method in controlling weed cultivated lands. After using mechanical, cultural and biological method then use chemical, is recommended in controlling a serious problem weed. 2-4-D was introduced in the mid 1940's to control broad leaf weeds in corn. Most corn herbicides are used to control annual weeds; however, some also control or suppress the growth of perennial weeds. Combination of two or more herbicides are often used as a tank mix or in sequential treatments to extend the period of control and/or broaden the spectrum of weeds controlled.

2.7.4. Integrated weed management

IWM is the application of many types of technology and supportive knowledge in the deliberate selection, integration and implementation of weed control strategies, with consideration of the economic, ecological and sociological consequences. It is to be successful if link he farmers' attitude, knowledge, performances and abilities with available tools that best fit each situation. The knowledge of the weed and cropping history of the site, knowledge of weed biology and ecology and knowledge of weed control methods are the most important in application of IWM. If farmers use these all knowledge to manage the system to obtain good high quality crop yields while minimizing and time reducing the harmful effects of weed IWM is effective economically and ecologically sound stresses integration of control to the larger picture of ecosystem *(*Knezevic*et al*., 2002).

As the crop receives a high amount of external nutrition coupled with initial slow growth, conditions favour weed emergence which later compete with the crop for moisture, nutrients, space and sun light. Ginger is slow growing and for germination it takes about more than one month. By that time different species of weeds cover up crop restricting growth and development of ginger. Very little work on weed management in ginger has been done. Little work on weed control through soil solarization and use of mulch has been reported by several workers (Swanton *et al.,* 2008). but they are too expensive, however, reports on integrated weed management involving manual, mulch and chemical method of weed control is lacking, Hence, an effort was done to find out effect of weed control measures on productivity and profitability of ginger. The basic principles related to weed and IWM is understood and considered in designing and implementing an effective IWM system. Those principles include the factor like what is a weed, the basic resource that weeds and crop compete for factors affecting weed seed emergences, weed growth and reproduction length of infestation and general population biology of weed plants (Thomas, 2002).

3. MATERIALS AND METHODS

3.1. Experimental Site Description

The experiment was conducted at Selam which is sub research site of Tepi Agricultural Research Center in South West, Ethiopia (Figure 1) during the 2022/23 main cropping season. Selam which is geographically located at about Latitude: 7^o 3'00" N Longitude: 35^o 0' 00"E with altitude of 1200 m.a.s.l. It has hot to warm humid lowland agro ecology with Maximum and minimum temperature 30^oC and 15^oC, respectively (EIAR, 2012). Mean annual rainfall of the area is 1591 mm (EIAR, 2012). Soils of the area are very deep (>150 cm) sandy loam soils and have a color of, dark brown when moist (EIAR, 2012). The texture is clay with moderate medium sub angular blocky structure. The pH (H_2O) of surface soil is 7.7 to 5.8 in subsurface horizon as indicated by the same author. The organic matter content is medium to very high (2.47 to 7.02%) and the total nitrogen content is low to very high (0.09 to 0.73%); while available phosphorous is low to medium (0.97 to 7.36 ppm), available micronutrients range between 1.1 to 6.92 ppm for Fe, 51 to 111.7 ppm for Mn, 1.96 to 5.16 ppm for Zn and trace to 2.46 ppm for Cu (EIAR, 2012).

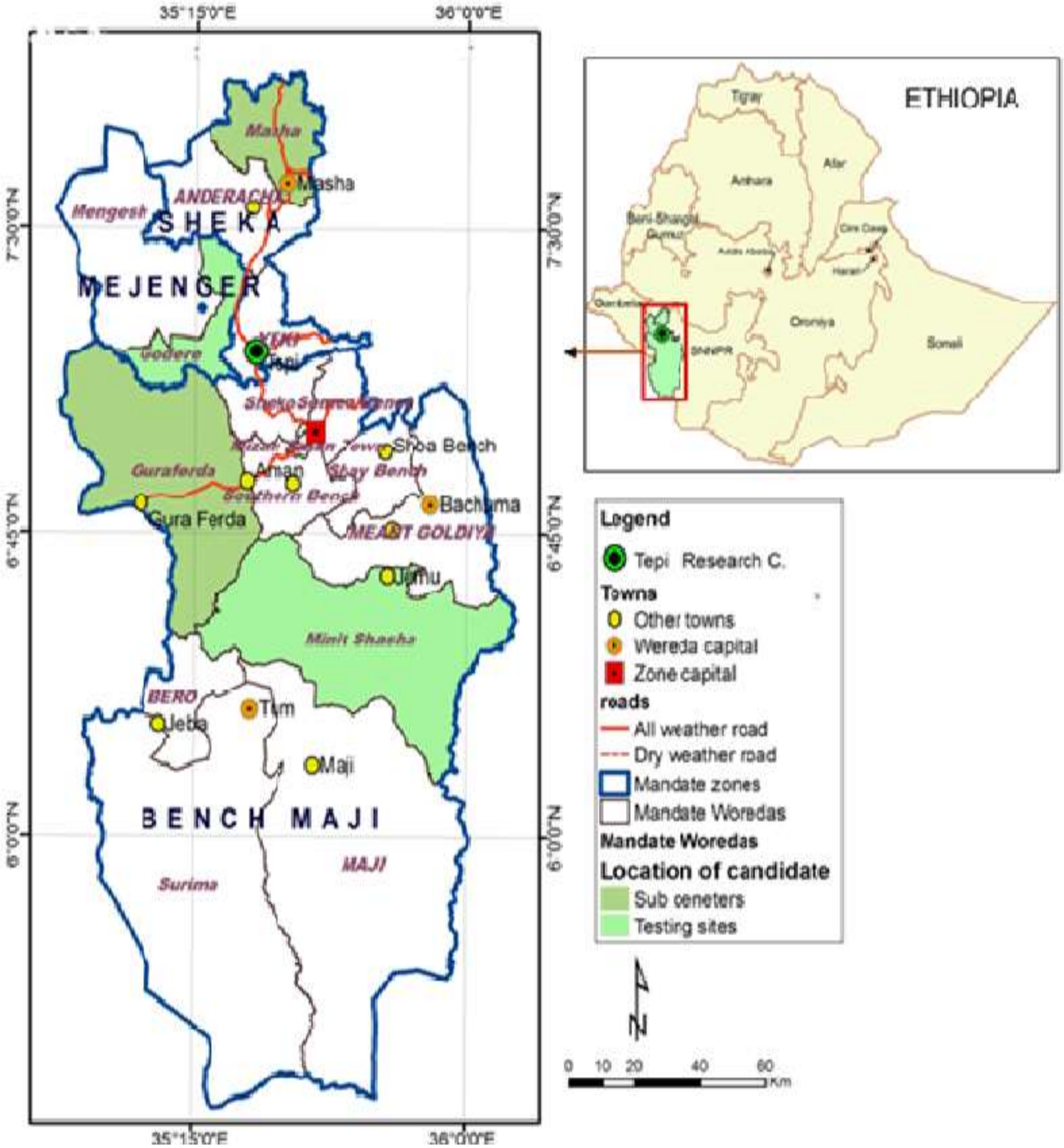

Figure 1. Map showing Selam Sub Resarch site of Tepi Agricultural Research Center, Yeki Woreda Shakka Zone South Western Region, Ethiopia

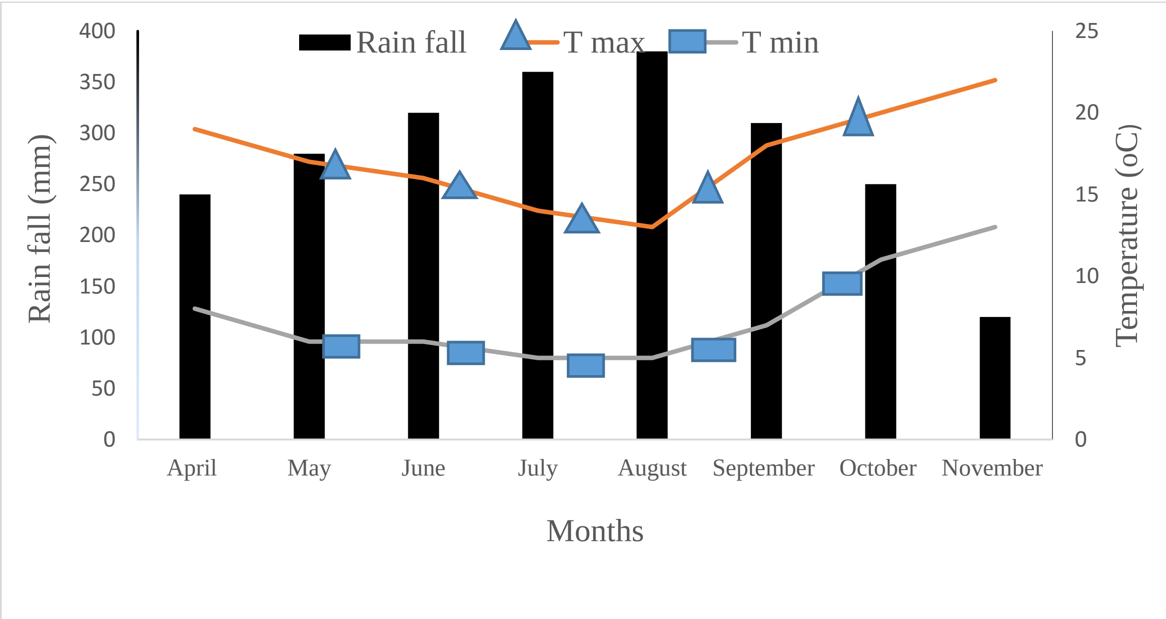

Figure 2. Rainfall, minimum and maximum temperatures recorded at Selam during 2023 main cropping season (Source: Tepi meteorological station)

3.2. Experimental Materials

Planting Material: Rhizome or Ginger variety '*Yali*' was used for the study (Table 1). This variety was selected because of its wider adaptation in South West, Ethiopia and it is highly affected by weed competition. The ginger variety; Yali (Miz.180/73) was released in 2005 (Zakir *et al*., 2018).

"Yali" variety attain physiological maturity within 155 to 175 days after planting and 210 to 240 days after planting for harvesting. The harvesting stage of ginger is governed by the demand of the end users of the produce; if the produce is for extraction harvesting 7-8 months after planting is recommended while for the whole home use of dry ginger harvesting 8-10 months after planting is recommended (Girma *et al*., 2008).

Table 1. Description of Yali variety

Variety and date of release	Source	Colour	Altitude	T^{o}
Yali (Miz.180/73 in 2005	Mizan	Light yellow	1500m	15-38^{o}c

Source: (Edossa, 1998; Girma *et al*., 2016)

3.3. Treatments and Experimental Design

The experimental treatments were arranged following the method described by (Neito *et al*., 1968). The experimental design namely randomized complete block with three replications for each set. To determine CPWC the experiment consists of 20 treatments in two sets, the first set weed-free set and the second one weedy set, each set comprising weed competition durations up to 15, 30, 45, 60, 75, 90, 105, 120, and 135 days after crop emergence up to physiological maturity and weedy control as well as weed-free plot throughout crop life cycle.

3.4. Experimental Procedure and Management

The experimental field was prepared with seedbeds of a fine tilt before planting the ginger variety, following the standard tillage method. The field layout was established following the design's variables, and each treatment was assigned at random within experimental plots across blocks. Ginger was planted on April 7, 2023, with a total area of 2.4 x 3 meter (7.2 m^2) with a net plot size of (1.2 x 2.4m). Treatments were categorized as weed-free or weed interference on different days after crop emergence (DACE). In the weed-free treatments, weeds were removed from ginger emergence until 15, 30, 45, 60, 75, 90, 105,120 and 135 DACE, and then weed growth was allowed up to crop harvesting time. In the weed interference treatments, weed vegetation was allowed to grow up to 15, 30, 45, 60, 75, 90, 105,120 and 135 DACE, and then plots were maintained weed-free up to crop harvest. The frequencies of weeding the weed-free plots were based on the appearance of weeds.

Weeds were removed by hand and hoeing in all plots according to the treatments. The yield data were from the four central rows in each Plot were harvested, and the rhizome yields were estimated.

Fertilizer: The recommended rate of chemical fertilizers at Tepi agricultural Research Center for an optimum yield of ginger, 375 kg/ha urea and 175kg/ha NPS was used (Tepi agricultural Research Center, 2011).

3.4. Data collected

3.4.1. Data collection on weeds

Weed community: The weed flora present in the experimental field was recorded from weedy check plots by placing a quadrat (0.25 m × 0.25 m) randomly at two spots in each replication. Then weeds were classified according to their families. This assessment was conducted to look for the late emerging weeds also.

Weed density: Weed data collected from each plot by using quadrat (0.25 m × 0.25 m) thrown randomly at two places. The weeds from the quadrat were counted and categorized (broadleaved, grass and sedges). Data on weed density was taken at the time of weed removal for early competition and about 10 days before final harvest in the case of late competition to avoid possible foliage and seed shading. But in the case of others, data was taken at the time of first weeding and about 15 days before the expected crop harvest to avoid possible foliage and seed shedding. The weed count was subjected to $\sqrt{x + 0.5}$ transformation for normality before analysis, wherever necessary. The weed density was expressed in m^2.

Weed dry biomass: Samples to record aboveground weed dry biomass were collected from the same area as in case of weed density at the time of recording data on weed density. After two or three days of drying in sun, the samples were oven dried at 65^oC and its oven dry weight was determined. The weed dry bio mass was subjected to $\sqrt{x + 0.5}$ transformation for normality before analysis, if need be. The weed dry biomass was expressed in gm. m^{-2}.

3.4.2. Data collection on crop

Plant height (cm): It was recorded from 10 randomly selected plants per net plot area before harvest from the base of plant to the tip of main stem and expressed as height per plant.

Rhizome length (cm): Measured after harvesting of crop and 10 rhizomes were taken from each net plot area.

Number of fingers per rhizome: Ten rhizomes were taken randomly from the net plot area after harvesting to determine the number of fingers per rhizome.

Number of tillers: - This was recorded by counting number of productive tillers per plant from the plants found in net plot area.

Number of leafs/tiller: - were **r**ecorded by counting number of leafs found on tillers at the time of 90% physiological maturity from the net plot area.

Rhizome weight (g): The rhizome weight was recorded from each net plot area and converted to kg per ha.

Yield loss due to weeds was estimated by comparing the mean Ginger yield obtained from treated and complete weed-free treatments (Nieto *et al*., 1968).

The Ginger yield loss due to weed competition was calculated as:

$$\left(1-\frac{\text{Ginger yield in weedy check}}{\text{Ginger yield in weed-free check}}\right)\times 100$$

3.4.3. Meteorological data collection

The climate of the location and weather data of the cropping season were collected from the nearby (Tepi) meteorological station.

Growing degree days (GDD), which was used as an independent variable in regression analysis, was calculated as:
GDD= Σ (Daily average temperature-Base temperature). The base temperature used in the calculation was 13°C (Evenson, *et al*., 1978; Hackett and Carolane, 1982).
Since the weather changes from time to time and from place to place, considering the critical period by using number of days may not be appropriate; therefore, it is recommended to calculate by using the cumulative growth degree days.

3.5. Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) and means were compared with the Least Significant Difference (LSD) test at 5% level of significance using SAS software program version 9.1 (SAS Institute, 2003).

3.6. Estimation of critical period of weed-crop competition

To calculate the critical period of weed control in ginger, the relative soybean yield (*Y*) of each treatment was calculated as:

$$\left(\frac{\text{Ginger yield in treatment}}{\text{Ginger yield in weed} - \text{free check}}\right) \times \ 100$$

And non-linear regression equations were used to fit the data. The onset and end of critical period, which is the duration mandatory for controlling weeds was estimated by the response curve when both curves attained 90% of the relative yield gain and 10% of the yield loss of the complete weed-free period. The critical period was determined and found to be in between these two threshold points.

Analysis was based on the models suggested by Knezevic *et al*., (2002). The Gompertz equation was used for describing the effect of increasing duration of weed control on ginger yield and the logistic equation was used for describing the effect of increasing duration of weedy period on ginger yield. The Gompertz equation used was:

$$Y = a\ exp(-b\ exp(-kT))$$

Where Y is relative yield, a is the yield asymptote, b and k are constants, and T is the time (x-axis expressed in GDD).

The logistic equation used was:

$$Y = \left[\left(\frac{1}{\{\exp[c\ x\ (T-d)] + f\}}\right) + \left[\frac{(f-1)}{f}\right]\right] x\ 100$$

Where Y is relative yield, T is the time (x-axis expressed in GDD); d is the point of inflection, c and f are constants.

4. RESULT AND DISCUSSION

4.1. Weed Parameters

4.1.1. Weed flora in the experimental sites

The experimental site was invaded by a variety of weeds. Data on weed population revealed the population of broad leaf weeds were high in the experimental field and it was observed the maximum weed population was recorded in the unwedded control plots. The weed community of the experimental site composed of 16 weed species and 12 weed families (Table 2). The occurrence of high species diversity could be due to the high amount of rainfall which rained during the experimental period (Figure 2). Similar to this result, Tamado and Milberg (2000) reported that altitude, rainfall, month of planting, number of weeding and soil type were the major environmental/crop management factors that influenced weed species occurrence.

The weed flora of the experimental site was highly composed of broad-leafed annual species and the most dominant species was *Bidens pilosa* L. (Asteraceae) with density and relative density of 73 m^{-2} and 18.4%, respectively (Table 2). *Cyperus esculentus* (Cyperaceae) and *Amaranthus hybridus* L. (Amaranthaceae) were the second and third dominant species with density and relative density of 41 m^{-2} (10.33%) and 37 m^{-2} (9.32%), respectively. The result agrees with Tadesse *et al*., (1998) who reported that, the environmental condition of southwest Ethiopia is characterized by high temperature and high rainfall which is highly conducive for year round emergence and growth of highly competitive perennial and annual weed species such as *Cynodon* spp., *Cyprus* spp., *Digitaria* spp. *Commelina* spp., *Bidens pilosa*, *Guizotia scabra*, and *Ageratum conyzoides.*

Table 2. Density and Relative density of Weed community in the experimental fields of Ginger at Selam during 2023 main cropping season

Weed species name	**Family**	**Density (m^{-2})**	**Relative density (%)**
Amaranthus hybridus L.	Amaranthaceae	37	9.32
Amaranthus spinosus L	Amaranthaceae	14	3.52
Bidens pilosa	Asteraceae	73	18.40
Cerastium arvense	Caryophyllaceae	24	6.05
Commelina benghalensis	Commelinaceae	31	7.80
Convolvulus arvensis L	Convolvulaeae	31	7.80
Cuscuta campestris Yunker	Convolvulaeae	3	0.75
Cynodon dactylon	Poaceae	21	5.29
Cyperus esculentus	Cyperaceae	41	10.33
Galinsoga parviflora	Asteraceae	19	4.78
Galium spurium L. *Var.*	Rubiaceae	11	2.78
Plantago lanceolata	Plantaginaceae	11	2.78
Mimosa pudica	Mimosaceae	23	5.80
Oxalis corniculata L	Oxalidaceae	26	6.54
Sida alba	Malvaceae	15	3.78
Solanum nigrum L.	Solanaceae	17	4.28

4.1.2. Weed density

The duration of the weed competition periods significantly ($P<0.01$) affected the weed density (Appendix Table 1). Higher number of weed populations were present in the experimental site (Table 2; Table 3). Generally, weed density increased with the increasing duration of the weedy period (IDWP) and decreased with the increasing duration of the weed-free period (IDWFP). Therefore, the highest density (1331.52 m^{-2}) of weeds was found in weedy control treatment. Because the weeds remained in the experimental plots without weeding throughout the crop growth period. On the other hand, the lowest weed density (204.40) of weeds m^{-2} was on plots which weeds were allowed to grow only for 15 DAE. The lowest number of weeds found in treatment 15 DAE of the IDWP. Firstly, the sample was taken at a very early period when some weeds could be just emerging. Secondly, the moisture of the soil might not be adequate to encourage germination of all the active weed seeds in the top soil layer. Thirdly, some weed seeds could not have broken their dormancy until the time of first removal of weeds. In agreement with this result, Vleehouwers (1999) confirmed that, in field crops weed germination patterns generally resulted in cohorts of seedlings emerging over an extended period and are heavily influenced by weather conditions, soil types, and cropping systems. Similarly, Ahanchede and Gasquez (1997) reported lower mean number of species per plot in the samples, which were taken during the early crop emergence than those samples taken at latter stages probably during the early crop emergence some weed species had not yet emerged in crop fields. Our observation indicated that weeds emerged and established throughout the growing season, but no significant difference was found between the plots which were kept weedy up to 75 and 90 DAE as well as 120 and 135 DAE (Table 3).

With regards to the IDWFP (increasing duration of weed free period), the highest number of weeds was found in treatment of 15 DAE (Table 3). The density of weeds at that period was (354.56 m^{-2}). There was decreasing trend of weed density as the weed free period increased was not consistence. Therefore, the weed density was reduced from 15 up to 60 and 90 up to 135 DAE. The frequent removal of weeds at early stages and crop canopy closure at latter stages might have resulted in the reduction in emergence and growth of weeds due to shading effect.

Table 3. Effect of increasing duration of weedy and weed-free periods on weed density and weed dry biomass at Selam during 2023 main cropping season

DAE		
IDWP	**Weed density (m^{-2})**	**Weed dry biomass (gm^{-2})**
15	14.30^{i} (204.40)	9.85^{k} (96.04)
30	17.36^{h} (301.36)	11.66^{j} (135.95)
45	21.9^{f} (479.61)	15.29^{i} (233.78)
60	23.24^{e} (540.09)	22.31^{g} (497.73)
75	25.90^{d} (670.81)	26.48^{e} (701.19)
90	26.01^{d} (676.52)	29.73^{d} (883.87)
105	27.55^{c} (759.00)	30.51^{d} (930.86)
120	31.24^{b}(975.93)	31.5^{c} (992.25)
135	32.16^{b} (1034.26)	33.01^{b} (1089.66)
WC	36.49^{a} (1331.52)	41.32^{a} (1707.34)
IDWFP		
15	18.83^{g} (354.56)	26.61^{e} (708.09)
30	16.89^{h} (285.27)	24.42^{f} (596.33)
45	12.92^{j} (166.92)	18.44^{h} (340.03)
60	11.07^{k} (122.54)	15.37^{i} (236.23)
75	12.31^{j} (151.53)	11.79^{j} (139.00)
90	10.89^{k} (118.59)	8.75^{k} (76.56)
105	8.21^{l} (67.40)	6.54^{m} (42.77)
120	3.99^{m} (15.92)	4.07^{n} (16.56)
135	0.7^{n} (0)	0.7^{o} (0)
WFC	0.7^{n} (0)	0.7^{o} (0)
$LSD_{(0.05)}$	1.06	0.79
CV (%)	3.69	6.84

DAE = Days after crop emergence; IDWFP = Increasing Duration of Weed Free Period; IDWP = Increasing Duration of Weedy Period; WC = Weedy Check; WFC = Weed-Free Check; Figures in parentheses are the original and those outside the parentheses are the square root transformed values; Means followed by the same letters within each column are not significantly different

It could also be due to depletion of seed bank in the upper soil layer. In line with this, Norsworthy (2004) reported the presence of dense soybean canopy resulted in reduced weed emergence indicating that, changes in microclimate, beneath the soybean canopy negatively affected weed seed emergence. Mohammadi (2005) also indicated that, in chickpea canopy closure might have reduced both the establishment and competitive ability of latter emerging weeds.

4.1.3. Weed Dry biomass

Weed dry biomass was significant ($P<0.01$) affected by durations of weed competition (Appendix Table 1). Significant differences were observed among the durations of weed competition on weed dry biomass (Table 3). Overall, weed dry biomass increased with the increasing duration of the weedy period (IDWP) and decreased with the increasing duration of the weed free period (IDWFP). In IDWP, the weeds might have exerted a severe competition and exploited the environmental resources for extended period of time consequently accumulating more dry matter.

While in IDWFP, the weeds emerged and grew after the respective weed free periods under stress, thus, accumulating lower dry weight. Therefore, the lowest weed dry weight (96.04 g m^{-2}) was found at 15 DAE under IDWP. This could be due to the early weed removal.

The highest weed dry biomass (1707.34 g m^{-2}) which was significantly different from than the rest of the treatments was observed in weedy control plots (Table 3). This could be due to the highest weed density occurred in these plots and the prolonged period of time which gave weeds to accumulate more dry matter. Similarly, Ahmadi *et al.* (2007) reported that prolonging the weedy period in crops increased the weed dry weight per unit area and caused an uninterrupted weed infestation throughout the crop growth period, resulting in the highest weed dry biomass.

In IDWFP, the highest weed dry biomass (708.09 g m^{-2}) was found at 15 DAE (Table 3). After that period the values were drastically reduced as the weed free period increased (Table 3). Weed dry biomass decreased significantly with the successive increases in the weed free period up to 120 DAE after this, there was no weed emergence. Similar result was reported by Brian *et al.* (1993) who reported that weed dry biomass decreased as the weed free period prolonged.

4.2. Crop Components

4.2.1. Growth parameters

4.2.1.1. Plant height

Plant height was significantly (P <0.01) affected by the durations of weed competition (Appendix Table 2). In IDWP treatments, the highest plant height (50.86 cm) was obtained from the plots which were kept weedy up to 15 DAE (Table 4). However, the result was in statistical parity with the plant height from plots kept weedy up to 30 DAE. The weedy check had the shortest plants (8.40 cm), which was in statistically at par with the plant height from plots kept weedy from 120 to 135 DAE (Table 3). On the other hand, there were no significant differences in plant height between IDWP 15 up to 45 DAE. Furthermore, keeping the plots weed-free from 60 DAE to 120 DAE resulted in plant height that was statistical similar with each other (Table 3).

In IDWFP the shortest plant height (14.98 cm) was recorded in plots which were kept weed-free up to 15 DAE, this was not statistically different from the plots which were weed free up to 30 DAE. It was also observed that the plots kept weed-free up to 135 DAE were as comparable as WFC (50.17 cm) in plant height.

From the characteristics of weeds, weeds first overtake crops in growth rate and cover the plant canopy; this lowers the amount of resources available to individual plants, which may result in a reduction in crop plant height. However, when weeds became more dominant over the crop, they grew taller. In general, in most of the treatments, plant height increased as weed interference decreased and the vice versa.

Table 4. Effect of increasing duration of weedy and weed-free periods on growth of ginger at Selam during 2023 main cropping season

DAE IDWP	Plant height (Cm)	Number of tillers per plant	Number of leaves per plant	Leaf length (cm)
15	50.86^{a}	6.33^{ab}	12.67^{b}	16.46^{ab}
30	47.02^{ab}	5.67^{b}	12.00^{b}	13.84^{bc}
45	40.14^{d}	5.00^{bc}	9.00^{cd}	13.13^{cd}
60	28.16^{ef}	3.00^{def}	7.67^{cde}	9.59^{efg}
75	27.23^{fg}	3.33de	7.00^{def}	8.76^{fgh}
90	25.59^{fg}	2.33^{ef}	6.33^{ef}	7.65^{fghi}
105	23.03^{g}	3.33^{de}	6.67^{ef}	7.53^{fghi}
120	11.23^{ij}	2.33^{ef}	3.67^{g}	6.12^{hi}
135	9.74^{j}	1.67^{f}	3.67^{g}	5.30^{i}
WC	8.40^{j}	2.00^{ef}	3.67^{g}	5.07^{i}
IDWFP				
15	14.98^{hi}	2.00^{ef}	3.67^{g}	6.51^{ghi}
30	17.27^{h}	2.00^{ef}	5.00^{fg}	6.66^{ghi}
45	23.50^{g}	3.00^{def}	6.33^{ef}	7.59^{fghi}
60	28.16^{ef}	3.33^{de}	7.33^{de}	7.59^{fghi}
75	33.89^{e}	3.00^{def}	7.67^{cde}	12.33^{cde}
90	40.30^{d}	4.00^{cd}	9.67^{c}	13.58^{bcd}
105	40.52^{d}	5.00^{bc}	12.67^{b}	12.47^{cde}
120	42.14^{cd}	5.33^{bc}	12.33^{b}	14.89^{abc}
135	46.02^{bc}	5.67^{b}	12.67^{b}	13.46^{bcd}
WFC	50.167^{ab}	7.33^{a}	15.33^{a}	17.809^{a}
$LSD_{(0.05)}$	4.47	1.36	2.13	3.22
CV (%)	8.88	21.84	15.64	18.69

DAE = Days after crop emergence; IDWFP = Increasing Duration of Weed Free Period; IDWP = Increasing Duration of Weedy Period; WC = Weedy Check; WFC = Weed-Free Check; Means followed by the same letters within each column are not significantly different

This could be due to increased weed density and dry weight as weedy period increased and vice versa (Table 3). In line with this result, Habetewold *et al.* (2015) reported that ginger plant height significantly increased with increasing length of weed-free period and decreased with increasing length of weed infested period in ginger.

4.2.1.2. Number of tillers per plant

Number of tillers per plant were significantly (P<0.01) affected by weed competition duration (Appendix Table 1). In IDWP treatments, the highest (6.33) number of tillers per plat was obtained when the crop was kept weedy up to 15 DAE, which was statistically at par with the weedy from 30 and 45 DAE (Table 4). The weedy check had the lowest (2.00) number of tillers per plant, which was comparable with the number of tillers per plant from plots kept weedy from 60 to 135 DAE.

In IDWFP, the lowest number of tillers per plant (2.00) was recorded in plots which were kept weed free up to 15 DAE; it was statistically different from the plots which were weed free up to 75 DAE (Table 4). It was also observed that the highest number of tillers per plat (7.33) was obtained from the plots kept weed free throughout the growth period. Furthermore, there was no significant difference between plots kept weed free from 90 to 135 DAE.

In general, in most of the treatments, number of tillers per plant was increased as weed interference decreased and vice versa. This could be due to increased weed dry weight as weedy period increased and vice versa (Table 4). In line with this result, Habetewold *et al*. (2015) reported that number of tillers per plants significantly increased with increasing length of weed-free period and decreased with increasing length of weed infested period in ginger.

4.2.1.3. Number of Leaves per plat

Number of leaves per plant was significantly (P<0.01) influenced by duration of weed competition. In IDWP, the highest number of leaves per plant (12.67) was obtained when the crop was kept weedy up to 15 DAE and then after remains weed free throughout the crop growth period (Table 4). However, this value was not significantly different from the value obtained from the crop kept weedy up to 30 DAE and remained weed free after this period. AS IDWP increased, the number of leaves per plant decreased. The probable reason could be as the crop remains with weeds for longer period of time the completion for resources could be increased and that could lead to lower number of leaves per plant. However, the number of leaves per plant statistically at par in IDWP treatments of 45 to 75 DAE, 75 to 105 DAE and 120 DAE to weedy control (Table 4).

In IDWFP treatments, the lowest number of leaves per plant (3.67) was observed from 15 DAE treatments, which was statistically at par with the value achieved from 30 DAE treatments (Table 4). Likewise, the highest number of leaves per plant (15.33) which was statistically different from the rest of the treatments was obtained from the treatment which was kept weed free throughout the crop growth period. Furthermore, in IDWFP treatments as weed free period increased the number of leaves per plant increased. This could be due to removal or minimum competition from the weeds as weed free period increased. Similarly, Habetewold *et al*, (2017) reported that weed competition were found significantly affect vegetative, yield and yield related parameters of ginger.

4.2.1.4. Leaf length (cm)

Leaf length was significantly ($P<0.01$) influenced by weed competition duration. In IDWP treatments, significant differences observed due to increasing weedy period (Table 4). In IDWP treatments, the highest significant leaf length (16.46 cm) was obtained when the crop kept weedy up to 15 DAE which was statistically at par with weedy up to 40 DAE. It was also revealed that keeping the plots beyond 90 DAE decreased the length of leaves which was statistically at par with weedy control (5.07 cm). Therefore, early weeding is advisable to increase leaf length. Since early weeding, helps to reduce competition. Furthermore, as IDWP increased leaf length decreased and vice versa.

In IDWFP treatments, though the shortest leaf length (6.51 cm) was recorded in plots kept weed free up to 15 DAE, it was not statistically different from the plots which were weed free up to 60 DAE. It was also observed that the highest leaf length (17.8 cm) recorded in plots which were kept weed free throughout the crop growth period. Furthermore, as IDWFP increased leaf length increased and vice versa. Similar to this experiment, Habetewold *et al.* (2017) reported that weed competition duration significantly affected leaf length.

4.2.2. Yield components and yield

4.2.2.1. Number of rhizome finger per plant

Number of rhizome finger per plant was significantly ($P<0.01$) affected by duration of weed competition (Appendix Table 2). Significant differences were observed in the number of rhizome finger per plant due to increasing weedy period (Table 5). In IDWP treatments, the highest number of rhizome finger per plant (7.33) was recorded from plots which were kept weedy for 15 DAE and remained weed free up to harvest (Table 5). However, it was not significantly different from treatments 30 and 45 DAE. The lowest the number of rhizome finger per plant (2.0) was recorded from weedy control treatment. However, it was not significantly different from the treatments kept weedy 60 and 90-135 DAE. Furthermore, as IDWP increased the the number of rhizome finger per plant decreased and vice versa. Even though, there was no consistency. The decrease in the number of rhizome finger per plant this was observed due to competition from the weeds as the crop remained with weed for longer period of time.

In IDWFP treatments, the highest number of fingers per plant (9.67) which was significantly different from the rest of the treatments was recorded from weed free control (Table 5). This might be due to the removal of weeds throughout the crop growth period. That might help to reduce competition from weeds; so that, the plat could express its potential. The lowest the number of rhizome finger per plant (2.00) was recorded in plots which were kept weed free only for 15 DAE, then after remained weedy throughout the crop growth period. However, the value recorded was not significantly different from the values recorded from 30-60 DAE treatments (Table 5). Likewise, the reduction in the number of rhizome finger per plant could be the competition from the weeds which imposed on ginger as ginger subjected to increased weed competition. This result agrees with Habetewold *et al.* (2017) who reported that weed completion reduced number of fingers per plant of ginger.

Table 5. Effect of increasing duration of weedy and weed-free periods on crop components at Selam during 2023 main cropping season

DAE IDWP	Number of rhizome finger per plant	Rhizome length (cm)	Rhizome Yield (kg/ha)
15	7.33^{b}	7.41^{bc}	15718.74^{b}
30	6.00^{bcd}	7.63^{bc}	12604.16^{de}
45	6.00^{bcd}	6.05^{cdefg}	11458.33^{d}
60	3.00^{ghi}	4.49^{figh}	4548.61^{hij}
75	3.67^{fgh}	4.49^{figh}	5034.72^{h}
90	2.67^{hi}	4.05^{hij}	3715.27^{jk}
105	2.33^{hi}	3.36^{ij}	3680.55^{jk}
120	2.00^{i}	3.90^{hij}	2430.55^{l}
135	1.67^{i}	3.21^{ij}	1423.61^{l}
WC	2.00^{i}	2.44^{j}	1145.83^{l}
IDWFP			
15	2.00^{i}	3.73^{hij}	2534.72^{l}
30	2.33^{hi}	4.39^{ghi}	3229.16^{kl}
45	2.67^{hi}	4.87^{efghi}	3993.05^{ijk}
60	3.00^{ghi}	6.20^{cdef}	4375^{hij}
75	3.67^{fgh}	5.25^{defgh}	4895.83^{hi}
90	4.33^{efg}	6.93^{bcd}	6666.67^{g}
105	4.67^{def}	6.47^{bcde}	7986.11^{f}
120	5.67^{cde}	6.33^{bcde}	10277.77^{e}
135	7.00^{bc}	7.98^{b}	12013.88^{cd}
WFC	9.67^{a}	11.07^{a}	17465.27^{a}
$LSD_{(0.05)}$	1.47	1.71	270
CV (%)	21.90	18.83	8.49

DAE = Days after crop emergence; IDWFP = Increasing Duration of Weed Free Period; IDWP = Increasing Duration of Weedy Period; WC = Weedy Check; WFC = Weed Free Check; Means followed by the same letters within each column are not significantly different.

4.2.2.2. Rhizome length (cm)

Rhizome length was significantly ($P<0.01$) affected by duration of weed competition (Appendix Table 2). Significant differences were observed in rhizome length due to increasing weedy and weed free period (Table 5). In IDWP treatments, rhizome length decreased as IDWP increased. In addition, in IDWFP treatments, rhizome length increased as increasing IDWFP increased and vice versa. Even though there is luck of consistency.

In IDWP treatments, the highest rhizome length (7.63 cm) were obtained from ginger remained with weeds up to 30 DAE. However, was statistically at par with 15 and 45 DAE (Table 5). Moreover, the lowest rhizome length (3.2 cm) was from ginger not weeded for 135 DAE. Nevertheless, it was statistically at par with 90-120 DAE and weedy control.

In IDWFP treatments, the highest rhizome length (11.07 cm) which was significantly different from the rest of the treatments was recorded from weed free plots (Table 5). This could be due to ginger remained weed free throughout the crop growth period. Furthermore, the lowest (3.73 cm) rhizome length was recorded from ginger weeded only for 15 DAE and remained with weed up to harvest. However, it was statistically at par with 30 and 45 DAE treatments. This could be due to early removal of weeds that is 15-45 DAE not controlled late emerging weeds, which compete with ginger and reduced rhizome length.

4.2.2.3. Rhizome yield (kg/ha)

Rhizome yield was significantly ($P<0.05$) affected by duration of weed competition (Appendix Table 2). In IDWP treatments, rhizome yield decreased as IDWP increased. In addition, in IDWFP treatments, rhizome yield increased as IDWFP increased and vice versa. Even though there is luck of consistency. Moreover, ginger responds well for weed competition duration.

In IDWP treatments, the highest rhizome yield (15718.74 kg/ha) which was significantly different from IDWP treatments was recorded from ginger plants which was remained with weeds 15 DAE and kept weed free then after (Table 5). The lowest (1123.61 kg/ha) rhizome yield was recorded from weedy control plot. However, it was statistically at par 120 and 135

DAE. This indicates that, weeding ginger after 105 DAE would not help to recover the rhizome yield.

In IDWFP treatments, the lowest rhizome yield was recorded from ginger plants which were kept weed free only for 15 DAE and remained with weeds up to harvest. However, it was statistically at par with 30 DAE. This indicates that late emerging weeds could reduce yield. And the critical period could be increased to remove the late emerging weeds. This demonstrates that the crop suffers serious early weed competition leading to high yield loss.
The highest (17465.27 kg/ha) rhizome yield recorded from ginger kept weed free throughout the crop growth period (Table 5). This could be due to removal of competition from weeds, which helped the plant to utilize available resources and recorded maximum rhizome yield. Besides, the increase in rhizome yield as IDWP decreased and IDWFP increased could be due to the reduction in weed density and weed dry biomass (Table 3) and the increased in yield components (Table 5). Similarly, Habetewold *et al*, (2017) reported that weed competition were found significantly affect vegetative, yield and yield related parameters. Furthermore, similar results from Akobunda (1987) reported that weeds result in 65% reduction in yield of root and tuber crops and takes 25% of total labor use in production.

4.3. Critical Periods of Weed Control

The Gompertz and logistic equations generally described the data well as indicated by high coefficients of determination (R^2) values (Table 6).

Table 6. Parameter estimates for the Gompertz and Logistic regression equations for relative yield of ginger rhizome yield at Selam during 2023 main cropping season

Yield	Gompertz regression equation					Logistic regression equation				
	A	B	K	R^2	SE	C	D	F	R^2	SE
	26.61	0.0646	8.27	89.50	5.68	101.80	-0.0699	15.72	88.50	6.48

[1]*a* is the yield asymptote, *b* and *k* are constants, and SE is standard errors.

[2]*d* is the point of inflection, *c* and *f* are constants, and SE is standard errors.

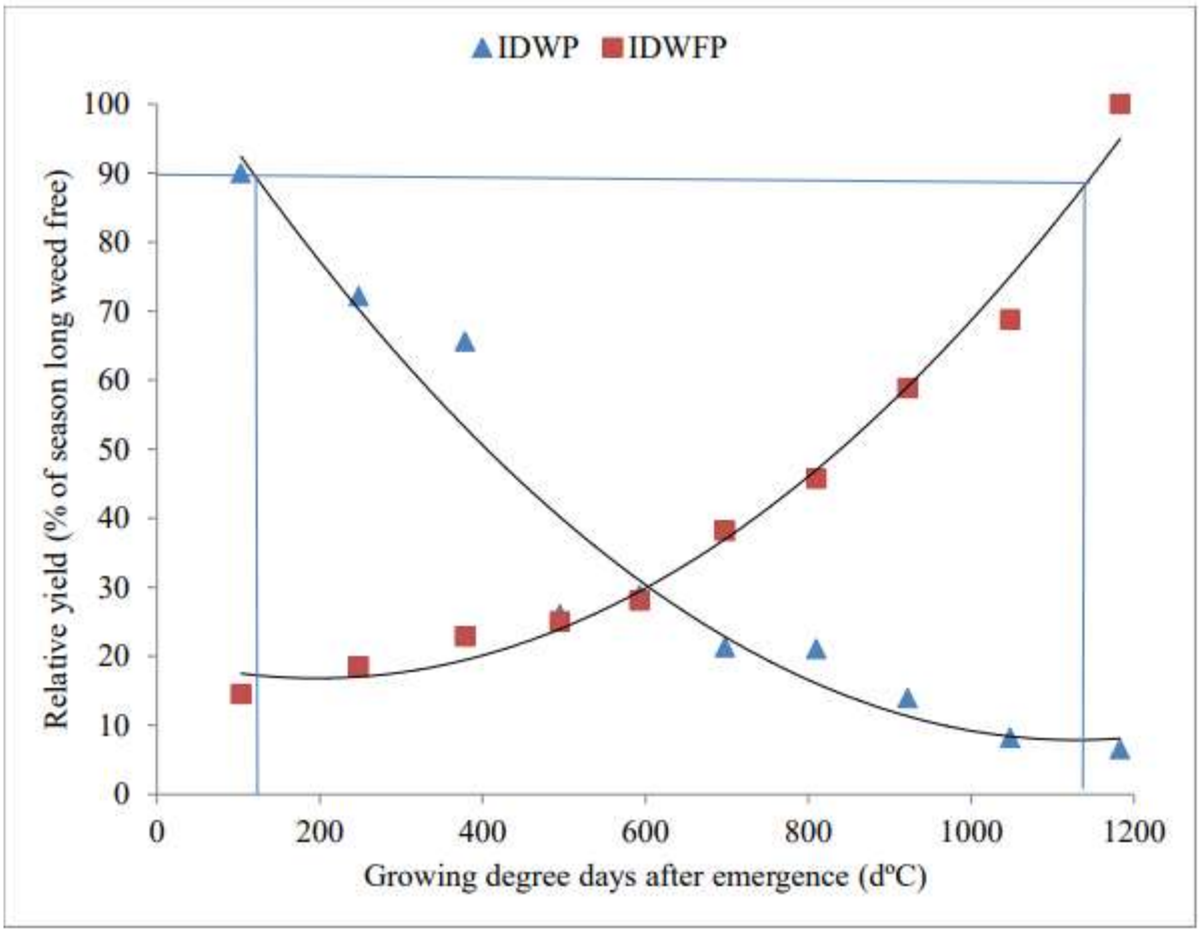

Figure 3. The predicted and the observed relative ginger yield as affected by the duration of the weed-free and weed-infested periods at Selam during 2023 main cropping season

Increasing the duration of weed interference (▲) and fitted curve as calculated by the logistic equation; increasing weed-free period (■) and fitted curve as calculated by the Gompertz equation. Horizontal line indicates 10% acceptable yield loss; vertical lines indicate the starting and end of CPWC.

The CPWC was carried out based on arbitrarily Selected Yield Losses (AYL) of 10% to estimate the begging and end of the critical periods, which were guessed to be good enough, bearing in mind the current economics of weed control. The beginning of CPWC based on 10% AYL occurred at 180 GDD, which was corresponded to 26 DAE.

On the other hand, the end of the CPWC at 10% AYL occurred by 1150 GDD corresponding to 143 DAE (Figure 3).

The study area was characterized by the higher minimum and maximum temperature at the time of cropping season, which may leads to earlier start of the critical period of weed interference that might have resulted in early emergence, development and rapid growth of weeds thus utilizing the available resources more efficiently and posing a stiffer competition of the weeds with the crop for growth resources. Some agreeing reports with this suggestion are, Gupta (2011) reported that the weeds that germinated earlier, before or at the same time as the crop emergence, posed a serious competition to the crop plants since they had an opportunity to establish and accumulate dry matter faster than the crop plants.

Knezevic *et al* (2002) similarly reported that the critical period of weed interference for a given crop can vary with the relative time of weed emergence, because earlier weed emergence can lead to the earlier beginning of the critical period. At very low weed densities there might be even no critical period of weed interference (Van Acker *et al.*, 1993; Martin *et al.*, 2001).

5. SUMMARY AND CONCLUSION

Ginger (*Zingiber officinale* Rosccoe) is the world's most important spice and cash crop in Ethiopia as well as in the world. So as its demand in local and foreign market has been increasing. The diverse climatic and soil types in Ethiopia is very conducive for ginger production and these all are good opportunities to improve production and productivity of ginger and to benefit from attractive prices that can generate significant revenue and hard currency for the nation.

But its production is limited by many biotic and abiotic factors, among which weeds are the major constraints. So that identification of critical period of weed control which is helpful to apply weed management strategies that provide consistent and effective broad spectrum control needed to make ginger growers more competitive in the local and world markets. Therefore, this study was designed to determine the critical period of weed competition and yield loss on ginger at Selam area of South Western Ethiopia during 2023main cropping season.

The experiment was laid in randomized complete block design with three replications for. The experiment consisted of 20 treatments in two sets, the first set was weed-free set and the second one weedy set, each set comprised of weed competition durations up to 15, 30, 45, 60, 75, 90, 105, 120, and 135 days after crop emergence up to physiological maturity and weedy control as well as weed-free plot throughout crop life cycle. Data were collected on weeds, growth parameters, yield and yield components of ginger. The collected data was subjected to analysis by using SAS software.

The weed species assessment showed that, *Bidens pilosa* L. (Asteraceae) with density and relative density of 73 m^{-2} and 18.4%, respectively was the dominate weed species in the study area.

The study clearly demonstrated that ginger responded well for duration of weed competition and increased weed free period increases rhizome yield of ginger. Whereas increased weed period decreased rhizome yield significantly. As ginger is inherently low germinating and slow growing crop it suffers from weed competition especially during early establishment period. This finding suggests that early weeding applied between 26 and 143 days after ginger emergence is the critical period to avoid early and late weed completion. The yield loss of ginger which occurred due to season long weed competition was 93%.

In both IDWP and IDWFP, all crop parameters associated with ginger yield increment and decrement were directly related to weed competition duration. Therefore, to get better yield of ginger crop at Selam South West Ethiopia, weeding applied between 26 and 143 days after ginger emergence is the critical period to avoid early and late weed competition. The experiment was conducted only at one location and it is recommended to conduct further research in different physiographic, edaphic and climatic conditions.

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7. APPENDIX

Appendix Table 1. Mean squares of analysis of variance for weed and plant parameters at Selam during 2023 main cropping season

Source of variation	DF	Weed density/ m^2	Weed dry biomass (g m^{-2})	Plant height (cm)	Number of tillers	Number of leaf per plant
Replication	2	0.92	0.98	2.71	0.82	1.29
Treatment	19	329.60**	7996.25**	568.95**	8.25**	39.39**
Error	38	0.51	0.41	7.35	0.68	1.66
CV (%)		25	24	8.88	21.84	15.64

** Significantly different at 5% P level, ** significantly different at 1% P level and DF =Degree of freedom, CV=Coefficient variance*

Appendix Table 2. Mean squares of analysis of variance for plant parameters at Selam during 2023 main cropping season

Source of variation	DF	Leaf length (cm)	No of rhizome finger	Rhizome length (cm)	Rhizome Yield (kg)
Replication	2	1.95	0.89	1.03	0.163
Treatment	17	45.34**	14.55**	12.78**	5.43*
Error	34	3.82	0.80	1.07	0.026
CV (%)		18.69	21.90	18.83	8.496

** Significantly different at 5% P level, ** significantly different at 1% P level and DF =Degree of freedom, CV=Coefficient variance.*

BIOGRAPHICAL SKETCH

The author, Mr Muluken Asfaw Wolde, was born on July 19, 1986, in Kaffa zone South West Ethiopia. He received his primary education at Bonga Primary School in Wush Wush, his intermediate education at Bonga Secondary School, and his college education at Mizan Agricultural College. He joined Mizan Teppi University Mizan Campus in 2017, and in 2019, he graduated with a BSc in Plant science. After graduating, he worked for three years as a Research Assistant at Teppi Agricultural research center. In October 2022, he enrolled in graduate studies to pursue a master's of science in crop protection at the Hawassa University College of Agriculture's School of Plant and Horticultural Sciences