International Journal of Agricultural and Applied Sciences, December 2021, 2(2):126-137
https://www.agetds.com/ijaas
ISSN: 2582-8053
https://doi.org/10.52804/ijaas2021.2219

Research Article

OPEN ACCESS

Effect of Foliar Application time and rates of exogenous salicylic acid on growth and grain yield performances of sorghum [*Sorghum bicolor* L. Moench]

Mesfin Bekele[1], Temesgen Teressa[2] and Birhanu Amsalu[2]
[1]*International Crop Research Institute for Sami Arid Tropics, ICRISAT, Ethiopia.*
[2]*Ethiopian Institute of Agricultural Research, Melkassa Agricultural Research Center, Adama, Ethiopia*
Corresponding author e-mail: mesfinswem@gmail.com
(**Received:** 17/05/2021; **Revised:** 13/10/2021; **Accepted:** 25/11/2021)

ABSTRACT

The experiment included two sorghum varieties, four salicylic acid (SA) rates, and three application times in a factorial design. Following foliar application of 0.5 or 1mM salicylic acid (SA), stem borer severity and stem lodging percentage were significantly reduced compared to controls (distilled water). For Meko, applying 0.5mM SA after 30 days of planting resulted in a 15% increase in grain yield above the control. Similarly, the application of 1Mm SA, 15 days after planting, increased the grain yield of ESH-1 by more than 20% than control. When sprayed with 0.5mM SA 30 days after planting, the hybrid ESH-1 produced the maximum dry biomass per plant (210.4g), while plants treated with distilled water produced the lowest dry biomass per plant (154.2 g). Similarly, for Meko, the highest dry biomass per plant (207.5 g) was found in plants sprayed with 0.5mM SA 45 days after planting, while the lowest dry biomass (124.3 g) was found in plants sprayed with distilled water 15 days after planting. So, in the Melkassa area, foliar sprays of 0.5 mM and 1 mM salicylic acid (SA) can boost grain yield of Meko and ESH-1 sorghum genotypes.
Keywords: Harvest Index, Salicylic Acid, Sorghum.

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is a monocot crop that belongs to the family Gramineae. It is a naturally self-pollinated short-day plant with high degree of spontaneous cross-pollination, in some cases up to 30 types of pending ears (Poehlman and Sleper, 1995). Sorghum is an annual crop plant, that follows the C4 photosynthetic pathway in which case the stomata open during the day, and the enzyme (PEP carboxylase) initially fixes CO2 in the mesophyll cells that would be converted to C4 acids. The C4 acids then diffuse to bundle sheath cells through the plasmodesmata where decarboxylation, fixation, and then re-fixation of CO2 by Rubisco takes place (Hall, 2001). Although sorghum is cultivated in tropical and temperate climates, it is best known for its adaptation to the marginal and drought-prone, semi-arid tropical (SAT) regions of the world (Poehlman and Sleper, 1995; Unger and Baummhardt, 2000). Sorghum is the fifth most important food crop in the world, stable food and feed grain crop in arid and semi-arid areas of sub-Saharan Africa (SSA), including Ethiopia, on which the livelihoods of millions of smallholder farmers depend (Wortmann *et al.*, 2009). Approximately 80% of the population in SSA depend on agriculture for food, feed, income generation and employment opportunity. Cereals, particularly sorghum are the most important staple food crops for millions of rural farm families in this region (Khan *et al.*, 2014). While significant amount of the produce is used for home consumption, even without reaching the commercial market, its grain is usually used as animal feed in the developed countries (Chantereau and Nicou, 1994). Sorghum grain is also used as a source of malt especially for processing the African opaque beer (Chantereau and Nicou, 1994; Hallgren, 1995). One of the desirable characteristics of sorghum cultivars is their potential bio-fuel sources due to their high biomass yield and sugar production (Collins, 2006). In Ethiopia, next to tef, sorghum is the second most important crop for making quality injera and it is also used for making the traditional foods (bread, injera, porridge) and distilled and non-distilled local beverages (Tella, Areke, Cheka, Borde, Korefe and Karibu) (Dendy, 1995). In addition, the "Durra" type of grain sorghum found only in Ethiopia can easily beassimilated by the digestive system due to their high lysine content (Wang *et al.*, 2008). In some parts of the country, it provides biomass for use as fuel, fodder and building materials. More than 4.7 million households in Ethiopia grow sorghum on 1.9 million ha of land and produce about 51.7 million tons of grain, which accounts for 16.89% of the total cereal production in the country. This makes sorghum production in the country to stand 3rd and 4thin terms of area and grain production (3.8 million tons) (CSA, 2018). In Ethiopia, sorghum grows almost entirely during the main rainy season except, Konso and Derashe (Adugna, 2012).

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zones of Ethiopia, it is more important in the dry lowland areas where crop letdown, due to more frequent drought and pests, is a common tricky (Adugna, 2007). Sorghum yield has not yet significantly increased in the country. For instance, the national average productivity of sorghum in the country is 2.7 t ha-1 (CSA, 2018), which is far below the global average (3.2 t ha-1) (CSA, 2018). This is because of a number of biophysical and socio-economic factors. Factors leading to low sorghum productivity could be mainly biotic and abiotic stresses (heat and humidity), not advanced agricultural techniques for developing new varieties, poor agronomic practices and a poor seed system to promote improved sorghum-based agricultural technologies to farmers (CACC, 2003). Cereals production, particularly sorghum and maize by smallholder farmers in the semi-arid tropics is severely constrained by yield limiting and reducing factors (Khan *et al.*, 2014), such as unavailability of enough soil moisture to support crop growth and development (Boyer, 1982). Rainfall variability in both amount and distribution, which varies within a year, among years and locations, is one of the most serious constraints to crop production in these regions (Rosenow *et al.*, 1996). As a result, farmers face serious problems related to poor stand organization due to poverty. Germination and damage to seedlings resulting from pests and extremely high temperature stress (Chiduza *et al.*,1995). These yield-reducing factors severely affect the germination, plant establishment, and biomass yield (Nabi *et al.*, 2013). In lowland areas of Ethiopia, moisture is mostly inadequate for plant establishment and growth because of the sporadic nature of rainfall and decreasing rainfall gradient during the main season and poor water holding capacity of the soil in these areas (Reddy and Kidane, 1993). In some cropping seasons, especially in association with El Niño, there is an inadequate amount of rainfall and subsequent soil moisture stress could lead to total crop loss (Sharafizad *et al.*, 2012). These moisture deficits also exacerbate the yield-reducing factors such as insect pests, diseases, and Striga infestation. These yield-reducing factors severely affect the germination; plant establishment and biomass yield as well (Nabi *et al.*, 2013). Economically, there are six major important insect pests of sorghum, that include maize stem borer (*Busseola fusca*), spotted stem borer (*Chilo partellus*), sorghum chaffer (*Pachnoda interrupta*), Termite (*Macrotermes bellicosus*), shoot fly (*Atherigon associate*), and sorghum midge (*Contarinia sorghicola*) (Abraham, 2006). According to Emana *et al.* (2002) and Elias (2003), *C. partellus*, *P. interrupta*, *C. sorghicola*, and *C. socata* are the major insect pests of sorghum and maize in dry, low lands of Ethiopia. Undeniably, attacks by insect pests can cause a reduction in the yield of cereal crops by more than 80% (Khan, 2002). Although the extent of sorghum yield loss due to major diseases differs from season to season, location to location, and variety to variety, yield loss particularly 2006).

Nevertheless, farmers have their traditional management practices to reduce the effects of drought and disease challenges. These include the use of crop rotation, intercropping and different conservation practices. However, they are inadequate to mitigate these production challenges and to substantially increase yield (Tamiru *et al.*, 2014). Researchers have also recommended several management techniques to reduce the effect of drought. These include the use of tillage operations, tie ridging and mulching (Teshome *et al.*, 1995). Furthermore, in order to enhance sorghum production and productivity through breeding, efforts also have been made to develop sorghum varieties that have different adaptive mechanisms to biotic and abiotic stresses. These include, development of some sorghum varieties with modified root architecture for enhancing water absorption and leaves for water retention, remains green for extending the photosynthetic process and N-use efficiency, and early maturing varieties that can escape the onset of moisture stress (Borell *et al.*, 2000a; Borell *et al.*, 2000b). Appropriate management strategies are also needed to stop the yield reduction in most of the semi-arid regions. As indicated in previous reports (Mohammad, 2014; Abdul *et al.*, 2013; Vlot *et al.*, 2009), foliar application of salicylic acid was found to have immense potential to overcome some of the challenges faced by resource poor farmers. Application of exogenous salicylic acid on crop plants induces defense related PR-proteins that may play a vital role in viral, bacterial, fungal pathogens, and insect pest resistance mechanisms by interfering with their digestive systems (Corina and D'Maris, 2010; Maffei *et al.*, 2007). Foliar application of salicylic acid can also bring significant yield increment for different crops (Yildirim and Dursun, 2009). As reported by Khodary (2004), exogenous application of salicylic acid can help alleviate stress conditions by activating photosynthetic activities in plants. Therefore, examining the potential use of exogenously applied salicylic acid to enhance sorghum production and productivity seems highly relevant. Thus, field trial was conducted at Melkassa Agricultural Research Center with the assumptions that the use of salicylic acid will help to reduce the effect of production challenges and thereby enhance productivity and furthermore, generate relevant information on the use of the exogenous salicylic acid application on sorghum. Thus, the general objective of this study was to evaluate the effect of exogenous salicylic acid application on the productivity of sorghum along with specific objectives of determining the effect of different rates and time of exogenous salicylic acid application on growth, yield and pest reaction of sorghum; and identifying the optimum rate and time of salicylic acid application for higher yields of two recently released sorghum varieties.

Salicylic acid (SA) is formally identified as Beta Hydroxy Acid (BHA) which is synonymous with 2-hydroxybenzoic acid or o-hydroxybenzoic acid. It has an

empirical formula and molecular weight of C7H6O3 and 138.12 g/mol, respectively. It is a colorless crystalline organic acid that is soluble in water (2.17 mg/ml at 20 0C), ethanol, and diethyl ether. This is chemically identical to the active component of aspirin (acetylsalicylic acid) (Sakhabutdinova *et al.*, 2003). Role of salicylic acid in plant physiology Salicylic acid (SA) is a phenolic compound which regulates plant growth and development and has the capacity to prevent the incidence of systemic diseases in plants (Abdul *et al.*, 2013; Mohammad, 2014). SA is an important regulator of plant growth that generates a wide range of metabolic and physiological responses in plants involved in plant defense in addition to their impact on plant growth and development (Raskin, 1992). Salicylic acid also activates the generation of reactive oxygen species (ROS) and other defensive processes such as hypersensitive response and cell death (Vlot *et al.*, 2009). It plays a natural role in reaction of thermogenesis in different plant species, induces flowering in a range of plants, controls ion uptake by roots and determining the degree of stomata activities (Kapulik *et al.*, 1992). SA plays an indispensable role in regulating plant growth and developmental processes through nutrient uptake and their status; i.e., vascular differentiation, stem elongation, leaf development, and senescence (Rubio *et al.*, 2009). Effects of salicylic acid on insect pests and diseases Application of exogenous salicylic acid to crop plants induces defense proteins that may play a vital rolein viral, bacterial, fungal pathogens, and insect pest resistance mechanisms by interfering with their digestive systems (Maffei *et al.*, 2007; Corina and D'Maris 2010). Foliar application of salicylic acid has resulted in a significant yield increase of various crops (Yildirim and Dursun, 2009). Bagizadeh *et al.*, (2014) also observed that foliar application of SA increased the remobilization and partitioning efficiency of assimilates in wheat. As Khodary (2004) examined, exogenous application of salicylic acid (SA) can mitigate stress condition by activating photosynthetic activities of the plants. Similarly, exogenous application of SA under salt stress condition can also improve the yield and yield components of Mung-bean by improving the nitrogen metabolic processes by enhancing protein enzymes (Robert-Seilaniantz *et al.*, 2011). Response of Sorghum to SA Application Growth and development Growth and development of plants, like all organisms, is regulated by various internal and external stimulants. Hayat *et al.*, (2005) showed the growth analysis parameters of wheat seedlings, obtained with seeds soaked in a lower concentration of SA, increased significantly. Similar growth-promoting responses were generated in barley seedlings sprayed with SA (Pancheva *et al.*, 1996). Khodary (2004) also found a significant increase in growth characteristics, pigment contents and photosynthetic rate in maize that was sprayed with exogenous SA application; and it also enhanced the carbohydrate content in maize (Khodary, 2004). Hussein *et al.*, (2007) in their pot experiment sprayed salicylic acid with seawater to the foliage of wheat plants and reported an enhanced productivity due to an improvement in all growth characteristics including plant height, number and area of green leaves, stem diameter and dry weight of stem and leaves of the plant.
Effect of salicylic acid on yield and yield components
Optimal application of SA significantly improves crop yield. Sharafizad *et al.* (2012) showed highest grain yield of wheat was obtained with the application of 0.7 mmol SA. It is believed that increasing the crop yield may be due to delayed senescence of plant organs (particularly leaves and flowers) in response to exogenous AS (Imran *et al.*, 2007) which will automatically help the plant to prolong the life of photosynthetically active sites and also prevent premature loss of flowers and fruits.This consequently results in the observed increase in the amount of crop yield. Moreover, Marschner (2003) described that phytohormones increase the degree of sink at the level of seeds, directing the flow of metabolites to the developing seeds consequent to an improvement in the seed mass and seed yield per plant at harvest. Effect of salicylic acid on tolerance to biotic and abiotic stresses Hormones play a significant role in controlling pathogen attack through the plant organs by developing different defense mechanisms (Robert-Seilaniantz *et al.*, 2011). Application of SA essentially reduces the change of phytohormone levels in wheat seedlings under salinity and water deficit. As Baghizadeh *et al.* (2014) reported; the application of SA increased the concentration of light harvesting antennas in plant leaves. The SA treatment balances in plant tissues other growth hormones, like IAA, abscisic acid (ABA), and cytokinins (CKs) content entirely, which provided the development of anti-stress reactions such as maintenance of proline accumulation. Thus, defensive SA action includes the development of anti-stress strategies and speeding up of normalized growth processes after removal of strain causes (Sakhabutdinova *et al.*, 2003).

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted in Adama Woreda, at Melkassa Agricultural Research Center (MARC), which is located in the Central part of Ethiopia in Oromia Regional State. MARC is geographically located at an altitude of 1550 meters above sea level, 8^{0}24' N Latitud,e and 39^{0}21' E Longitude.

The area is characterized by hot to warm dry low land with a mono-modal rainfall pattern. The rainy season starts at the end of April and lasts up to the end of October with the maximum rainfall in June, July, and August. The annual mean minimum and mean maximum temperatures of the center for 2015 were 14.8 and 30.3 OC, respectively (MARC, 2015). The total annual average rainfall for the 2015 was 478.8 mm (MARC, 2015). According to the soil analysis result, the soil type of the experimental area is Andosols of volcanic origin with pH ranging from 7-8.2. The textural class of the soil was sandy clay loam and soil CEC ranges from medium to high (20-37.8 meq/100). The values of organic carbon, OC, (0.778-1.496%) and total nitrogen, TN, (0.067-0.154%) are too low to fulfill the nitrogen demand of the plant and to maintain soil nitrogen dynamic constant (MARC, 2006). In 2014, cropping season precursor crop of the experimental field was 'tef'. This field experiment was conducted in the main cropping season of 2015 under rainfed conditions.

Treatments, Experimental Design and Crop Management Procedures

The treatments included combinations of two sorghum varieties Meko (improved farmers' preferred sorghum variety) and ESH-1 (hybrid variety), three scheduled times of salicylic acid (SA) foliar application (F1, F2 and F3), and four concentrations of SA (0, 0.5, 1.0 and 1.5 mM). The experimental design was factorial combination of varieties, application time and concentration of salicylic acid (2 x 3 x 4). The treatments were laid out in RCBD with three replications. One improved farmer's preferred sorghum variety (Meko) and one hybrid variety (ESH-1) were used as test crops. Meko was released in 2000, which has large size and high-quality seed; whereas, ESH-1 was the first Ethiopian sorghum hybrid variety released in 2010. Both materials were released for lowland moisture stressed areas by MARC. Salicylic acid was obtained from Abron Chemicals Limited (India). Three different weights of crystalline salicylic acid were arranged by using an electronic balance and for each weight, the SA solution was prepared with distilled water. Before the SA solution was prepared, the molecular weight was changed to molarity so as to get the exact amount of SA weight that could be formulated in distilled water. The three application times F1, F2, and F3 were 15, 30 and 45 days after planting, respectively. The experimental design was a factorial combination of varieties, application time and concentration of salicylic acid (2 x 3 x 4). The treatments were laid out in RCBD with three replications.

Land preparation was done by plowing with a tractor and plots were prepared manually. Sowing was performed by manually drilling the seeds in rows and 75 cm apart, and keeping the intra row spacing at 15 cm. Seeds were sown on four rows and plant population was maintained to nine plants per m^2. The row length of the plot was 5 meters and 3 meters width. The distance between the two plots was 100 cm. After emergence or at the three-leaf stage, the spacing was maintained by thinning based on the recommended spacing. Two central rows were used for data collection and yield determination. The recommended rate of (DAP) (100 kg ha^{-1}) at sowing, and nitrogen fertilizer (50 kg ha^{-1}) in the form of urea at the five-leaf stage, was applied. Insecticide and fungicide were not applied in this field experiment. The experimental field was maintained weed-free by hand weeding and hoeing.

Data Collected

Crop phenology and growth parameters

Stand count (SC): Stand count per plot was determined, soon after thinning and at harvesting, by counting the total number of plants in the two central rows.

Date to 50% flowering (DF): Days to 50% flowering was determined by taking the number of days from emergence to the date when 50% of the plants have started flowering.

Number of leaves per plant: Total number of leaves per plant was determined through its life cycle starting from the three leaves stage.

Root Lodging (RL): The number of plants that are root-lodged was scored on a scale of 1-5, where 1 = not lodged, 2 = few lodged, 3 = moderately lodged, 4 = lodged and 5 = heavily lodged.

Stalk Lodging (SL): The number of plants that are stalk lodged was scored on a scale of 1-5, where 1 = not lodged, 2 = few lodged, 3 = moderately lodged, 4 = lodged and 5 = heavily lodged.

Plant height (PH): The height of the plants in centimeters was determined from the base of the plant to the tip of the panicles by taking five randomly selected plants at physiological maturity.

Several senescence leaves: The number of senescent leaves was determined by taking the mean of five randomly selected plants.

Days to Physiological Maturity (DTM): The number of days from emergence to the date when 50% of the plants are physiologically matured was recorded.

Yield and yield components

Number of panicles harvested (NH): Total number of productive heads was determined per plot at harvesting time.

Biomass yield per plant (BY): Biomass yield per plant was determined after above-ground dry matter of five randomly selected plants were weighed with head and their mean value was taken after being completely dried in sunlight.

Dry panicle weight (HW): Head weight in gram/plot was taken after the panicle was completely dried in the sun.

Grain yield (GY): Grain yield in gram/plot was determined after measuring the grain weight from the two middle rows and correcting the results to 12% moisture.

100-grain weight (SW): The weight of 100 grains was measured in grams.

Harvest Index (HI): Harvest index in percentage was determined after measurement of grain weight and above the ground biological yield of the five randomly selected plants in each plot were measured after sun-dried. The harvest index is the ratio of the economic yield to the total biological yield, expressed as a percentage.

Disease and insect-pest reactions

Overall disease score: level of infection was scored on scale of 1-5 where 1 = highly resistant, 2 = resistant, 3 = moderately resistant, 4 = susceptible and 5 = highly susceptible.

Insect damage score: level of infestation was scored on scale of 1-5 where 1= no infestation, 2 = infested, 3 = highly infested, 4 = severely infested and 5 = dead plants.

Several crops suffering "dead heart" before and after foliar application of SA were recorded.

Statistical Analysis

Analysis of variance (ANOVA), mean separation, and Pearson correlation was conducted using SAS statistical computer package following SAS (Version 9.0) statement for factorial RCBD design (SAS, 2004). The means were compared using LSD mean separation method at 1% and 5% probability levels. Association among variables was determined using Pearson's correlations coefficient test at 0.05 probability levels.

RESULTS AND DISCUSSION

The effects of exogenous application of salicylic acid at different rates and application time on phenological, growth, yield, and yield attributes of two farmers preferred improved sorghum varieties were compared. The interaction of the treatments significantly affected the dry biomass, harvest index, and grain yield of the crop.

Main Effects of the Two Varieties

Effect on plant phenological and growth Parameters

The results following the Analysis of variance showed that varietal differences did not show a significant difference on days to 50% flowering of the two sorghum cultivars. However, days to plant maturity showed significance differences between varieties (Table 1). The hybrid ESH-1 physiologically matured earlier than the Meko variety. Significant differences in plant height and number of leaves per plant were also observed between the two varieties compared (Table 1).

Table 1. Effect of varieties on plant height, leaf numbers, and days to maturity

Variety	Plant height(cm)	Number of leaves	Days to maturity
Meko	121.19a	15.44a	106.67a
ESH-1	107.44b	14.439b	105.03b
LSD (0.05)	3.3	0.285	0.472
CV %	6.1	4.06	0.94

Means with different superscript letters are significantly different from one another ($p < 0.05$).

Effects on Yield and Yield components

Sorghum head weight per plant, grain yield per plant, 100-grain weight and dry biomass per plant showed significant differences between the two varieties. The hybrid ESH-1 showed superior performance over Meko in all yield and yield component parameters (Table 2). Comparing the two sorghum varieties concerning 100 grain's weight, there were highly significant ($P< 0.01$) differences in their performances which could be due to genotypic differences. Of the two sorghum varieties, the maximum of 100 grains weight was produced by ESH-1 (Table 2).

Effects of Application Time

Effects on all parameters

Analysis of variance showed that all the parameters of growth, phenology, yield, and yield components, and overall diseases and pest score were not affected by the main effect of SA application time.

Table 2. Effects of varieties on head weight, grain yield per plant, 100-grain weight, and dry biomass.

Variety	Head weight(g)	Grain weight per plant (g)	100grain weight(g)	Dry biomass per plant(g)
Meko	113.44[b]	90.49[b]	3.32[b]	161.18[b]
ESH-1	132.03[a]	101[a]	3.49[a]	178.36[a]
LSD (0.05)	11.48	5.58	0.124	10.44
CV %	19.71	12.8	0.124	12.96

Means with different superscript letters are significantly different from one another ($p < 0.05$).

Effect of Salicylic Acid Application Rates

Effects on yield and yield components

Exogenous application of salicylic acid did not improve the growth and phenological characteristic of the crops under this experimental condition. However, grain yield and dry biomass were significantly affected by the application of salicylic acid exogenously (Table 3).

Table 3. Effect of salicylic acid application rates on grain yield and dry biomass.

Concentration of SA (mM)	Grain yield per plant(g)	Dry biomass per plant(g)	Grain yield (t/ha)
0	93.18[b]	162.15[b]	4.98[b]
0.5	104.63[a]	185.6[a]	5.88[a]
1	94.7[b]	167.51[b]	5.57[a]
1.5	90.46[b]	163.82[b]	4.88[b]
LSD (0.05)	7.89	14.768	14.77
CV%	12.28	12.96	13.23

Means with different superscript letters are significantly different from one another ($p < 0.05$).

Interaction Effects of Varieties and SA Application Rates

Interaction effect on growth and phenology of two sorghum varieties

Time of SA application did not improve growth and phenological characteristic of this crop. The results of this study are not in conformity with the reports of Manikandan and Sathiyabama (2014) in finger millet and Hussein *et al.*, (2007) in wheat. According to Manikandan and Sathiyabama, (2014) finger, millet plants treated with SA flowered earlier than the controls (Manikandan and Sathiyabama, 2014), while Hussein *et al.* (2007) also reported improvement in most of the growth characteristics of wheat. Khodary (2004) reported a significant increment in plant height and number of leaves per plant and this delayed leaf senescence in maize plants due to exogenous application of SA. In common bean, Omid and Parviz (2012) reported increased plant height due to exogenous application of SA, when the plants were grown under normal and water-stressed conditions.

Interaction Effects of Varieties and SA Application Time

Interaction effects on grain yield and harvest index of two sorghum varieties

The interactions between variety and application time of salicylic acid significantly influenced the grain yield and harvest index of Meko variety. Similarly, the interaction effect of variety and application time after 45 days of planting showed a better harvest index for variety ESH-1 but not on grains yield (Table 4).

Table 4. Interaction effects of varieties and SA application time on grain yield and harvest index of two sorghum varieties.

	Variety Meko		Variety ESH-1	
Application time	Grain yield (t/ha)	Harvest Index	Grain yield (t/ha)	Harvest index
15 days after planting	4.6417[b]	0.5468[ab]	5.6917[a]	0.5708[ab]
30 days after planting	5.875[a]	0.5792[a]	5.3083[a]	0.5532[ab]
45 days after planting	4.7167[b]	0.5413[b]	5.7417[a]	0.5806[a]
LSD (0.05)	0.5773	0.036	0.5773	0.036
CV%	13.18	7.75	13.18	7.75

Means with different superscript letters are significantly different from one another ($p < 0.05$).

Interaction Effects of SA Application Rates and Time on Yield and Yield Components

Interaction effect of SA application rates and time on grain yield

Analysis of variance for grain yield per plant showed that the interaction between application rates and application time of salicylic acid significantly influenced the grain yield per plant at 1% probability levels. Application of 0.5mM SA at 45 days after planting significantly increased grain yield per plant of sorghum, which was by far better than the grain yield obtained from the control (Table 5).

Table 5. Interaction effects of SA application rates and time on grain yield per plant in gram.

SA Application rates (mM)	SA application time		
	15 days after sowing	30 days after sowing	45 days after sowing
0	82.95[de]	95.02[b-d]	101.58[ab]
0.5	95.15[b-d]	108.55[ab]	110.2[a]
1	101.5[ab]	96.42[bc]	86.18[c-e]
1.5	108.4[ab]	82.7[de]	80.28[e]
LSD (0.05)	13.663	13.663	13.663
CV%	13.18	13.18	13.18

Means with different superscript letters are significantly different from one another ($p < 0.05$).

Interaction effect of SA application rates and time on dry biomass

Analysis of variance showed that the interaction between application rates and application time of salicylic acid significantly influenced the dry biomass per plant at ($P < 0.01$). Exogenous application of 0.5 mM salicylic acid at 30 days after planting significantly increased dry biomass per plant of sorghum variety (Table 6).

Table 6. Interaction effect of SA application rates and time on dry biomass per plant in gram.

SA Application rates (mM)	SA application time		
	15 days after sowing	30 days after sowing	45 days after sowing
0	153.64[cd]	165.25[b-d]	167.55[a-d]
0.5	178.28[a-c]	191[a]	187.53[ab]
1	169.29[a-d]	172.6[a-d]	160.62[cd]
1.5	190.19[ab]	148.96[d]	152.32[d]
LSD (0.05)	25.579	25.579	25.579
CV%	12.96	12.96	12.96

Means with different superscript letters are significantly different from one another ($p < 0.05$).

Interaction effect of SA application rates and time on harvest index

Analysis of variance for harvest index revealed that the interaction of SA application rates and SA application time significantly ($P < 0.01$) affected the harvest index. The maximum harvest index was obtained following foliar application of distilled water after 45 days of planting (Table 7).

Table 7. Interaction effect of SA application rates and time on harvest index.

Application rates (mM)	SA application time		
	15 days after sowing	30 days after sowing	45 days after sowing
0	0.5285[cd]	0.5778[a-c]	0.6077[a]
0.5	0.536[cd]	0.5707[a-d]	0.5868[ab]
1	0.60[ab]	0.5563[b-d]	0.5237[d]
1.5	0.5707[a-d]	0.5598[a-d]	0.5257[d]
LSD (0.05)	0.0506	0.0506	0.0506
CV%	7.75	7.75	7.75

Means with different superscript letters are significantly different from one another ($p < 0.05$).

Interaction effect of SA application rates and times on 100-grain weight

The interaction effects of SA foliar application rate and time on 100-grain weight showed significant ($P < 0.01$) differences in performances (Table 8). The maximum 100 grains weight was obtained in seed samples produced by plants that were treated with distilled water at 45 days after planting.

Table 2. Interaction effects of SA application rates and time on 100-grain weight in gram.

Application rates (mM)	SA application time: 15 days after sowing	30 days after sowing	45 days after sowing
0	3.08^{d}	3.4^{a-d}	3.72^{a}
0.5	3.15^{cd}	3.48^{a-d}	3.52^{a-c}
1	3.5^{a-c}	3.3^{b-d}	3.367^{a-d}
1.5	3.567^{ab}	3.5^{a-c}	3.23^{b-d}
LSD (0.05)	0.4057	0.4057	0.4057
CV%	7.68	7.68	7.68

Means with different superscript letters are significantly different from one another ($p < 0.05$).

Interaction Effects of Varieties, Salicylic Acid Application Rates and Times

The Effects of varieties, rates, and time of SA application on dry panicle weight and grain yield per plant

Analysis of variance for head weight per plant and grain yield per plant showed that the interactions between variety, application rate, and time of salicylic acid application highly significantly influenced the head weight and grain yield per plant at 5% and 1% probability levels respectively (Table 9).

Table 9. The effects of varieties, rates, and time of SA application on dry panicle weight and grain yield per plant in gram.

Variety	Application time	Levels of SA (mM)	Head weight per plant (g)	Grain yield per plant (g)	Grain yield (t/ha)	Dry biomass per plant (g)	Harvest index
Meko	15 days after planting	0	95.31^{d}	55.03^{g}	3.03^{h}	124.27^{i}	0.4487^{h}
		0.5	111.65^{b-d}	96.03^{b-e}	5.77^{c-f}	169.8^{c-f}	0.568^{a-g}
		1	108.71^{b-d}	92.17^{b-f}	5.8^{b-f}	160.71^{d-h}	0.578^{a-f}
		1.5	110.65^{b-d}	106.77^{a-d}	3.93^{gh}	180.01^{a-e}	0.593^{a-d}
	30 days after planting	0	118.11^{a-d}	95.8^{b-e}	4.93^{fg}	159.37^{d-i}	0.604^{a-c}
		0.5	122.22^{a-d}	99.77^{b-e}	6.97^{ab}	171.58^{b-f}	0.582^{a-f}
		1	127.87^{a-d}	106.63^{a-d}	6.73^{a-c}	177.59^{a-f}	0.601^{a-d}
		1.5	95.42^{d}	75.27^{e-h}	4.87^{fg}	142.39^{f-i}	0.53^{d-g}
	45 days after planting	0	142.37^{ab}	104.83^{b-d}	5.73^{c-f}	180.87^{a-e}	0.577^{a-f}
		0.5	137.44^{a-c}	127.93^{a}	6.47^{b-d}	207.53^{ab}	0.62^{ab}
		1	92.42^{d}	56.77^{g}	3.07^{h}	127.25^{hi}	0.449^{h}
		1.5	99.17^{cd}	68.9^{fg}	3.6^{h}	132.74^{g-i}	0.519^{e-h}
ESH-1	15 days after planting	0	141.98^{ab}	110.87^{a-d}	5.4^{d-f}	183.01^{a-e}	0.608^{a-c}
		0.5	124.12^{a-d}	94.27^{b-f}	4^{gh}	186.76^{a-e}	0.5047^{gh}
		1	131.1^{a-d}	110.83^{a-d}	7.63^{a}	177.87^{a-f}	0.622^{ab}
		1.5	142.48^{ab}	110.03^{a-d}	5.73^{c-f}	200.37^{a-c}	0.548^{c-g}
	30 days after planting	0	129.05^{a-d}	94.23^{b-f}	5.83^{b-f}	171.12^{c-f}	0.552^{b-g}
		0.5	153.58^{a}	117.33^{ab}	5.57^{d-f}	210.41^{a}	0.559^{b-g}
		1	111.24^{b-d}	86.2^{d-f}	4.07^{gh}	167.61^{c-g}	0.512^{f-h}
		1.5	141.71^{ab}	90.13^{c-f}	5.77^{c-f}	155.53^{e-i}	0.589^{a-e}
	45 days after planting	0	123.37^{a-d}	98.33^{b-e}	4.97^{e-f}	154.22^{e-i}	0.6383^{a}
		0.5	115.3^{a-d}	92.47^{b-f}	6.5^{a-d}	167.53^{c-g}	0.554^{b-g}
		1	151.98^{a}	115.6^{a-c}	6.1^{b-e}	194^{a-d}	0.599^{a-d}
		1.5	118.5^{a-d}	91.67^{b-f}	5.4^{d-f}	171.9^{b-f}	0.532^{d-g}
	LSD (0.05)		39.768	25.794	1.1545	36.174	0.0715
	CV%		19.71	12.28	13.18	12.96	7.75

Means with different superscript letters are significantly different from one another ($p < 0.05$).

The effects of varieties, rates, and time of SA application on grain yield per hectare

Sorghum grain yield per ha showed a significant difference between the two varieties compared as well as the interaction between the variety and foliar application of salicylic acid at different times and rates. Overall results showed that foliar application of SA at different concentrations and time of application after planting affected the grain yield of the two sorghum varieties. However, in some instances, the differences in grain yield per ha were inconsistent between the two varieties, time of application, and concentration of SA used. In the control plants, significant ($P < 0.01$) differences in grain yield per ha between the two varieties were observed when distilled water was applied at 15 days after planting; whereas, the difference was insignificant between the two varieties when distilled water was applied after at 30 or 45 days of planting. Application of 0.5 mM or 1.0 mM SA significantly increased grain yield per ha, which was far better than the grain yield obtained following foliar application of either 1.5 mM SA or distilled water. While the sorghum variety Meko gave maximum grain yield when SA was applied 30 days after planting, variety ESH-1 gave the maximum grain yield ha-1 after the first foliar application of SA, which was15 days after planting (Figure 1).

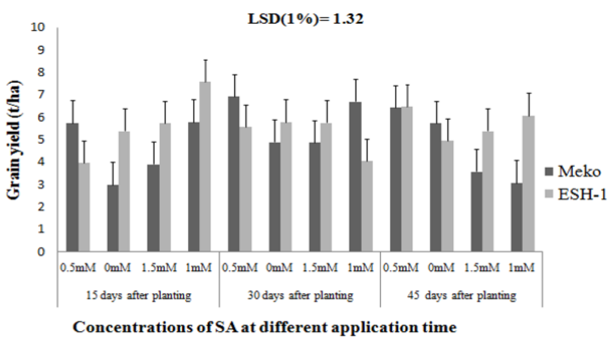

Figure 1. Effect of different rates and application time of SA on grain yield of two sorghum varieties.

However, when 0.5 mM SA was applied 45 days after planting, the grain yield ha-1 in both varieties was not significantly different. Exogenous application of 0.5 mM SA at 30 days after planting significantly increased grain yield ha-1of the sorghum variety Meko that was 15% more than that of the control applied at 30 days after planting. Correspondingly, exogenous application of 1.0 mM SA 15 days after planting significantly increased grain yield ha-1of the hybrid sorghum variety ESH-1 >20% higher than what was recorded in control plants applied at 30 days after planting. Grain yield per hectare was positively correlated ($p<0.01$) with head weight, 100 seed weight, and harvest index (Table 10). The results obtained in the current study corresponded to the findings of Sharafizad *et al.* (2012), who reported a significant positive correlation between grain yield of wheat with the number of spikes per head, number of grains per spike, biological yield and harvest index. Moreover, similar to the results of the current study, the reports of Sharafizad *et al.* (2012) indicated improvement in grain yield and 100-grain weight in different crops in response to foliar application of SA. Sanaz *et al.* (2013) concluded that the application of 0.5 mM and 1.5 mM SA increased the grain yield and 100-grain weight of wheat under rainfall conditions. The findings of Sharafizad *et al.* (2012) also indicated the effect of foliar application of 0.7 mM SA improved the grain yield of wheat under non-stressed conditions.

The effects of varieties, rates, and time of SA application on dry biomass

Dry biomass per plant was significantly ($P < 0.01$) affected by the main effects of variety and its interactions with application times and rates of SA. The hybrid sorghum variety ESH-1 produced the highest dry biomass per plant (210.4 g) when the plants were treated with 0.5 mM SA applied at 30 days after planting; while the lowest dry biomass per plant (154.2 g) was produced in plants treated with distilled water at 15 days after planting. Similarly, the variety Meko produced the highest dry biomass per plant (207.5 g) in response to 0.5 mM SA that was applied 45 days after planting (Table 9). Pearson correlation coefficient also indicated that dry biomass per plant exhibited a highly significant positive association with days to maturity, head weight per plant, grain yield, and 100-grain weight (Table 10). Similar to the results of the current experiment, Sanaz *et al.* (2013) had reported that exogenous application of SA enhanced the dry biomass of wheat cultivars under rainfed conditions.

The effects of varieties, rates, and time of SA application on harvest index

Analysis of variance for harvest index revealed that the interactions of SA application rates and SA application times significantly ($P < 0.01$) affected the harvest index in three ways interactions of the two varieties. The maximum harvest index was obtained following foliar application of distilled water and 0.5 mM SA, at after 45 days of planting for both ESH-1 hybrid and Meko variety, respectively (Table 9). Similar to these results, Nabi *et al.* (2013) had also reported that exogenous SA improved the harvest index by barely.

Relationship between the crop phenology, growth and yield components

Information expressing the degree of association between the growth and yield characters could serve for the simultaneous improvement of those characters. The correlation between and among the various phenological and growth parameters and the yield components were strong and significant, while some others have a weak association (Table 10). Days to maturity was shown to be significantly negatively correlated with leaf senescence. Plant height was moderately, but significantly, positively correlated with the number of leaves per plant and negatively associated with dry biomass. This is a common phenomenon in sorghum where tall varieties have higher leaf numbers and biomass in general. But the study area is dry low land, and varieties grown in this environment have a short growth cycle and produce low biomass with average grain yield. Among the yield components, grain and biomass yields were significantly positively correlated with head weight per plant, 100-grain weight, and harvest index (Table 10). These results are in agreement with previous findings by Borrell *et al.* (2000b) and Gul *et al.* (2005) where grain yield was reported to have been strongly associated with the major yield components as well with total biomass and harvest index. Many of these yield components, however, are regulated by different genetic mechanisms indicating that grain yield is a function of multiple factors.

Table 10. Pearson correlation coefficient among different growth & yield parameters of sorghum varieties at different foliar application times and rates of exogenous salicylic acid.

Parameters	DTF	PHT	ISC	SL	DTM	HWP	GYP	100GW	DHP	DBM	HI	NL	LS
DTF	1												
PHT	-0.11	1											
ISC	0.032	-0.07	1										
SL	0.27*	0.19	0.46*	1									
DTM	0.094	-0.27	-0.11	-0.03	1								
HWP	0.1	-0.21	-0.16	-0.09	0.47**	1							
GYP	0.08	-0.22	-0.02	-0.13	0.25	0.65**	1						
100GW	0.04	-0.13	-0.02	-0.09	0.3	0.34	0.4**	1					
DHP	0.001	-0.13	0.202	0.16	0.09	0.036	-0.01	0.12	1				
DBM	0.02	-0.3*	-0.09	-0.17	0.30*	0.64**	0.90**	0.24*	-0.01	1			
HI	0.124	-0.02	0.11	0.022	0.09	0.31**	0.62**	0.42**	0.14	0.19	1		
NL	0.06	0.26*	0.091	0.19	-0.22	-0.08	-0.16	-0.32**	0.19	-0.14	-0.1	1	
LS	0.04	-0.11	0.25*	0.009	-0.41**	-0.174	-0.023	-0.24*	0.046	-0.03	-0.01	0.4**	1

DTF= Days to 50% flowering; PHT= Plant height; ISC= Insect score; SL= Stem lodging; DTM= Days to maturity; HWP= Head weight per plant; GY= Grain yield; GYP= grain yield per plant; 100GW= 100 grain weight; DHP= Number of dead heart plants; DBM= Dry biomass per plant; HI= Harvest index; NL= Number of leaves per plant; LS= Leaf senescence per plant
R^2 value = 0.82; P value = 0.0001
**, * = highly significant at 1% and 5% probability level respectively.

Effect of SA Rates on overall Insect Score and Stem Lodging

Analysis of variance for overall disease score revealed that the SA application rates effect did not significantly influence this parameter. However, stem borer damage and stem lodging were significantly affected by foliar application of salicylic acid (Table 11). The severity of stem borer damage and stem lodging were significantly reduced due to foliar application of 0.5- and 1.0-mM SA as compared with the control (Table 11). Simple correlation coefficient analysis also revealed a significant ($p < 0.05$) association between stem lodging and insect-pest score (Table 10). Sorghum plants grown in plots sprayed with distilled water showed susceptibility to stem borer and were highly exposed to stem lodging due to the stem borer damage. Stem lodging due to severe stem borer damage was higher on plots sprayed with distilled water per se. Similar to this experiment, Abdul *et al.* (2013) reported that the application of phytohormones like SA and Jasmonic acid improved the defense mechanisms of groundnut plants against *Helicoverpa armigera*.

Although the number of dead heart plants due to the effect of shoot fly ranged from 12 to 14 for all SA application rates (Table 11), the analysis of variance showed no significant differences among the control and the application of different rates of SA. This could be due to the low incidence of shoot fly during the growing season.

Table 11. Effect of salicylic acid concentration on insect pest score and stem lodging score.

Concentration (mM)	Insect- pest score	Stem lodging	Dead heart plants due to shoot fly
0	3.11a	2.39a	14
0.5	2.5b	1.78bc	12
1	2.17b	1.5c	12
1.5	2.67ab	2ab	13
LSD (0.05)	0.5122	0.4787	NS
CV%	29.24	37.23	30.09

CONCLUSION

Sorghum yield can be enhanced by developing suitable management practices that can improve plant coping mechanisms. The analysis of variance revealed that foliar application of different rates and application times of SA on the two sorghum varieties did not significantly ($p > 0.05$) affect the number of leaves per plant, physiological maturity, plant height, days to 50% flowering, diseases score, leaf number, leaf senescence and several dead heart plants. However, the number of leaves per plant, physiological maturity, and plant height were significantly affected due to varietal difference. However, the exogenous application of SA at different rates and application times significantly ($p < 0.01$) affected the grain yield per plant, grain yield per hectare, dry biomass per plant, and harvest index. Thus, foliar spray of 0.5 mM and 1.0 mM SA showed better grain yield over 1.5 mM SA and distilled water (control) for both varieties. Both varieties produced similar and better grain yield (6.5 t/ha^{-1}) at 0.5mM SA following foliar application of SA at 45 days after planting. In general, the application of 0.5 mM SA at 15 days after planting increased grain yield per hectare of variety Meko by 15% over the control applied at 30 days after planting. Also, exogenous application of 1.0 mM SA at first foliar application time (15 days after planting) improved the grain yield of ESH-1 hybrid sorghum by more than 20% as compared to the control.

The hybrid ESH-1 produced the highest dry biomass per plant (210.4 g) due to the application of 0.5 mM SA at 30 days after planting, while the lowest dry biomass per plant (154.2 g) was produced due to foliar spray of distilled water at 15 days after planting. Similarly, the Meko variety produced the highest dry biomass per plant (207.5 g) due to the foliar spray of 0.5 mM SA at 45 days after planting; whereas, the lowest dry biomass per plant (124.3 g) was obtained due to spray of distilled water at 15 days after planting. The maximum harvest index of 0.64 and 0.62 was obtained at the third foliar spray of distilled water at 45 days after planting and the third foliar application of 0.5 mM SA at 45 days after planting for ESH-1 and Meko varieties, respectively.

Application of exogenous salicylic acid at different times and rates had no significant effect on all phenology and growth parameters (Days to 50% flowering, days to maturity, plant height, leaf number, and leaf senescence). However, it significantly affected the insect pest score, stem lodging, and yield and yield components. Considering the overall effect on the performance of sorghum grain yield and yield components foliar spray of 0.5 mM and 1.0 mM salicylic acid (SA) could be recommended for improving sorghum productivity under the Melkassa environment. Exogenous application of 0.5 mM & 1.0 mM SA at 15 & 30 days after planting conferred the highest average grain yield and dry biomass over control at any three application times.

Therefore, 0.5 mM or 1.0 mM of salicylic acid application at 15 or 30 days after planting as blanket recommendation reduces production challenges and increases sorghum crop productivity. Although, the result of this experiment gave a promising outcome to reduce the production challenges and enhance sorghum productivity, conducting a similar study at more locations and different years might be important. Since this experiment was done only at one location and one cropping season, it would be better to replicate it to get combined location and season data to come up with recommendations that are more consistent.

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Citation: Bekele, M.; Teressa, T. and Amsalu, B. 2021. Effect of Foliar Application time and rates of exogenous salicylic acid on growth and grain yield performances of sorghum [*Sorghum bicolor* L. Moench]. *International Journal of Agricultural and Applied Sciences*, **2**(2):126-137. https://doi.org/10.52804/ijaas2021.219