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Assimilate Partitioning and Photosynthetic Parameters of Rice (*Oryza sativa* L.) in Response to Salicylic Acid Application

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Abstract

Salicylic acid (SA), a signaling molecule is known to affect various physiological processes like growth and development, photosynthesis, absorption and translocation of assimilates etc. Therefore, an experiment was conducted to study the effect of salicylic acid on assimilate partitioning and yield of rice. The experiment comprised of 14 treatments replicated thrice in Randomized Complete Block Design (RCBD). Foliar application of SA @ 50, 100, 150 & 200 µg ml^{-1} was done at boot leaf stage (BL), one week after boot leaf stage (1WABL) and at BL + 1WABL. Treatment of water spray and unsprayed (control) were also included. Findings reveal that application of 100 µg ml^{-1} SA at BL + 1WABL resulted in the highest grain yield, which was statistically similar to 150 µg ml^{-1} SA at BL + 1WABL. The higher productivity under respective treatments can be ascribed to higher crop growth rate, relative growth rate, net assimilation rate and improvement in partitioning of dry matter from vegetative parts to grains due to improved vascularization. Also there was improvement in photosynthetic efficiency in terms of total chlorophyll content; carotenoid content and Hill reaction activity under SA treated plots. Thus, the productivity enhancement in rice can be achieved through 2 foliar sprays of salicylic acid @ 100 µg ml^{-1} each at boot leaf stage + one week after boot leaf stage.

Keywords: Dry matter partitioning, photosynthetic efficiency, rice, salicylic acid, yield

Introduction

Rice (*Oryza sativa* L.) belonging to family *Poaceae* is commonly cultivated as an annual plant. In tropical Asia, rice is consumed by 90% population (Bandumula 2017). India is world's second largest rice producing country after China. Amongst the various factors responsible for low yield of rice, poor grain filling is the most important one. The grain filling may be influenced by number of factors such as environmental conditions, hormonal balance, nutrient supply, water supply through effect on photosynthetic rate, leaf senescence or altered source-sink ratio etc. A balance between source and sink largely determines the grain filling. Although the sink capacity of large panicle rice is also huge but poor assimilate partitioning and export of sucrose content may lead to poor inferior spikelet filling, low seed setting rate and reduced yield. Srivastava *et al.,* (2017) reported that grain weight is reduced due to decrease in mobilization of reserve pre-anthesis assimilates leading to decrease in grain filling. Interruption in photosystem II is observed due to alterations in thylakoid membrane. Thus, negative influence on photosynthetic activity. Moreover, it leads to excessive production of ROS, which results in disturbed integrity of membrane and also may lead to death of the cell. Zhang *et al*., (2019) opined that variation in grain development between spikelets in a panicle is greatly influenced by phytohormones. Assimilates stored in the sheath and stem before heading and those produced after heading contribute to grain filling. Carbohydrates in the form of sucrose are translocated from source tissues to the sink (grain) and a number of enzymes catalyse the conversion of these assimilates to starch. Inadequate supply of carbohydrate causes the slow grain filling and low grain weight of inferior spikelets. During early grain filling, hormone levels play an essential role in the grain development. Fu *et al*., (2011) observed the effect of temperature on grain filling of rice and reported that temperature may affect grain filling in inferior spikelets. Nazar *et al*., (2017) reported that under environmental extremes salicylic acid enhances heat tolerance capacity of plants. To cope with the adverse effects of various stresses, plant growth regulators and antioxidant compounds have been used extensively (Iqbal *et al*., 2013). Exogenous application of SA improved the growth and biomass of heat tolerant as well as sensitive genotypes of rice. Physiological and biochemical processes are adversely affected under extreme temperature conditions which result in reduction. Salicylic acid protect the membranes and enzymes against heat-induced ROS-mediated degradation, thus increasing the crop productivity. The present study was thus planned with the objective to investigate the effect of salicylic acid on photosynthetic parameters and on mobilization of assimilates in rice.

Materials and Methods

Experiment was conducted during *kharif* 2019 at Research Farm and Laboratory of department of Botany, Punjab Agricultural University, Ludhiana, India [30°56' N latitude; 75°52' E longitude; 247 m altitude] located in the Western Indo-Gangetic Plains (WIGPs). Climate of experimental site is characterized as subtropical, semi–arid with an annual rainfall of 733 mm, out of which about 80% is received during June to September. The data on rainfall, sunshine hours, maximum and minimum temperatures were measured at agro-meteorological observatory of Punjab Agricultural University, Ludhiana, situated at 200 meters away from experimental site **(Table 1)**. The soil of the experimental field was sandy-loamy in texture, high in available-P and available-K but low in available N and soil organic carbon (SOC) status. The electrical conductivity and pH of the soil were within normal range.

Table 1: Mean monthly meteorological data during crop growth season (*Kharif* 2019)

Month	Temperature (°C)			Rainfall (Mm)	Sun-shine Hours
	Maximum	Mini-mum	Mean		
	2019	2019	2019	2019	2019
June	40.4	26.8	33.6	29.9	305.4
July	34.0	26.7	30.3	218.4	129.8
August	33.8	26.7	30.3	331.4	200.4
September	33.1	25.5	29.3	264.8	184.0
October	30.6	18.4	24.5	0.0	197.6
Mean/Total	34.4	24.8	29.6	844.5	1017.2

Experiment comprising 14 treatments was laid in Randomized Complete Block Design (RCBD) with three replications. The treatments included foliar application of Salicylic acid (SA) @ 50, 100, 150 & 200 µg ml1 at boot leaf stage (BL), one week after boot leaf stage (1WABL) and at BL + 1WABL. Treatment of water spray and unsprayed (control) were also kept. The sowing of short duration variety 'PR 126' was done during last week of May and was transplanted during last week of June using 30 days old seedlings. Crop was transplanted with a spacing 15 cm x 20 cm and size of plot was 2.2 x 3.5 metre. All other production and protection technologies were followed as per recommendations of Punjab Agricultural University, Ludhiana (Anonymous, 2019). Recommended dose of fertilizer (N @ 105 kg/ha and $ZnSo_4$ (21%) @ 25 kg/ha) was applied to the crop. Nitrogen was applied in the form of urea in three equal splits at 7, 21 and 35 days after transplanting (DAT). Whole of $ZnSo_4$ was applied as basal. Owing to sufficient level of available P and K, these nutrients were not applied to the experiments crop.

Total chlorophyll content, carotenoid content and Hill reaction activity was measured from randomly chosen leaves from each plot and calculated by using the equation suggested by Hiscox and Israelstam (1979) for chlorophyll and carotenoid content and Hill reaction activity was calculated by using the equation given by Cherry (1973). For recording dry matter partitioning, five plants were cut at ground level from each plot and were separated into different parts (leaf, stem, grains, chaff) and then oven dried at 60-65 ºC to a constant weight. Dry matter remobilization efficiency (%) and dry matter conversion rate (%) was calculated by using the formulae suggested by Ntanos *et al.*, (2002) and Xiong *et al.*, (2013). The crop growth rate (CGR), Relative growth rate (RGR) and Net assimilation rate (NAR) were calculated as suggested by Watson (1958), Radford (1967) and Vernon and Allison (1963), respectively. For recording grain yield, the grains obtained after threshing net plots were sun dried, winnowed, cleaned and weighed on an electronic balance. For valid comparison of different treatments, moisture in grains was estimated using moisture meter. Grain yield was measured after reducing moisture content to 14% moisture using digital moisture meter (Kett's RICETER J Handheld grain moisture meter) and expressed as q ha^{-1}. Data were subjected to analysis of variance (ANOVA) using Proc GLM procedure of SAS software (SAS 9.3.) as per RCBD. The multiple comparisons among treatment means were carried out by Tukey's test ($p \leq 0.05$).

Results and Discussion

Photosynthetic parameters

SA treatments caused an increase in total chlorophyll and carotenoid content as compared to control **(Figure 1)**. At anthesis stage, the highest total chlorophyll and carotenoid content was recorded in leaves of plants treated with 100 µg ml^{-1} SA at BL + 1WABL. A decrease in total chlorophyll content was recorded at physiological maturity stage. However, at this stage also 100 µg ml^{-1} SA at BL + 1WABL showed maximum total chlorophyll content (2.31 mg g^{-1} fresh weight) as compared to 1.44 mg g^{-1} fresh weight in unsprayed control. Application of SA also caused an increase in Hill reaction activity at both the stages as compared to control (unsprayed).

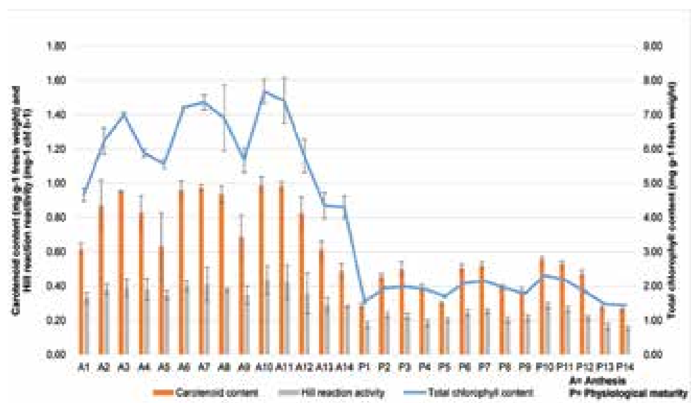


Figure 1: Effect of different concentrations of salicylic acid on photosynthetic parameters

At anthesis stage plants treated with 100 µg ml^{-1} SA at BL + 1WABL showed the highest Hill reaction activity (0.44 Δ O.D. mg^{-1} chl h^{-1}). At maturity stage also, same treatment resulted in the highest Hill reaction activity. It was least in control plants (0.15 Δ O.D. mg^{-1} chl h^{-1}). SA application improved the carotenoid content in leaves. Muthulakshmi and Linga Kumar (2016) also observed improved chlorophyll and carotenoid content in SA treated mungbean plants.

Anatomy of peduncle

Plates 1 show the transverse sections of peduncle in control (unsprayed), water sprayed and SA treated plants. The sections were hand-cut and observed under Leica Bright Field Research Microscope at 4x magnification. A variation in number of vascular bundles was observed in all the treatments as compared to control. The peduncle of unsprayed control plants showed least number of vascular bundles (12). Application of 50 µg ml^{-1} SA at boot leaf stage caused an increase in number of vascular bundles (14) in the peduncle. The number of vascular bundles in plants treated with 100 µg ml^{-1} SA at boot leaf stage was 17 while those treated with 150 and 200 µg ml^{-1} SA had 16 and 13 vascular bundles, respectively, in their peduncles. The plants treated with 50, 100, 150 and 200 µg ml^{-1} SA at one week after boot leaf stage had 13, 16, 15 and 14 vascular bundles, respectively, in their peduncles. The number of vascular bundles in peduncles of plants treated with 50, 100, 150 and 200 µg ml^{-1} SA at boot leaf + one week after boot leaf stage were 13, 19, 17 and 16, respectively. Plants treated with 100 µg ml^{-1} SA at boot leaf + one week after boot leaf stage showed maximum number of vascular bundles in their peduncles. The increase in number of vascular bundles led to an increase in area of conducting tissues which might be responsible for translocation of more assimilates to the grains.

Dry matter partitioning, growth analysis and grain yield

Data presented in **Table 2** reveals significant influence of SA application on dry matter partitioning of rice. It is evident that application of 100 µg ml^{-1} SA at BL + 1WABL resulted in the highest values of dry matter accumulation (DMA) in leaves, stem and panicle (at anthesis stage) compared to control (unsprayed), which was onpar with 150 µg ml^{-1} SA at BL + 1WABL. Application of 100 µg ml^{-1} SA at BL + 1WABL resulted in 35.4, 34.15, 13.5 and 65.6% enhancement in DMA in leaves, stem, chaff and grains over control respectively at physiological maturity stage. Although water sprayed plots showed improvement in DMA by panicle at anthesis stage and by chaff at physiological maturity but differences in DMA by other plant parts could not reach the level of significance amongst these two treatments **(Table 2).** Our results are supported by the observations recorded by Parveen *et al*., (2020) and Sha *et al*., (2019).

Data in **Figure 2** shows that dry matter remobilization efficiency also increased following SA application as compared to control (Unsprayed). Plants treated with 100 µg ml^{-1} SA at BL + 1WABL had maximum dry matter remobilization efficiency (40.2%) which was followed by 150 µg ml^{-1} SA treated plants (38.8%), whereas, control (unsprayed) and water spray treatments registered the least dry matter remobilization efficiency (30.9 and 31.9%).

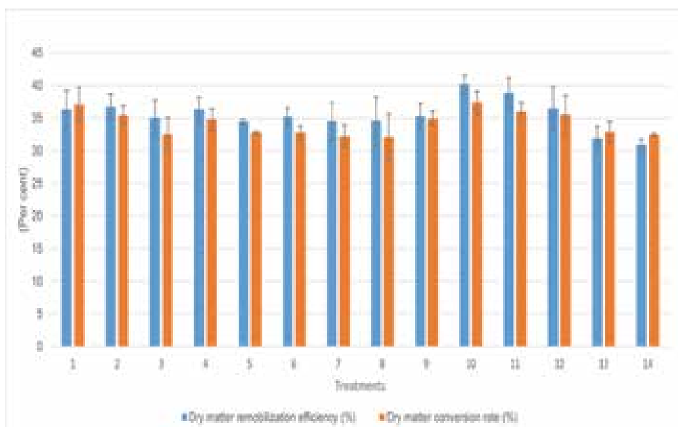


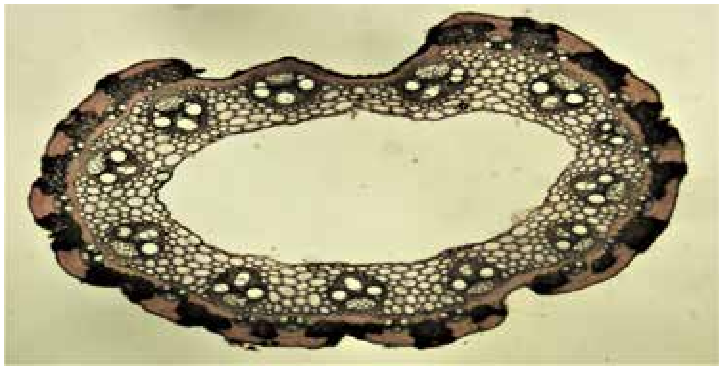
Figure 2: Effect of different concentrations of salicylic acid on dry matter remobilization efficiency (%) and dry matter conversion rate (%)

In general, dry matter remobilization efficiency ranged between 30.9 to 40.2% among different treatments. Increase in dry matter remobilization efficiency in plants treated with 100 µg ml^{-1} SA was due to increase assimilates translocation. Dry matter conversion rate was in the range of 32.5% to 37.3% and the trend was similar to that observed for dry matter remobilization efficiency. **Figure 3** depicts growth analysis (CGR, RGR and NAR) from vegetative to anthesis stage and anthesis to physiological maturity stage as affected by SA application. SA treated plants maintained higher CGR as compared to control (water sprayed and unsprayed). During vegetative to anthesis stage, the highest CGR, RGR and NAR was registered under 100 µg ml^{-1} SA at BL + 1WABL. As crop advanced to physiological maturity stage, there was decline in CGR, RGR and NAR but SA treated crop maintained higher values of these indices as compared to control. Foliar application of SA increased CGR, RGR and NAR in maize which is corroborated by the findings of Amin *et al*., (2013). The treatment of water spray although recorded numerical increment in grain yield over control (unsprayed) but difference was statistically not significant. Data further brings out that the highest grain yield was recorded under the treatment of 100 µg ml^{-1} SA at BL + 1WABL due to better yield attributes under this treatment. The former treatment was statically similar to the treatment of 150 µg ml^{-1} SA at BL + 1WABL. Both these treatments excelled over the control (unsprayed) by a respective margin of 14.6% and 13.5% **(Table 2)**. Increase in grain yield in SA treated plants might be due to role of SA in mobilization of assimilates from source to developing sink on account of increased vascularization **(Plate 1)**. Saranraj (2014) also reported an increase in grain yield following SA application. Similar results were obtained by Jatana *et al*., (2020) and Parveen *et al*., (2020).

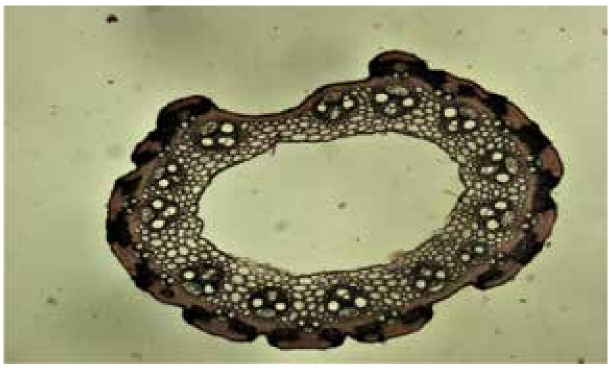
Table 2: Effect of different concentrations of salicylic acid on periodic dry matter partitioning (g $plant^{-1}$) and grain yield of rice

Treatments	Anthesis Stage			Physiological Maturity				Grain yield (q ha^{-1})
	Leaves	Stem	Panicle	Leaves	Stem	Chaff	Grains	
50 µg ml^{-1} SA at BL	14.88^{c} ± 0.50	10.29^{c-e} ± 0.19	11.98^{hi} ± 0.01	10.83^{de} ± 0.20	9.11^{c-e} ± 0.09	7.33^{de} ± 0.07	26.57^{e} ± 0.18	74.8^{de} ± 0.35
100 µg ml^{-1} SA at BL	16.68^{ab} ±0.24	11.80^{a-c} ± 0.13	13.32^{d-f} ± 0.09	12.96^{ab} ± 0.27	9.71^{a-e} ± 0.23	7.90^{a-c} ± 0.01	31.65^{cd} ± 0.12	78.0^{b-d} ± 0.53
150 µg ml^{-1} SA at BL	16.84^{ab} ± 0.07	11.86^{ab} ± 0.65	13.64^{c-e} ± 0.17	13.41^{ab} ± 0.19	9.94^{a-d} ± 0.16	8.00^{ab} ± 0.01	33.79^{bc} ± 0.58	79.3^{a-d} ± 0.73
200 µg ml^{-1} SA at BL	16.65^{ab} ± 0.09	11.05^{b-d} ± 0.19	13.29^{d-f} ± 0.15	12.94^{ab} ± 0.09	9.34^{b-e} ± 0.27	7.80^{bc} ± 0.02	31.38^{d} ± 0.06	78.0^{b-d} ± 1.16
50 µg ml^{-1} SA at 1WABL	15.08^{c} ± 0.06	10.42^{b-e} ± 0.28	12.40^{gh} ± 0.04	11.84^{cd} ± 0.15	9.14^{c-e} ± 0.08	7.21^{e} ± 0.01	29.61^{d} ± 0.58	76.0^{c-e} ± 0.75
100 µg ml^{-1} SA at 1WABL	17.37^{ab} ± 0.04	11.93^{ab} ± 0.15	13.94^{b-d} ± 0.04	13.63^{ab} ± 0.24	10.20^{a-c} ± 0.37	8.16^{a} ± 0.03	34.28^{b} ± 0.58	79.8^{a-c} ± 0.81
150 µg ml^{-1} SA at 1WABL	17.40^{ab} ± 0.23	11.94^{ab} ± 0.56	14.30^{bc} ± 0.21	13.74^{ab} ± 0.16	10.57^{a-c} ± 0.34	8.17^{a} ± 0.05	34.62^{b} ± 0.58	80.2^{a-c} ± 1.05
200 µg ml^{-1} SA at 1WABL	16.72^{ab} ± 0.16	11.83^{a-c} ± 0.44	13.41^{de} ± 0.23	13.29^{ab} ± 0.22	9.94^{a-d} ± 0.14	7.96^{a-c} ± 0.01	33.61^{bc} ± 0.58	78.5^{a-d} ± 1.50
50 µg ml^{-1} SA at BL + 1WABL	16.34^{b} ± 0.32	10.88^{b-d} ± 0.07	12.52^{f-h} ± 0.10	12.81^{c} ± 0.27	9.27^{c-e} ± 0.69	7.30^{de} ± 0.01	29.64^{d} ± 0.06	76.5^{c-e} ± 1.26
100 µg ml^{-1} SA at b BL + 1WABL	17.78^{a} ± 0.19	13.25^{a} ± 0.20	15.32^{a} ± 0.10	13.89^{a} ± 0.06	11.00^{a} ± 0.02	8.17^{a} ± 0.12	38.50^{a} ± 0.61	83.1^{a} ± 1.56
150 µg ml^{-1} SA at BL + 1WABL	17.72^{a} ± 0.10	12.66^{a} ± 0.14	14.53^{ab} ± 0.10	13.79^{ab} ± 0.25	10.94^{ab} ± 0.23	7.63^{cd} ± 0.06	35.65^{b} ± 0.07	82.3^{ab} ± 1.72
200 µg ml^{-1} SA at BL + 1WABL	16.39^{b} ± 0.19	10.95^{b-d} ± 0.17	13.01^{e-g} ± 0.19	12.89^{ab} ± 0.09	9.29^{c-e} ± 0.62	7.40^{de} ± 0.01	30.40^{d} ± 0.58	77.0^{c-e} ± 1.74
Water sprayed	14.10^{d} ± 0.10	10.19^{de} ± 0.14	11.46^{i} ± 0.27	10.56^{e} ± 0.29	8.41^{de} ± 0.08	8.15^{a} ± 0.13	24.71^{f} ± 0.18	74.5^{de} ± 1.00
Control (Unsprayed)	13.67^{d} ± 0.31	9.20^{e} ± 0.05	10.72^{j} ± 0.20	10.26^{e} ± 0.05	8.20^{e} ± 0.16	7.20^{e} ± 0.12	23.25^{f} ± 0.21	72.5^{e} ± 0.85

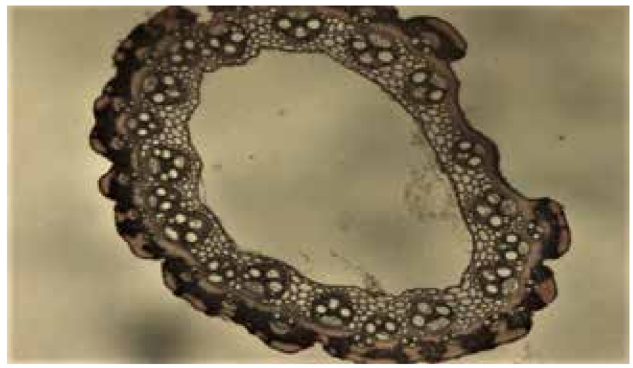
Means in the same column followed by different letters are significantly different at p<0.05.



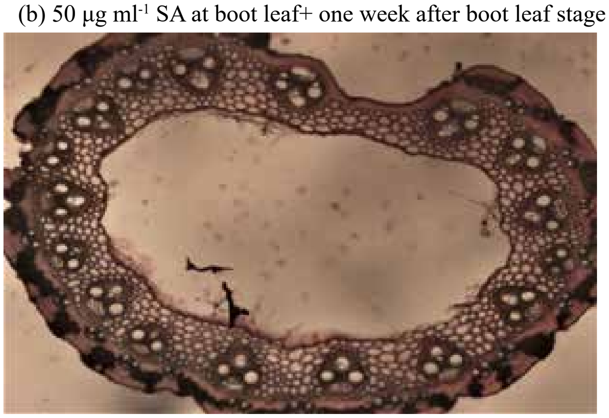
(a) Control (no spray)



(b) 50 µg ml^{-1} SA at boot leaf+ one week after boot leaf stage



(c) 100 µg ml^{-1} SA at boot leaf+ one week after boot leaf stage



(d) 150 µg ml^{-1} SA at boot leaf+one week after boot leaf stage

(e) 200 µg ml^{-1} SA at boot leaf+ one week after boot leaf stage

Plate 1: Variation in number of vascular bundles in peduncle of plants under different treatments

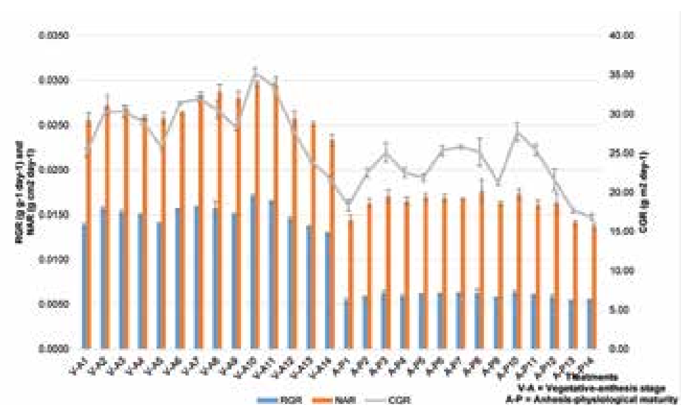


Figure 3: Effect of different concentrations of salicylic acid on crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR)

References

Amin A A, El-Kader A A A, Shalaby M A F, Gharib F A E, Rashad EL-SM, and Da Silva J A T. 2013. Physiological Effects of Salicylic Acid and Thiourea on Growth and Productivity of Maize Plants in Sandy Soil. *Communications in Soil Science and Plant Analysis,* 44: 1141-55.

Anonymous. 2019. *Package of practices for kharif crops of Punjab.* pp 20-25 Punjab Agricultural University, Ludhiana, India.

Bandumula N. 2017. Rice Production in Asia: Key to Global Food Security. Proc. National Academy of

Science, India Section B *Biological Science* 88: 1323-28.

Cherry J H. 1973. Molecular Biology of Plant: Text manual. Pp 46-49. Columbia University press, London.

Fu J, Huang Z, Wang Z, Yang J and Zhang J. 2011. Pre-anthesis nonstructural carbohydrate reserve in the stem enhances the sink strength of inferior spikelets during grain filling of rice. *Field Crops Research,* 123: 170-82.

Hiscox J D and Isrealstam G F. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany* 57: 1332-34.

Iqbal M and Ashraf M. 2013. Gibberellic acid mediated induction of salt tolerance in wheat plants: Growth, ionic partitioning, photosynthesis, yield and hormonal homeostasis. *Environmental Experimental Botany,* 86: 76-85.

Jatana B S, Ram H and Gupta N. 2020. Application of seed and foliar priming strategies to improve the growth and productivity of late sown wheat (*Triticum aestivum* L.). *Cereal Research Communications* 48: 383-90.

Muthulakshmi S and Lingakumar K. 2016. Salicylic acid induced responses on growth and biochemical constituents in Vigna mungo (L.) hepper. *European Journal of Experimental Biology* 6: 9-14.

Nazar R, Iqbal N and Umar S. 2017. Heat Stress Tolerance in Plants: Action of Salicylic Acid. R. Nazar *et al*., (eds.), Salicylic Acid: A Multifaceted Hormone pp 145-61.

Ntanos D A and Koutroubas. 2002. Dry matter and N accumulation and translocation for indica and japonica rice under mediterranean conditions. *Field Crops Research,* 74: 93-101.

Okamura M, Arai-Sanoha Y, Yoshida H, Mukouyama T, Adachia S, Yabe S, Nakagawa H, Tsutsumi K, Taniguchi Y, Kobayashia N and Kondoa M. 2018. Characterization of high yielding rice cultivars with different grain-filling properties to clarify limiting factors for improving grain yield. *Field Crops Research,* 219: 139 -47.

Parveen S, Issak M, Rahman Md S, Talukder F U and Islam S. 2020. A Rice Variety (BRRI dhan29) Yield Performance as Influenced by Foliar Application of Salicylic Acid in Bangladesh. *Agricultural Sciences,* 2: 263-74.

Radford P J. 1967. Growth Analysis Formulae: Their Use and Abuse. *Crop Science,* 7: 171-75.

Saranraj P. 2014. Effect of salicylic acid and *Pseudomonas fluorescens* on growth and yield of paddy IR-50. *International Journal of Microbiology Research,* 5: 54-60.

Sha H J, Liu H L, Hu B W, Gu J J, Hu W C, Jia Y, Wang X P, Chang H L and Zhao H W. 2019. Effect of salicylic acid on the dry matter and nitrogen accumulation, partitioning and translocation in two contrasting rice genotypes under salt stress. *Pakistan Journal of Botany,* 51: 1541-50.

Srivastava A, Srivastava P, Sharma A, Sarlach R S and Bains N S. 2017. Effect of stem reserve mobilization on grain filling under drought stress conditions in recombinant inbred population of wheat. *Journal of Applied and Natural Science* 9: 1-5.

Vernon A J and Allison J C S. 1963. A method of calculating net assimilation rate. *Nature,* 200: 814.

Watson D J. 1958. The dependence of Net Assimilation Rate on leaf area index. *Annals of Botany,* 22: 37-54.

Xiong J, Ding C Q, Wei G B, Ding Y F and Wang S H. 2013. Characteristic of dry-matter accumulation and nitrogen-uptake of super-high-yielding early rice in China. *Agronomy Journal,* 105: 1142-50.

Zhang W, Sheng J, Xu Y, Xiong F, Wu Y, Wang W, Wang Z, Yang J and Zhang J. 2019. Role of brassinosteroids in rice spikelet differentiation and degeneration under soil-drying during panicle development. *BMC Plant Biology,* 19: 409.