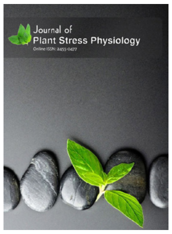
Journal of Plant Stress Physiology 2022, 8: 1-7
doi: 10.25081/jpsp.2022.v8.7300
https://updatepublishing.com/journal/index.php/jpsp

Research Article



ISSN: 2455-0477

The roles of strigolactones: Mineral compounds, indole-3 acetic acid and GA_3 content in grapevine on drought stress

Emine Sema Çetin[1]* Hale Seçilmiş Canbay[2], Selda Daler[1]

[1]Yozgat Bozok University, Faculty of Agriculture, Department of Horticulture, Yozgat/TURKEY,
[2]Mehmet Akif Ersoy University, Faculty of Science and Literature, Department of Chemistry, Burdur/TURKEY

ABSTRACT

Plants have an extremely important place in the life of living creatures and in the ecological cycle. First of all, they undertake a complex phenomenon such as photosynthesis and perform critical tasks such as being raw material for different industrial branches especially for human and animal nutrition, preventing erosion, contributing to the soil in terms of organic matter, and assuring temperature control. It is also known that the environmental conditions of plants, which have such a significant place in our lives are changing day by day and the plants are faced with a vast number of adverse factors. Plants are affected by these factors of biotic or abiotic origin, which are not suitable for them, and as a consequence, they get stressed. Drought is the leading one of these stress factors. It is clearly acknowledged that endogenous hormones play a major role in the expression of plants as sensitive or tolerant as a result of responses to different types of stresses. It is known that some other substances such as jasmonates, brassinosteroids, salicylic acid and nitric oxide have been included in the endogenous hormones, which were examined under five basic groups until recently, namely auxin, gibberellin, cytokinin, abscisic acid and ethylene. One of these hormones derived from carotenoids is strigolactones (SL). Recent studies demonstrate that this substance produced in plant roots is also at the forefront in terms of stress tolerance. In this study, the effect of SL applications on drought resistance was investigated in Kober 5 BB and 110 R American grapevine rootstocks with different drought tolerance. Rootstocks were treated with 5 and 10 μM SL and exposed to drought stress. In order to measure the effects of SLs on stress, some physical (shoot length, shoot weight, average number of leaves per shoot) and biochemical (mineral substance and endogenous hormones) analysis were carried out. In the study, it was determined that SLs are a sort of hormone that has positive effects in terms of plant growth and development, promotes plant mineral nutrition, and that there is a positive relationship between the synthesis of the endogenous hormones IAA and GA3. According to the results obtained, it is comprehended that SLs can be used as growth regulators to alleviate drought stress.

KEYWORDS: Grapevine, strigolactone, hormone, drought, mineral matter

Received: September 22, 2021
Revised: January 13, 2022
Accepted: January 15, 2022
Published: March 10, 2022

***Corresponding Author:**
Emine Sema Çetin
Email: esema.cetin@yobu.edu.tr

INTRODUCTION

Plants are faced with numerous stress factors that cause physiological and metabolic changes, negatively affecting growth and development, as well as reducing yield and quality. The most prevalent and increasing factor among these is drought. Global climate change, decrease in precipitation and water resources also cause an increase in arid and semi-arid areas, thus global climate change prolongs the duration and aggravates the severity of drought. In fact, plants try to maintain their growth and development by responding to these stress factors in varying degrees depending on their genetic adaptations (Wolters and Jurgens, 2009; Golldack *et al*., 2011). In the event that the aforementioned stress factor is removed or a resistance is gained, recycling is occasionally possible. However, the stress incident weakens the plant in any case and causes serious damage when the plant's utmost capacity is reached (Özcan *et al*., 2004). Plants have developed various adaptation mechanisms in order to survive by tolerating these negative effects of drought stress (Bartels and Sunkar, 2005). For example, limiting the growth of the plant is the most basic mechanism in this regard, and it is known that shoot development slows down, leaf area is reduced and new leaf formation is limited (Mahajan and Tuteja, 2005). Moreover, in some plants, the leaf surfaces are covered with dense villus and the thick waxy cuticle layer formed on the leaf surface is one of the reactions given to reduce the transpiration rate (Göksoy and Turan, 1991). It is also known that drought stress initiates some cellular reactions (Bartels and Sunkar, 2005). These reactions continue in the form of slowing the rate of photosynthesis, closure of stomata (Mahajan and Tuteja, 2005), decrease in CO_2 uptake and decrease in photosynthesis rate (Bota *et al.*, 2004). It is often not possible to eliminate the drought stress situation. In recent years, the focus has been on the use of genetic engineering in gaining resistance against stress. Studies are carried out to develop plants resistant to different stress factors using molecular techniques (Sanan Mishra *et al.*, 2005; Cuartero *et al.*, 2006). However, these methods are expensive, difficult to put into practice and require a great deal of knowledge. For these reasons, it is of great importance to use natural, easy-to-use, practical and harmless alternatives to human health.

It is noteworthy to increase stress tolerance in the plant, and this tolerance becomes even more important when the plant in question is a plant with commercial value and also important in terms of nutrition and human health. The vine and its fruit, the grape, are of high commercial value and notably significant in terms of medicine and pharmacy based on phytochemical content. Grape contains more than 1600 compounds, especially resveratrol and anthocyanin (Pezzuto, 2008) and in this way, it helps to reduce LDL known as bad cholesterol, reduce cardiovascular diseases, regulate blood sugar, increase immunity and prevent cancer formation, and even prevent diseases such as Alzheimer's thus plays an important role in plenty of fields (German and Walzem, 2000; Middleton *et al.*, 2000).

Considering that in modern viticulture, vineyards are established with seedlings grafted on American vine rootstocks, high quality grapes are also possible to be cultivated with varieties grafted on rootstocks that can adapt to environmental conditions. The vine is partially drought tolerant (Kennedy *et al.*, 2000; Esteban *et al.*, 2001), and product quantity and quality are adversely affected when the stress factor is severe. A study has shown that crop yields decrease when the leaf water potential drops below -0.9 mega pascals (MPa) (Grimes and Williams, 1990). In drought stress, shoot elongation in the vineyards and thus plant growth stops, shoot tips and tendrils dry, leaves fall, sugar content in berry decreases and color formation regresses (Çelik, 2011). Therefore, the quantity and quality of the product decreases first, and it causes deaths in the later phases (Battany, 2004). Therefore, it is of great importance to prevent the grapevine plant from being damaged by drought stress.

When the mechanisms of plant responses and reactions against stress are examined, it is known that endogenous hormones are extremely effective and plants are categorized as "sensitive" or "tolerant" according to these responses (Christmann *et al.*, 2006; Perez Torres *et al.*, 2008; Evelin *et al.*, 2009; Santner and Estelle, 2009; Wang *et al.*, 2009; Messing *et al.*, 2010). Until recently, plant hormones were studied under five groups: auxin, gibberellin, cytokinin, abscisic acid and ethylene. In recent studies, it has been stated that some compounds that have functions similar to hormones will be evaluated in this group. It has been determined that jasmonates, brassinosteroids, salicylic acid, nitric oxide and some other substances synthesized by plants have very important vital functions in the plant, just like hormones. One of these aforementioned substances is strigolactone (SL), a hormone derived from carotenoids and produced in plant roots.

SLs are molecularly composed of an ABC tricyclic lactone attached to the unsaturated α, β-furanone moiety (D ring) via an enol ether bridge. Before its emergence as a plant hormone, SLs were thought to be a germination promoting substance only in some root parasitic plants such as *Striga*, *Orobanche* and *Phelipanche*, and studies have been conducted for this feature for many years. In one of these studies, the effect of different extracts on the germination of Striga and Orobanche seeds was investigated. The extracts obtained from corn, cowpea and sorghum plants treated with fluridone, which inhibits carotenoid biosynthesis, were compared with the root extracts obtained from carotenoid biosynthesis mutants of maize plant. As a result of the research, it was determined that plant extracts with inhibited carotenoid biosynthesis reduced parasitic plant germination by up to 80% (Matusova *et al.*, 2005). In subsequent studies on SL, it has been determined that SLs act as a signal in the rhizosphere in the regulation of arbuscular mycorrhizal fungus (AMF) - plant symbiosis, which plays an important role in the development of plants (Akiyama *et al.*, 2005; Foo and Reid, 2012; Yoshida *et al.*, 2012; Lopez Obando *et al.*, 2015). Later on, it was determined that SLs can inhibit the development of lateral shoots in plants, suppress shoot branching (Gomez Roldan *et al.*, 2008; Umehara *et al.*, 2008; Brewer *et al.*, 2009) and subsequently shape the root structure (Ruyter Spira *et al.*, 2011) because SLs play an important role. While it has long been thought that auxin, cytokinin and abscisic acid control shoot branching, it is now known that SL also controls stem branching in harmony with these hormones. It has been determined that the inhibitory effects of SLs on shoot branching can be inhibited in the same way by exogenous SL application in densely branching mutant types (Ruyter Spira *et al.*, 2011).

There are also relevant studies revealing that SLs are effective in secondary development, rooting and tuber formation in relation to auxins (Roumeliotis *et al.*, 2012; Foo, 2013; Liu *et al.*, 2013; Shinohara *et al.*, 2013; Dierck *et al.*, 2016). Studies regarding SL have also found that this substance is related to other hormones (Lopez Raez *et al.*, 2010). For example, the accumulation of PIN1 proteins that are problematic in auxin transport to the plasma membrane is inhibited by SL (Crawford *et al.*, 2010). In this manner, auxin transport is reduced and shoot growth is inhibited. The absence of this inhibition in shoot development in SL mutants supports this condition (Sorefan *et al.*, 2003; Bennett *et al.*, 2006). According to this theory, instead of directly inhibiting shoots, SL inhibits them indirectly by reducing auxin canalization (Waldie *et al.*, 2014). It has been determined that gibberellins and SLs, which regulate seed germination in Arabidopsis, have synergistic effects (Toh *et al.*, 2012). However, it was determined that the transcription of gibberellin-3-oxidase 2, which is the key enzyme in gibberellin biosynthesis, was not increased in the application of GR24, a synthetic SL (Zhang *et al.*, 2013).

Since the discovery of SLs as phytohormones, extensive research has also provided new insights into their biosynthesis and signaling function. Considering all the roles they have undertaken in terms of plant growth and development, it is seen that SLs have important functions in increasing product yield and quality. SLs are natural compounds as they are plant hormones. Not a single adverse impact on human health have been detected. On the contrary, it has been determined that SLs inhibit cancer cells in breast, prostate, lung and colon cancer cases without harming healthy cells, reduce apoptosis and inhibit the proliferation of cancerous cells (Pollock *et al*., 2012; Yarden and Pollock, 2013).

According to the international literature, there are limited number of studies on the external use of SLs in tomato (Einav *et al*., 2010), arabidopsis (Ha *et al*., 2014) and wheat (Sedaghat *et al*., 2017) plants. With respect to the comprehensive literature review, no research was found to determine the effect of external SL applications on drought stress in these grapevine rootstocks. By way of this study, it was aimed to examine the effects of external SL applications on drought stress in Kober 5 BB (5BB) and 110 R American grapevine rootstocks with different stress tolerances. Physical (shoot length, shoot weight, average number of leaves per shoot) and biochemical (mineral compounds and endogenous hormones) analyzes were also the main criteria for the research to achieve its goal.

MATERIAL AND METHODS

Material

In this study, which was carried out to examine the impacts of SL applications on the mechanism of resistance to drought stress in grapevine, two American grape rootstocks; Kober 5 BB (5 BB) which is sensitive to drought and 110 R, which is more resistant to drought, were used as plant material. Required plant materials were procured from Bursa Agriculture Company/TURKEY.

Methods

The cuttings of 5 BB and 110 R rootstocks used as plant material were taken in the second week of April and were prepared to have approximately 5 buds measured as 35-40 cm. They were then planted in 2 L pots containing 1:1 perlite/peat and taken into growing rooms under controlled conditions at 25±1°C. Within 2 months following planting, the cuttings were regularly watered with a 1/10 liquid Murashige and Skoog (1962) solution. In the third week of June, SL applications were initiated in order to determine the effects on drought stress. GR 24, an SL analogue, was used in the study. There are different studies during which GR 24 was applied to the leaves as a spray (Ha *et al*., 2014; Sedaghat *et al*., 2017) or to the root zone (Foo, 2013). Considering that the plant material used in this study was used as annual and rootstock, it was thought that it would be more accurate to apply the results to the root zone in terms of applying the results into practice. For this reason, at the end of the second month following planting, two different concentrations of GR 24 in 5 and 10 μM were applied to the root regions of the plants. GR 24 was applied every other day until the 14th day, no application was made to the control plants. Drought stress applications were applied one month after the GR 24 application. Drought stress applications were carried out with limited water use, and control plants were irrigated every two days during this period. The plants were removed following the beginning of damage of the stressed plants, and after the measurements and counts that had to be made in the fresh form of the shoots, the samples were kept in deep freezer until the biochemical analysis.

The study was planned as recurrent in 3 stages and 15 plants (15 pots) were used in each replication. The data obtained at the end of the experiment were evaluated in the SPSS 20 statistical program according to the randomized plot design, and the differences between the averages were determined according to the Duncan multiple comparison test.

In order to examine the effects of SL applications against drought stress in grapevine, the following physical and biochemical analyzes were carried out.

Physical Analyzes

Determination of shoot length: The shoot length of the plants in each replication was measured in cm with the help of a ruler.

Determination of shoot weight: The fresh weight of the plants in each replication was determined in g.

Determination of the average number of leaves per shoot: The average number of leaves per shoot in each replication was determined as pieces.

Biochemical Analyzes

Determination of mineral substance amounts

Nitrogen (%) content was determined according to Dumas method (Shea and Watts, 1939) using the (Gerhardt Dumatherm) nitrogen combustion system. Phosphorus, potassium, calcium, magnesium, copper, boron, zinc, and sodium contents were also determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICPOES) device (Perkin Elmer Otima-8000). For this purpose, leaf samples were washed using 0.1% detergent solution and distilled water, and after drying on blotting paper, they were kept in an oven at 65°C. The leaves, which reached a constant weight, were ground with the help of a blender and made ready for analysis. Plant samples were burned in Milestone Start D device. Samples of 0.5 g were placed in microwave containers. 9 mL of 10 M HNO_3 and 3 mL of 10 M HCl were added to it (EPA 3051A, 1998). The two-stage temperature program of the combustion process was carried out as follows. In the first stage, the temperature of the microwave device was increased to 110°C in 15 minutes, and in the second stage, the implementors waited at 110°C for 15 minutes. After the device cooled down, samples were taken and readings were made in the ICPOES device. The conditions of the device are as follows; Rf power (W) 1450; Injector: Alumina 2 mm i.d.; Sample tubing: Standard 0.76 mm i.d; Drain tubing: Standard 1.14 mm i.d.; Quartz torch: Single slot; Sample capillary: PTFE 1 mm i.d.; Sample vials: Polypropylene; Source equilibrium delay: 15 sec; Plasma viewing: Axial; Processing mode: Peak area;

Gases: Argon and Nitrogen; Shear Gas: Air. The wavelengths (nm) in mineral substances are as follows: phosphorus: 214,9; potassium: 766,4; calcium: 315,8; magnesium: 279,0; copper: 324,7; boron: 249,6; zinc: 213,8; sodium: 589,7.

Endogenous hormone analyzes

Extraction procedures for the determination of the amount of Indole acetic acid (IAA) and Gibberellic acid (GA_3) were carried out according to the method used by Gomes *et al*. (1999). Hormone amounts were determined by HPLC (Cheikh and Jones, 1994). The HPLC conditions were as follows: Shimadzu Prominence HPLC; CBM: 20ACBM; Detector: DAD (SPD-M20A); Column Furnace: CTO-10ASVp; Pump: LC20 AT; Autosampler: SIL 20ACHT; Computer Program: LC Solution; Mobile Phase: A: 3% Formic acid B: Methanol; Column: Zorbax Eclips XDB-C18 (250*4.6 mm, 5μ); Column temperature: 30°C.

RESULTS AND DISCUSSION

The aim of this study was carried out to determine the physically observable effects of external SL applications on drought stress in 110 R (drought-tolerant) and 5BB (drought -sensitive) American grapevine rootstocks with different stress tolerances, as well as to demonstrate the relationship between mineral intake, auxin and gibberellin in this process. As a result of the statistical analyzes made in order to interpret the results obtained in the research, it is seen that there is no statistical difference between the applications made in the shoot length values (Table 1).

In the shoot length parameter under irrigated conditions, it is seen that the values in SL applications are numerically high in both genotypes. In arid conditions, it is seen that the shoot lengths are numerically higher than the control in both SL doses in 110 R rootstocks, and in the application of 10 μM SL in 5 BB, the said values are numerically higher than the plants in the control group. The highest shoot length value in terms of numbers was obtained from the 110 R genotype in irrigated conditions with 37.94 cm and 10 μM SL. Although a statistically significant difference could not be determined, it is thought that this difference can be revealed more clearly with the diversifications to be made in the concentrations of SLs. It is seen that there is no statistical difference between the applications in the data obtained in terms of shoot weight. However, a numerically high shoot weight value of 8.27 g was reached in 5 BB genotypes under irrigated conditions when 10 μM SL is applied. Again, numerically lower shoot weight value was also detected in 110 R genotypes in arid conditions without SL applied. From this, it is understood that even if there is no stress factor in the environment, SLs have a positive effect on plant growth. In terms of shoot weight data, as in the shoot length criterion, it is thought that there will be a statistical difference between the applications, as the dose range is more diversified.

Table 1: Effects of SL applications on some physical properties and endogenous hormones

	SL (μM)	Shoot length (cm)	Shoot weight (g)	ANL (piece)	IAA (μg/g)	GA_3 (μg/g)
Control						
110 R	0	27,56	6,69	8,63^{ab*}	1911,02^{f}	5634,02^{h}
	5	33,49	7,66	9,77^{a}	3938,51^{c}	14987,05^{g}
	10	37,94	8,16	9,72^{a}	5508,61^{a}	5544,69^{h}
5 BB	0	26,06	6,86	6,39^{b}	1775,16^{f}	20964,59^{f}
	5	28,38	7,27	6,55^{b}	1080,33^{g}	70368,04^{d}
	10	33,27	8,27	6,24^{b}	2745,17^{d}	86882,65^{c}
Drought						
110 R	0	31,83	5,53	8,87^{ab}	906,60^{g}	16477,99^{fg}
	5	32,63	5,76	8,78^{ab}	2246,68^{e}	62692,60^{e}
	10	32,02	5,85	8,33^{ab}	4368,32^{b}	18220,35^{fg}
5 BB	0	31,70	5,66	5,94^{b}	2878,91^{d}	243964,60^{a}
	5	26,19	6,80	6,33^{b}	4486,30^{b}	72157,63^{d}
	10	34,23	6,41	6,02^{b}	5636,58^{a}	220957,00^{b}

*There is a difference between the means with different letters in the same column ($p < 0.05$).
ANL: Average number of leaves per shoot

In terms of the average number of leaves per shoot, it is seen that the 5 BB genotype has lower values than the other genotype regardless of whether irrigation is done or whether SL is applied.

Hormones grouped as auxins, gibberellins, cytokinins, abscisic acid, ethylene, brassinosteroids, jasmonic acid, salicylic acid, nitric oxide and strigolactones have important functions in regulating plant growth and development in response to environmental changes. It is known that hormones do not act alone and freely in the fulfillment of these functions, but interact with each other synergistically or antagonistically as signal molecules. For example, lateral bud growth is inhibited by auxins transported downwards from the apex of the shoot, as well as by SLs transported upwards from the roots. Conversely, cytokinin, which is carried from the root to the stem, promotes bud formation. These different signals are regulated in response to different environmental factors such as light and nutrition (Smith, 2014). Auxins are the most important hormones that regulate phenomena such as cell division, cell growth, cell and tissue differentiation. Physiological studies have tried to elucidate the relationship between auxin and SL. Although it is known that SL regulates stem branching together with auxin, the mechanism by which it inhibits bud growth has not been fully resolved. SLs are thought to act as a secondary messenger for auxin in suppressing bud growth. In this study, the content of indole acetic acid (IAA), an auxin, was investigated. It is seen that the highest amount of IAA was obtained from 110 R (5508.61 μg/g) and 5 BB (5636.58 μg/g) genotypes in arid conditions, 10 μM SL was applied to both of the groups. Therefore, it is seen that higher doses of SL application have a positive effect on the amount of auxin, regardless of the presence of a stress factor in the environment. However, it is also striking that the amounts of IAA in the groups in which SL was not applied were lower in all groups compared to the groups in which 10 μM SL was applied.

Gibberellin (GA) is a hormone that stimulates germination, stem elongation and flowering, and accelerates fruit growth. Toh *et al*. (2012) determined that GA and SLs showed synergistic effects on seed germination in Arabidopsis. However, in our study, it is noteworthy that the highest GA_3

Table 2: Effects of SL on nitrogen (%) and other mineral compounds (mg kg^{-1})

	SL (μM)	N	P	K	Ca	Mg	Cu	B	Zn	Na
Control										
110 R	0	0,59^{*fg}	989,51^{g}	7723,55^{g}	6679,18^{i}	2656,14^{f}	1,83^{d}	23,00^{j}	9,67^{İ}	304,27^{g}
	5	0,56^{gh}	1085,42^{e}	8583,33^{f}	9125,00^{g}	3929,40^{b}	2,99^{d}	27,88^{g}	19,46^{e}	386,69^{e}
	10	1,59^{b}	1314,79^{c}	9977,06^{d}	10411,70^{e}	3971,33^{b}	3,39^{b}	35,13^{b}	24,37^{b}	327,64^{f}
5 BB	0	0,52^{h}	1086,60^{e}	11789,92^{c}	11161,60^{c}	3136,88^{e}	2,20^{e}	29,64^{e}	19,53^{e}	463,59^{d}
	5	1,15^{c}	1105,90^{d}	18651,75^{a}	12851,53^{a}	3708,52^{c}	3,35^{b}	31,40^{d}	27,58^{a}	644,65^{c}
	10	0,85^{e}	1024,32^{f}	8595,89^{f}	12561,64^{b}	3965,75^{b}	3,05^{cd}	36,61^{a}	20,26^{d}	377,51^{e}
Drought										
110 R	0	3,59^{a}	1915,86^{a}	14551,47^{b}	11196,43^{c}	2754,33^{f}	3,09^{c}	34,73^{c}	20,35^{d}	850,74^{b}
	5	1,05^{d}	1016,82^{f}	8587,62^{f}	8267,52^{h}	3126,17^{e}	1,77^{f}	25,28^{i}	12,55^{h}	196,79^{h}
	10	1,10^{c}	1391,23^{b}	11906,93^{c}	9603,90^{f}	4656,51^{a}	1,63^{g}	26,45^{h}	12,93^{h}	912,99^{a}
5 BB	0	0,63^{f}	768,12^{i}	9430,13^{e}	11036,03^{cd}	3445,42^{d}	2,23^{e}	28,95^{f}	15,31^{g}	377,84^{e}
	5	1,14^{c}	909,62^{h}	7050,91^{h}	9024,89^{g}	3123,30^{e}	3,96^{a}	26,65^{h}	21,24^{c}	380,54^{e}
	10	1,15^{c}	995,99^{g}	14288,92^{b}	10896,23^{d}	3439,86^{d}	3,11^{c}	29,03^{f}	18,69^{f}	302,36^{g}

*There is a difference between the means with different letters in the same column ($p < 0.05$)

content was reached in 5 BB genotypes in arid conditions without application of SL. On the other hand, while SL application in 110 R genotype encouraged an increase in GA_3 content in arid conditions, 10 μM SL application in irrigated plants of the same genotype also provided lower GA_3 content compared to the control. Therefore, it has not been possible in this context to clearly reveal the relationship between SL and GA. In a study in which it was stated that the transcription of gibberellin-3-oxidase 2, which is the key enzyme in GA biosynthesis, was not increased in exogenous GR24 application, this was based on the fact that the effect of SL in GA biosynthesis could only occur with the regulation of some other key steps (Zhang *et al*., 2013).

In the study, the effects of SL applications on the amount of mineral substances were also examined (Table 2). All nutrients except nitrogen and phosphorus were found in higher amounts in the SL treated groups. The highest nitrogen content, determined as %, was determined in the 110 R genotype, which was not treated with SL and in arid conditions. However, it is also observed that nitrogen content in all other groups was higher in the SL treated groups compared to the control group. It is also noteworthy that the highest phosphorus content was obtained from plants belonging to the same group as in the nitrogen content, however, an increase in the phosphorus content occurred in other application groups in SL applications compared to the control in parallel with the nitrogen content.

Potassium, calcium and zinc elements were found at the highest levels in the 5 BB genotype under irrigated conditions and in the plants treated with 5 μM SL. Magnesium and sodium were determined at the highest levels in 110 R genotype plants treated with 10 μM SL in arid conditions. While copper was detected at the highest level in 5 BB genotype, again in arid conditions and in plants treated with 5 μM SL; The highest boron content was determined in plants of 5 BB genotypes irrigated with 36.61 mg/kg and treated with SL. Therefore, it is seen that SL applications are an encouraging application by showing statistical differences in the intake of other mineral substances other than nitrogen and phosphorus, and the content of nitrogen and phosphorus increases with the application of SL in most groups.

Thanks to recently conducted studies, it is known that SLs play a role in the emergence of responses to different stresses such as salinity, drought and low temperature (Xiong *et al*., 2002; Ha *et al*., 2014). It has been stated that SL application increases plant resistance in arid conditions (Kapulnik and Koltai, 2014; Van Ha *et al*., 2014). Ha *et al*. (2014), in their study on mutant Arabidopsis plant in vitro, explants were cultured in GM medium for 14 days at 22°C, 16/8 hours of light/dark period. 100 μM ABA was applied for drought stress. The plants were treated with 5 mL of 5 μM rac-GR24 twice a day until the 13^{th} day. In the study, it was determined that SL treatment to SL-deficient mutants increased tolerance in drought-sensitive phenotypes. According to another study among the imited number of relevant studies including external applications to determine the impact of SLs on drought stress, the impact of SL and salicylic acid on drought in two drought sensitive and winter resistant wheat genotypes was tried to be determined. SL (GR 24) and salicylic acid were applied through foliar, and it was determined that the treated plants demonstrated higher tolerance (Sedaghat *et al*., 2017). In the light of these effects of SLs on drought stress, the researchers stated that SLs could be used as an alternative to drought-resistant transgenic plants in the future. In a study on the effects of SLs on the plant defense mechanism (Torres Vera *et al*., 2014), the mutant tomato line Slccd8 with SL deficiency was compared in terms of gray mold (*Botrytis cinerea*) and alternaria rot (*Alternaria alternata*) and it was found to be more sensitive than wild types containing SL. These studies confirm that SL plays a role as a positive stimulus in response to biotic and abiotic stresses. In addition to all these results, further studies are needed to precisely comprehend the mechanism of reaction of SLs in stress tolerance.

CONCLUSION

In this study, which was carried out to determine the possible effects of SLs under arid conditions, two American grapevine rootstocks, which are widely used in viticulture and differ in drought resistance, were used and the effects of SL applications on drought stress were tried to be examined. The obtained results demonstrate and indicate that SLs have potential to be used in this regard. However, it is thought that different trials at SL doses are necessary in order to interpret the results clearly.

In order to understand the stress responses and mechanisms of SLs more clearly, their interaction mechanisms with other plant hormones in particuar need to be studied.

ACKNOWLEDGEMENTS

This work was financially supported by the Yozgat Bozok University Project Coordination Application and Research Center (Grant numbers: 6602c-ZF/18-164).

AUTHOR CONTRIBUTION STATEMENT

Dr. Cetin contributed to this work in the experimental design and setup, lab processing of samples, data analysis, manuscript writing and discussion. Dr. Secılmıs Canbay and Dr. Daler contributed to lab processing of samples, data interpretation and manuscript writing. The authors read and approved the manuscript.

REFERENCES

Akiyama, K., Matsuzaki, K., & Hayashi, H. (2005). Plant sesquiterpenes induce hyphal branching in arbuscular mycorrhizal fungi. *Nature,* 435, 824-827. https://doi.org/10.1038/nature03608

Bartels, D., & Sunkar, R. (2005). Drought and salt tolerance in plants. *Critical Reviews in Plant Sciences, 24*(1), 23-58. https://doi.org/10.1080/07352680590910410

Battany, M. (2004). Grape notes: Salinity management for drought years. University of California Cooperative Extension, 8.

Bennett, T., Sieberer, T., Willett, B., Booker, J., Luschnig, C., & Leyser, O. (2006). The Arabidopsis MAX pathway controls shoot branching by regulating auxin transport. *Current Biology, 16*(6), 553–563. https://doi.org/10.1016/j.cub.2006.01.058

Bota, J., Medrano, H., & Flexas, J. (2004). Is photosynthesis limited by decreased Rubisco activity and RuBP content under progressive water stress? *New Phytologist, 162*(3), 671-681. https://doi.org/10.1111/j.1469-8137.2004.01056.x

Brewer, P. B., Dun, E. A., Ferguson, B. J., Rameau, C., & Beveridge, C. A. (2009). Strigolactone acts downstream of auxin to regulate bud outgrowth in pea and arabidopsis. *Plant Physiology, 150*, 482-493. https://doi.org/10.1104/pp.108.134783

Christmann, A., Moes, D., Himmelbach, A., Yang, Y., Tang, Y., & Grill, E. (2006). Integration of abscisic acid signalling into plant responses. *Plant Biology, 8*, 314-325. https://doi.org/10.3390/plants8120592

Crawford, S., Shinohara, N., Sieberer, T., Williamson, L., George, G., Hepworth, J., & Leyser, O. (2010). Strigolactones enhance competition between shoot branches by dampening auxin transport. *Development, 137*, 2905-2913. https://doi.org/10.1242/dev.051987

Cuartero, J., Bolarín, M. C., Asíns, M. J., & Moreno, V. (2006). Increasing salt tolerance in the tomato. *Journal of Experimental Botany, 57*, 1045-1058. https://doi.org/10.1093/jxb/erj102

Çelik, S. (2011). Ampelology. Namık Kemal University, Faculty of Agriculture, Department of Horticulture, Tekirdağ/TURKEY, 1, p. 428.

Dierck, R., Dhooghe, E., Huylenbroeck, J. V., De Riek, Jan., De Keyser, E., & Van Der Straeten, D. (2016). Response to strigolactone treatment in *Chrysanthemum* axillary buds is influenced by auxin transport inhibition and sucrose availability. *Acta Physiologia Plantarum, 38*, 271. https://doi.org/10.1007/s11738-016-2292-6

Einav, M. G., Lekkala, S. P., Resnick, N., Wininger, S., Bhattacharya, C., Lemcoff, J. H., Kapulnik, Y., & Koltai, H. (2010). Strigolactones are positive regulators of light-arvesting genes in tomato. *Journal of Experimental Botany, 61*(11), 3129-3136. https://doi.org/10.1093/jxb/erq138

Esteban, M. A., Villanueva, M. J., & Lissarrague, J. R. (2001). Effect of irrigation on changes in the anthocyanin composition of the skin of cv. Tempranillo (*Vitis vinifera* L.) grape berries during ripening. *Journal of the Science of Food and Agriculture, 81*(4), 409-420. https://doi.org/10.1002/1097-0010(200103)81:4<409:AID-JSFA830>3.0.CO;2-H

Evelin, H., Kapoor, R., & Giri, B. (2009). Arbuscular mycorrhizal fungi in alleviation of salt stress: A review. *Annual Botany, 104*, 1263-1280. https://doi.org/10.1093/aob/mcp251

Foo, E., & Reid, J. B. (2012). Strigolactones: New physiological roles for an ancient signal. *Journal of Plant Growth Regulation*, *32*(2), 429-442. https://doi.org/10.1007/s00344-012-9304-6

Foo, E. (2013). Auxin influences strigolactones in pea mycorrhizal symbiosis. *Journal of Plant Physiology, 170*, 523-528. https://doi.org/10.1016/j.jplph.2012.11.002

German, J. B., & Walzem, R. L. (2000). The health benefits of wine. *Annual Review of Nutrition, 20*(1), 561-593. https://doi.org/10.1146/annurev.nutr.20.1.561

Golldack, D., Luking, I., & Yang, O. (2011). Plant tolerance to drought and salinity: Stress regulating transcription factors and their functional significance in the cellular transcriptional network. *Plant Cell Reports, 30*(8), 1383-1391. https://doi.org/10.1007/s00299-011-1068-0

Gomes, T., Caponio, F., & Alloggio, V. (1999). Phenolic compounds of virgin olive oil: Influence of paste preperation techniques. *Food Chemistry, 64*, 203-209. https://doi.org/10.1016/S0308-8146(98)00146-0

Gomez Roldan, V., Fermas, S., Brewer, P. B., Puech Pages, V., Dun, E. A., Pillot, J. P., Letisse, F., Matusova, R., Danoun, S., Portais, J. C., Bouwmeester, H., Bécard, G., Beveridge, C. A., Rameau, C., & Rochange, S. F. (2008). Strigolactone inhibition of shoot branching. Nature, *455*, 189-194. https://doi.org/10.1038/nature07271

Grimes, D. W., & Williams, L. E. (1990). Irrigation effects on plant water relations and productivity of Thompson Seedless grapevines. *Crop Science, 30*(2), 255-260. https://doi.org/10.2135/cropsci1990.0011183X003000020003x

Ha, C. V., Leyva Gonzalez, M. A., Osakabe, Y., Tran, U. T., Nishiyama, R., Watanabe, Y., Tanaka, M., Seki, M., Yamaguchi, S., Dong, N. V., Yamaguchi Shinozaki, K., Shinozaki, K., Herrera Estrella, L., & Tran, L. S. (2014). Positive regulatory role of strigolactone in plant responses to drought and salt stress. *Proceeding National Academy of Science* USA, *14*(111), 851-856. https://doi.org/10.1073/pnas.1322135111

Kapulnik, Y., & Koltai, H. (2014). Strigolactone involvement in root development, response to abiotic stress and interactions with the biotic soil environment. *Plant Physiology, 166,* 560-569. https://doi.org/10.1104/pp.114.244939

Kennedy, J. A., Matthews, M. A., & Waterhouse, A. L. (2000). Changes in grape seed polyphenols during fruit ripening. *Phytochemistry, 55*(1), 77-85. https://doi.org/10.1016/s0031-9422(00)00196-5

Liu, J., Mehdi, S., Topping, J., Friml, J., & Lindsey, K. (2013). Interaction of PLS and PIN and hormonal crosstalk in Arabidopsis root development. *Frontiers in Plant Science*, *4*(75), 1-8. https://doi.org/10.3389/fpls.2013.00075

Lopez Obando, M., Ligerot, Y., Bonhomme, S., Boyer, F. D., & Rameau, C. (2015). Strigolactone biosynthesis and signaling in plant development. *Development, 142*(21), 3615-3619. https://doi.org/10.1242/dev.120006

Lopez Raez, J. A., Kohlen, W., Charnikhova, T., Mulder, P., Undas, A. K., Sergeant, M. J., Verstappen, F., Bugg, T. D., Thompson, A. J., Ruyter Spira, C., & Bouwmeester, H. (2010). Does abscisic acid affect strigolactone biosynthesis? *New Phytologist, 187*, 343-354. https://doi.org/10.1111/j.1469-8137.2010.03291.x

Mahajan, S., & Tuteja, N. (2005). Cold, salinity and drought stresses: An overview. *Archives of Biochemistry and Biophysics, 444*(2), 139-158. https://doi.org/10.1016/j.abb.2005.10.018

Matusova, R., Rani, K., Verstappen, F. W. A., Franssen, M. C. R., Beale, M. H., & Bouwmeester, H. J. (2005). The strigolactone germination stimulants of the plant-parasitic Striga and Orobanche spp. are derived from the carotenoid pathway. *Plant Physiology, 139*, 920-934. https://doi.org/10.1104/pp.105.061382

Messing, S. A. J., Gabelli, S. B., Echeverria, I., Vogel, J. T., Guan, J. C., Tan, B. C., Klee, H. J., Mc Carty, D. R., & Amzel, L. M. (2010). Structural insights into maize viviparous14, a key enzyme in the biosynthesis of the phytohormone abscisic acid. *Plant Cell, 22*, 2970-2980. https://doi.org/10.1105/tpc.110.074815

Middleton, E., Kandaswami, C., & Theoharides, T. C. (2000). The effects of plant flavonoids on mammalian cells: Implications for inflammation, heart disease, and cancer. *Pharmacological Reviews, 52*(4), 673-751.

Murashige, T., & Skoog, F. (1962). A revised medium for rapid growth and bioassays with tobacco tissue cultures. *Physiologia Plantarum, 15*(3), 472-497. https://doi.org/10.1111/j.1399-3054.1962.tb08052.x

Özcan, M. E., Güleç, M., Özerol, E., Polat, R., & Akyol, O. (2004). Antioxidant enzyme activities and oxidative stress in affective disordes. *International Clinical Psychopharmacology, 19*, 89-95. https://doi.org/10.1097/00004850-200403000-00006

Perez Torres, C. A., Lopez Bucio, J., Cruz Ramirez, A., Ibarra Laclette, E., Dharmasiri, S., Estelle, M., & Herrera Estrella, L. (2008). Phosphate availability alters lateral root development in arabidopsis by modulating auxin sensitivity via a mechanism involving the TIR1 auxin receptor. *Plant Cell, 20*(12), 3258-3272. https://doi.org/10.1105/tpc.108.058719

Pezzuto, J. M. (2008). Grapes and human health: A perspective. *Journal of Agricultural and Food Chemistry, 56*(16), 6777-6784. https://doi.org/10.1021/jf800898p

Pollock, C. B., Koltai, H., Kapulnik, Y., Prandi, C., & Yarden, R. I. (2012). Strigolactones: A novel class of phytohormones that inhibit the growth and survival of breast cancer cells and breast cancer stem-like enriched mammosphere cells. *Breast Cancer Research and Treatment*, 134, 1041-1055. https://doi.org/10.1007/s10549-012-1992-x

Roumeliotis, E., Kloosterman, B., Oortwijn, M., Kohlen, W., Bouwmeester, H. J., Visser, R. G. F., & Bachem, C. W. (2012). The effects of auxin and strigolactones on tuber initiation and stolon architecture in potato. *Journal of Experimental Botany, 63*, 4539-4547. https://doi.org/10.1093/jxb/ers132

Ruyter-Spira, C., Kohlen, W., Charnikhova, T., Van Zeijl, A., Van Bezouwen, L., De Ruijter, N., Cardoso, C., Lopez Raez, J. A., Matusova, R., Bours, R., Verstappen, F., & Bouwmeester, H. (2011). Physiological effects of the synthetic strigolactone analog GR24 on root system architecture in arabidopsis: Another below ground role for strigolactones? *Plant Physiology, 155*, 721-734. https://doi.org/10.1104/pp.110.166645

Sanan Mishra, N., Pham, X. H., Sopory, S. K., & Tuteja, N. (2005). Pea DNA helicase 45 over expression in tobacco confers high salinity tolerance without affecting yield. *Proceeding of the National Academy of Science* USA, *102*, 509-514. https://doi.org/10.1073/pnas.0406485102

Santner, A., & Estelle, M. (2009). Recent advances and emerging trends in plant hormone signaling. *Nature, 459*, 1071-1078. https://doi.org/10.1038/nature08122

Sedaghat, M., Tahmasebi Sarvestani, Z., Emam, Y., Mokhtassi Bidgoli, A. (2017). Physiological and antioxidant responses of winter wheat cultivars to strigolactone and salicylic acid in drought. *Plant Physiology and Biochemistry, 119*, 59-69. https://doi.org/10.1016/j.plaphy.2017.08.015

Shea, F., & Watts, C. E. (1939). Dumas method for organic nitrogen. *Industrial Engineering Chemistry and Analytical Edition, 11*, 333-334. https://doi.org/10.1021/ac50134a013

Shinohara, N., Taylor, C., & Leyser, O. (2013). Strigolactone can promote or inhibit shoot branching by triggering rapid depletion of the auxin efflux protein PIN1 from the plasma membrane. *PLOS Biology, 11*, 1-14. https://doi.org/10.1371/journal.pbio.1001474

Smith, S. M. (2014). What are strigolactones and why are they important to plants and soil microbes? *BMC Biology, 12*,19. https://doi.org/10.1186/1741-7007-12-19

Sorefan, K., Booker, J., Haurogne, K., Goussot, M., Bainbridge, K., Foo, E., Chatfield, S., Ward, S., Beveridge, C., Rameau, C., & Leyser, O. (2003). MAX4 and RMS1 are orthologous dioxygenase-like genes that regulate shoot branching in arabidopsis and pea MAX4 and RMS1. *Genes and Development, 17*, 1469-1474. https://doi.org/10.1101/gad.256603

Toh, S., Kamiya, Y., Kawakami, N., Nambara, E., McCourt, P., & Tsuchiya, Y. (2012). Thermo inhibition uncovers a role for strigolactones in *Arabidopsis* seed germination. *Plant and Cell Physiology, 53*, 107-117. https://doi.org/10.1093/pcp/pcr176

Torres Vera, R., Garcia, J. M., Pozo, M., & Lopez Raez, J. A. (2014). Do strigolactones contribute to plant defence? *Molecular Plant Pathology, 15*(2), 211-216. https://doi.org/10.1111/mpp.12074

Umehara, M., Hanada, A., Yoshida, S., Akiyama, K., Arite, T., Takeda Kamiya, N., Magome, H., Kamiya, Y., Shirasu, K., Yoneyama, K., Kyozuka, J., & Yamaguchi, S., 2008. Inhibition of shoot branching by new terpenoid plant hormones. Nature, *455*, 195-200. https://doi.org/10.1038/nature07272

US Environmental Protection Agency Method 3051A (EPA). 1998. Microwave assisted acid digestion of sediments, sludges, soils, and oils.

Van Ha, C., Leyva Gonzálezc, A., Osakabed, Y., Trana, T. U., Nishiyama, R., Watanabea, Y., Tanakae, M., Sekie, M., Yamaguchif, S., Dong, N. V., Yamaguchi Shiozakig, K., Shinozakid, K., & Herrera Estrellac, L. (2014). Positive regulatory role of strigolactone in plant responses to drought and salt stress. *Plant Biology, 111*(2), 851-856. https://doi.org/10.1073/pnas.1322135111

Waldie, T., McCulloch H., & Leyser O. (2014). Strigolactones and the control of plant development : Lessons from shoot branching. *The Plant Journal, 79*, 607-622. https://doi.org/10.1111/tpj.12488

Wang, H., Feng, T., Peng, G. X., Yan, M., Zhou, P., & Tang, X. (2009). Ameliorative effects of brassinosteroid on excess manganese-induced oxidative stress in *Zea mays* L. leaves. *Agricultural Science China, 8*, 1063-1074. https://doi.org/10.1016/S1671-2927(08)60314-4

Wolters, H., & Jurgens, G. (2009). Survival of the flexible: Hormonal growth control and adaptation in plant development. *Nature Reviews Genetics, 10*, 305-317. https://doi.org/10.1038/nrg2558

Xiong, L., Schumaker, K. S., & Zhu, J. K. (2002). Cell signaling during cold, drought and salt stress. *Plant Cell, 14*, S165-S183. https://doi.org/10.1105/tpc.000596

Yarden, R. I., & Pollock, C. B. (2013). Abstract 5575: Strigolactones: A novel class of plant hormones inhibit cancer cell and cancer stem-like cell growth and survival. *Cancer Research, 73*, 8. https://doi.org/10.1158/1538-7445.AM2013-5575

Yoshida, S., Kameoka, H., Tempo, M., Akiyama, K., Umehara, M., Yamaguchi, S., Hayashi, H., Kyozuka, J., & Shirasu, K. (2012). The D3 F-box protein is a key component in host strigolactone responses essential for arbuscular mycorrhizal symbiosis. *New Phytologist, 196*, 1208-1216. https://doi.org/10.1111/j.1469-8137.2012.04339.x

Zhang, Y., Haider, I., Ruyter-Spira, C., & Bouwmeester, J. H. (2013). Strigolactone biosynthesis and biology. *Molecular Microbial Ecology of the Rhizosphere, 1*, 355-371. https://doi.org/10.1002/9781118297674.ch33