

JASMONIC ACID AS GROWTH REGULATOR IN MS MEDIA: A REVIEW

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Abstract

As a natural (PGR), jasmonic acids are found in plants in a wide distribution. The jasmonic acid functions in conjunction with other plant hormones as a component of a complex signalling network rather than alone. They are utilised to elicit a reaction during wounding and are frequently employed for stimulating the formation of secondary metabolites in various in vitro culture systems. The use of jasmonic acid appears to be effective at various stages of the micropropagation system for various species. Jasmonic acids increase the rate of shoot, root, and callus proliferation, as well as the development of microtubers and bulblets. However, there are also reports of adverse effects of jasmonic acids on the health of plant tissues, such as leaf senescence, decreased growth, and impaired somatic embryogenesis. This study provides an overview of the present state of knowledge on the use and characteristics of jasmonates under in vitro circumstances.

Keywords- Cell proliferation, Micropropagation, Organogenesis, Somatic embryogenesis, Abiotic stress

Introduction

Within the plant kingdom, jasmonic acid (JA) is a family of endogenous plant growth regulators (PGRs) that is extensively distributed. JA was first linked to the induction of senescence and the development of microtuber in potato, but more recent research has revealed that JA has special and possibly beneficial qualities that influence plant growth and development when given exogenously. When jasmonic acid was added to the growth media, it had an impact on the vegetative growth of plantlets and encouraged the production of roots in the in vitro cultivated potato explants. Jasmonic acid significantly increased the quantity of plantlets, their root length, and fresh mass in the shoots (Kumlay 2016). Additionally, jasmonic acid can cause plant senescence, leaf abscission, and seed and pollen inhibition. It also limits root development, potato tuberization, and causes cell proliferation in potato tubers. Also, jasmonic acid controls the plant's water supply and is essential for the defensive mechanisms used by plants to fend off viruses and pests (Ružić et al. 2012).

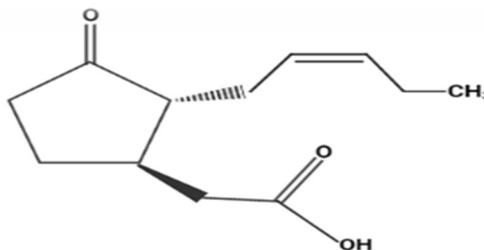


Figure 1 Structure of Jasmonic acid

Jasmonic acid along with its related chemicals, which are strong biological regulators in the plant kingdom, appear to be involved in a variety of morphogenic processes of plants. The ability of JA to affect several facets of plant growth and development has been demonstrated. Jasmonates have vital and noteworthy functions in the regulation of plant morphogenesis, which is mostly governed by the direction and frequency of cell division and growth (Ružić et al. 2012).

Use of jasmonic acid in micro propagation

The basic components of Murashige and Skoog media (MS media) provide the explant with nutrients and energy for its cell growth but the addition of plant growth regulators must be required for the regulation of various developmental processes during micropropagation. The success of micropropagation technique will only depends upon the appropriate selection of plant growth regulators along with their concentration. The auxins and cytokinins are commonly used to organize and regulate the growth and development of explant. Generally, the auxin regulates the cell division and the cytokinin regulates the cell differentiation process (Kaminska 2021). But also some more components like gibberellins, ethylene, salicylic acid, brassinosteroids, abscisic acid and jasmonates affects the plant tissue culture (Phillips and Garda 2019).

Jasmonic acids applied exogenously to plants can have an impact on a wide range of physiological and morphological responses. As with other growth regulators, jasmonates participate in a complex network of signalling interactions including several signalling pathways of plant hormones (Yang et al. 2019). Numerous investigations carried out under various in vitro circumstances have demonstrated that exogenous jasmonic acid hinder plant development by stifling cell proliferation and expansion. It was observed that changes in the level of endogenous cytokinins, which affect and regulate the cell cycle, may be the cause of changes in the endogenous JAs-mediated physiological response because high levels of endogenous jasmonic acids were found, particularly in young organs with high rates of cell division (Avalbaev et al. 2016).



Figure 2 Preparation of MS media

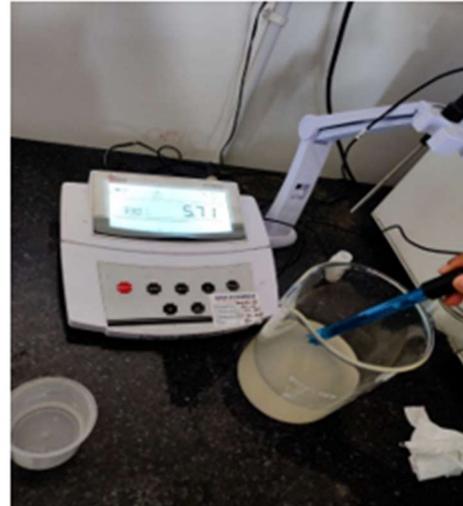


Figure 3 pH adjustment of MS media



Figure 4 Sterilization of media in autoclave at 121⁰ C and 15psi for 15 to 20 minutes



Figure 5 Inoculation of explant on MS media

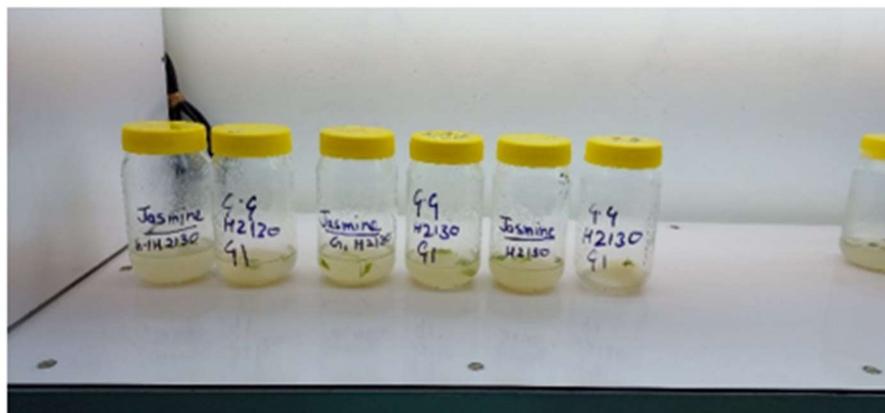


Figure 6 Inoculated explants in the bottles containing MS media

Cell cycle and cell proliferation

One of the earliest known physiological ex vivo effects of JAs was the potted *Vicia faba* pericarp's growth inhibition due to a disruption in the cell cycle. On the basis of this, several research examining the inhibitory effect of jasmonates on the development of plant have also been created in in-vitro circumstances. However, jasmonates treatment causes cells to be reprogrammed due to the activation of certain transcription factors and proteins. Methyl jasmonate was shown to largely activate the expression of various genes that are involved in jasmonate production; therefore, later phases of the cell cycle saw a suppression in the expression of genes which stimulate JA synthesis (Gumerova et al. 2015).

Reactive oxygen species (ROS), which are produced by cell-wall class III peroxidases from hydrogen peroxide, polymerize into lignin, and it has been observed that methyl jasmonates elicitation enhances the concentration of these compounds in *Arabidopsis thaliana*. JA also promotes the production and activity of peroxidase. Due to an increase in the cross-linking of the major components of the cell wall, these alterations in response to jasmonates are connected to a stop of growth and a reduction in cell expansion (Napoleao et al. 2017 and Hyde et al. 2018). It is quite complicated how oxidative stress and jasmonates are related. According to the theory, JAs showed both pro- and anti-oxidative action by directly altering the structure of superoxide dismutase (SOD) at a certain concentration (Ho et al. 2020). For plants to respond to parasite infection, the JA-dependent regeneration network is crucial (Zhou et al. 2019).

The ester derivative of jasmonic acid added had an impact on callus development as well. Methyl Jasmonate (MeJA) enhanced the rate of callus formation in *Dianthus caryophyllus* leaf explants when coupled with 2,4-dichlorophenoxyacetic (2,4-D) and kinetin (Matter et al., 2017). MeJA in MS medium with BA and NAA at even a ten-fold greater concentration boosted the fresh and also the dry weight of callus of *Catharanthus roseus* (Al-Zuhairi and Ghanm 2017). The action of JAs may also be influenced by the stage of plant development. The early phases of pulp formation in *Malus pumila* planted in open field have a high endogenous level of JA, hence the effect of exogenous JA under in vitro circumstances differed across samples from ex vivo plants taken on different days after full bloom (DAFB).

Organogenesis

According to an analysis of addition of JAs during micro-propagation of a plant, these substances exhibit a range of actions, either encouraging or inhibiting. For e.g. JA at concentrations of 0.5 to 2.0 μM enhanced the number of nodes, leaves, and roots in the nodes of the stem of *S. tuberosum* grown on MS media and decreased the time required for shoot initiation (Kumlay 2016). Also, with increasing concentrations of jasmonic acid in MS media, the development of the *Oryza sativa* seedling was subsequently suppressed. Even in the presence of 1 μM JA, root growth was reduced by twice compared to the control. As was seen, the function of JAs appears to depend on the species and the circumstances (Lakehal and Bellini 2018). In most cases, it is assumed that JA promotes defence and that GA favours expansion. Plant growth inhibition brought on by JA therapy is likely due to the suppression of the GA-mediated pathway (Nguyen et al. 2019).

Proliferation of shoots and the growth of above ground parts

Development and proliferation cytokinins are essential for the shoot induction process. It was shown that exogenous JA altered the ratio between physiologically active and inactive cytokinins in *S. tuberosum* stem node cells without altering the overall amount. Conversely, the treatment of seedlings of *Triticum aestivum* with MeJA displayed a two times increase in cytokinin accumulation without altering levels of Abscisic acid (ABA) and auxins (Avalbaev et al. 2016). When cytokinin-induced plant growth was observed in *A. thaliana* and *O. sativa* as lower biomass, JAs were thought to be inhibitors (Yang et al. 2012 and Hibara et al. 2016).

Additionally, it was revealed that methyl jasmonate boosted cytokinin accumulation despite the antagonistic relationship between jasmonic acid and cytokinin observed in *A. thaliana*'s xylem growth (Jang et al. 2017). The addition of 1–10 μM jasmonic acid to MS medium supplemented with 6-benzylaminopurine (BA), Indole-3-butyric acid (IBA), or 1-naphthaleneacetic acid (NAA) boosted leaf growth and the fresh and dry weight of the shoots in *Pyrus communis* and *P. cerasus* and *P. canescens* (Ružić et al. 2013). On MS medium supplemented with PGRs, *Ziziphora persica* multiplied shoots showed the reverse effect, where methyl jasmonate lowered shoot proliferation rate but increased its elongation (Zare-Hassani et al. 2019).

Rooting of plantlets

Auxins, particularly indole-3-butyric acid and indole-3-acetic acid, are the most crucial PGRs during the rooting process of in vitro produced shoots. The conversion of IBA to IAA in Nitric oxide-mediated (NO) activation of JA biosynthesis genes may promote increased endogenous JA accumulation during adventitious root development (Fattorini et al. 2017). Methyl jasmonate functions during the dedifferentiation phase by making the founder cells more susceptible to auxin, which causes them to divide, and the descendant cells to become more determined to produce roots in response to the auxin signal. Also, it has been shown that JA and auxins inhibit root development (Yang et al. 2019). *A. thaliana*'s cytokinin-dependent pathway is involved in the JA-induced inhibition of adventitious root initiation (Lakehal et al. 2020). Auxin reduces the level of free JA while increasing the efficiency of JA conjugation. This auxin-JA interaction backs up the idea that in *Arabidopsis hypocotyls*, the JA signalling pathway negatively controls adventitious roots (Gutierrez et al. 2012). Other research showed that JAs restrict

elongation of primary root but stimulate lateral roots development, and it was found that methyl jasmonate needs IAA biosynthesis to do this (Lakehal and Bellini 2018). Additionally, it was believed that JAs and cytokinins work together to prevent the onset of adventitious roots development in *Arabidopsis* under persistent red light circumstances, suggesting that JAs' influence on adventitious roots formation may be influenced by the lighting environment during culture (Lakehal et al. 2020).

Somatic embryogenesis

A competent cell or cell group will go through biochemical and molecular changes during somatic embryogenesis, which is a developmental process that results in the production of a somatic embryo. Somatic embryos have two polar structures, each with its own meristem: an apical pole (the future shoot) and a basal pole (the future root) (Horstman et al. 2017). Due to the low incidence of chimeras, the high number of regenerants, and the low amount of somatic diversity, this regeneration strategy is chosen over organogenesis (Carra et al. 2019).

Somatic embryogenesis consists of two steps in *Arabidopsis*. Early cotyledonary zygotic embryos are grown on auxin-supplemented media in the first step to promote the development of embryogenic tissue. The elimination of auxins from the media in the following stage stimulates the development of the somatic embryos. JA is a crucial element in the pathway controlling embryogenesis, together with phytoglobin 2 (PGB2), NO, and a number of JA-responsive intermediates (Mira et al. 2016). Also, the exogenous methyl jasmonate caused changes in endogenous hormone levels that, when cells are transferred to hormone-free media, inhibit the embryogenesis process from being activated (Gumerova et al. 2015).

Formation of microtubers and bulbets

Due to the genetic purity, propagating some species by bulblets or microtubers has proven to be more successful. Sucrose levels, photoperiods, and plant growth regulators, as well as biochemical and genetic variables, may all have an impact on the development of these two storage organs in vitro (Gheisari and Miri 2017). There are a number of phytohormones linked to the tuberization processes. GA₃, which controls the shift in the orientation of cell growth from longitudinal to radial swelling of the tip of the stolon, was given a prominent significance which is the typical stage of formation of tubers (Hannapel et al. 2017).

With the beginning of creation of storage organs, jasmonic acid also cause modifications to cell division characterised by reorientation of cortical microtubule and radial expansion direction. JAs indirectly governs the tuberization by interacting with gibberellic acid signals (Siddiqi and Husen 2019). However, tuberous root growth was impeded by higher jasmonic acid accumulation in *Manihot esculenta* pretuberous roots that were grown in the field. The variations between potato (i.e. stem tuber) and cassava (i.e. root tuber) and the differing effects of jasmonates on cell processes in tissues that differ, for example, in sensitivity to this plant hormone and endogenous levels of other plant growth regulators, could account for these inconsistencies (Utsumi et al. 2020). Other PGRs e.g. cytokinins have been shown to counteract the effect of jasmonates on growth of microtuber in *S. tuberosum* microtuber after induction. Cultivars that are developed commercially can also be grown using other vegetative tissue, like bulbs. Scales have traditionally

been used to produce bulbs for a very long time. Although small scale-explants are employed under in vitro conditions and scales that have been removed from new bulblets can be used as beginning material, micropropagation is similar to scaling and propagation cycles can be carried out a few times per year (Askari et al. 2018).

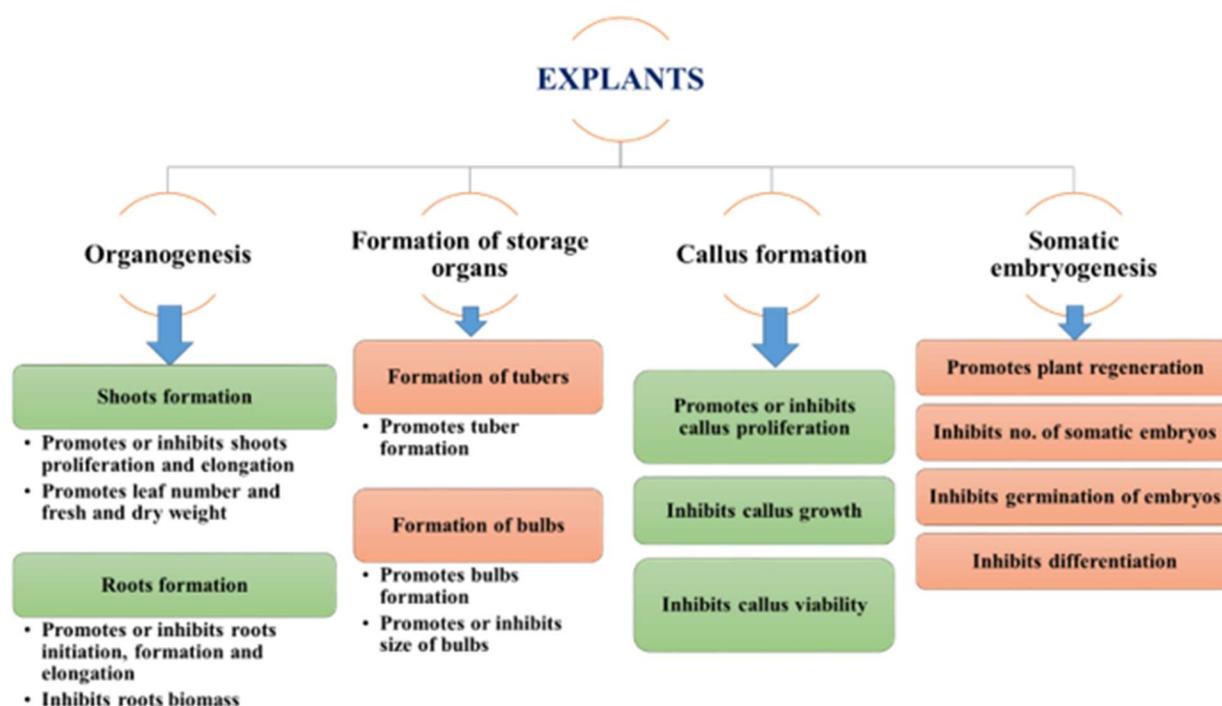


Figure 7 Illustration on impacts of exogenous application of jasmonic acid on explant

JAs as a stimulator of secondary metabolism

In several plant in vitro cultures, JAs have been extensively employed as elicitors to trigger the formation of secondary metabolites. Decreased explant development was frequently correlated with increased secondary metabolite build up. The use of JA on the hairy roots of *Calendula officinalis* resulted in a small reduction in the development of the explants but increased release of oleanolic acid glycosides in the media (Alsoufi et al. 2019). For *C. asiatica*, a comparable connection was reported.

MeJA suppressed the growth of shoot, callus, and cell suspension cultures while simultaneously promoting the production of asiaticoside in shoot and callus cultures, and asiatic acid in callus cultures (Krishnan et al. 2019). The treatment of *Ajuga bracteosa* adventitious roots with NAA and MeJA increased total phenolic content and maximal dry biomass formation (Saeed et al. 2017). As with other growth regulators, the effectiveness of jasmonates is solely dependent on the concentration being employed. MeJA treatment of *Vitis vinifera* revealed that 100 μM and 50 μM concentrations, respectively, increased and decreased the biomass of hairy roots and the secretion of resveratrol into the culture medium (Hoseinpanahi et al. 2020).

JAs under stress conditions

On the impact of JAs on in vitro cultured plant tissue under stress circumstances, there are a few research published. In tests using foliar jasmonic acid spray in pots and fields, much more observations and conclusions were produced e.g. under stress due to salinity (Taheri et al., 2020), drought (Tayyab et al. 2020), heavy metal (Ali et al. 2018), heat (Lee et al. 2019), cold (Ghanbari et al. 2018) and biotic factors (Burdziej et al. 2021). Plant output, growth, and stress response were all controlled by endogenous jasmonic acids and to fight against abiotic stress, jasmonic is employed (Per et al. 2018). In response to methyl jasmonate and jasmonic acid, improved explant development under water stress was seen for *M. acuminata* along with *Fragaria x ananassa*. Increased Peroxidase and Superoxide dismutase (POD and SOD) enzyme activity may be associated with JAs protective effects via reducing oxidative stress (Yosefi et al. 2020). JAs had inconsistent effects on *Verbascum nudicuale* seedlings at much higher concentrations (Ghasemlou et al. 2019). The main player in the physiological process of drought avoidance, tolerance, and resistance is ABA. The targets of JA and ABA in a signalling cascade connected to drought appear to be similar. During a cold stress, the relationship between these two plant hormones was also revealed (Wang et al. 2016).

Conclusion

It is well known that jasmonates are strong biological regulators in the kingdom of plants, acting in a variety of capacities. Exogenous jasmonates can have either promoting or inhibiting effects. Under both ideal and stressful environments, jasmonates can have different effects on explant's growth and development. Further thorough studies are required to establish the processes that govern how jasmonic acid affects the plant physiologically. It is clear that JA is crucial in the production of a secondary metabolite and is best investigated as an elicitor. It is currently unclear how exactly JAs contribute to the development of a whole plant or of explants. For the effectiveness of shoot proliferation, rooting, and embryogenesis in many species, the interactions between JAs and other phytohormones, particularly auxins, cytokinins and gibberellins, appear to be critical. Understanding how jasmonic acid works in explants would be helpful for species with poor propagation and mass-propagation systems.

References

- Ali, E., Hussain, N., Shamsi, I.H., Jabeen, Z., Siddiqui, M.H., Jiang, L.X., 2018. Role of jasmonic acid in improving tolerance of rapeseed (*Brassica napus* L.) to Cd toxicity. *J Zhejiang Univ Sci B* 19: 130–146. <https://doi.org/10.1631/jzus.B1700191>.
- Alsoufi, A.S.M., Pączkowski, C., Szakiel, A., Długosz, M., 2019. Effect of jasmonic acid and chitosan on triterpenoid production in *Calendula officinalis* hairy root culture. *Phytochem Lett* 31: 5–11. <https://doi.org/10.1016/j.phytol.2019.02.030>.
- Al-Zuhairi, E.M.A., Ghanm, N.S., 2017. Effect of jasmonic acid (JA) and glutamine on callus induction of Madagascar periwinkle plant (*Catharanthus roseus* L. cv. Nirvana Pink Blush) by in

- vitro culture. *Int J Curr Microbiol App Sci* 6(5):1415–1422. <https://doi.org/10.20546/ijcmas.2017.605.154>.
- Askari, N., Visser, R.G.F., De Klerk, G.J., 2018. Growth of lily bulblets in vitro, a review. *Int J Hort Sci Technol* 5: 133–143. <https://doi.org/10.22059/IJHST.2018.268870.263>.
- Avalbaev, A., Yuldashev, R., Fedorova, K., Somov, K., Vysotskaya, L., Allagulova, C., Shakirova, F., 2016. Exogenous methyl jasmonate regulates cytokinin content by modulating cytokinin oxidase activity in wheat seedlings under salinity. *J Plant Physiol* 191: 101–110. <https://doi.org/10.1016/j.jplph.2015.11.013>.
- Burdziej, A., Bellée, A., Bodin, E., Fonayet, J.V., Magnin, N., Szakiel, A., Richard, T., Cluzet, S., Corio-Costet, M.F., 2021. Three types of elicitors induce grapevine resistance against downy mildew via common and specific immune responses. *J Agric Food Chem* 69: 1781–1795. <https://doi.org/10.1021/acs.jafc.0c06103>.
- Carra, A., Carimi, F., Bettoni, J. C., Pathirana, R., 2019. Progress and challenges in the application of synthetic seed technology for ex situ germplasm conservation in grapevine (*Vitis* spp.). *Synthetic Seeds* 439-467. https://doi.org/10.1007/978-3-030-24631-0_21.
- Fattorini, L., Veloccia, A., Rovere, F.D., D, Angeli, S., Falasca, G., Altamura, M.M., 2017. Indole-3-butyric acid promotes adventitious rooting in *Arabidopsis thaliana* thin cell layers by conversion into indole-3-acetic acid and stimulation of anthranilate synthase activity. *BMC Plant Biol* 17: 121. <https://doi.org/10.1186/s12870-017-1071-x>.
- Ghanbari, F., Fatahi, S., Mohammadi, M., Shayan, A.A., 2018. Improvement of tolerance to chilling in watermelon seedlings with methyl jasmonates and methyl salicylate. *Thai J Agric Sci* 51: 1–9.
- Ghasemlou, F., Amiri, H., Karamian, R., Mirzaie-asi, A., 2019. Alleviation of the effects of drought stress *Verbascum nudicuale* by methyl jasmonate and titanium dioxide nanoparticles. *Iran J Plant Physiol* 9: 2911–2920. <https://doi.org/10.22034/IJPP.2019.668857>.
- Gheisari, M., Miri, S.M., 2017. In vitro callus induction and bulblet regeneration of hyacinth (*Hyacinthus orientalis* L.). *Plant Cell Biotechnol Mol Biol* 18: 145–155
- Gumerova, E.A., Akulov, A.N., Rummyantseva, N.I., 2015. Effect of methyl jasmonate on growth characteristics and accumulation of phenolic compounds in suspension culture of tartary buckwheat. *Russ J Plant Physiol* 62: 195–203. <https://doi.org/10.1134/S1021443715020077>.
- Hannapel, D.J., Sharma, P., Lin, T., Banerjee, A.K., 2017. The multiple signals that control tuber formation. *Plant Physiol* 174: 845–856. <https://doi.org/10.1104/pp.17.00272>.
- Hibara, K., Isono, M., Mimura, M., Sentoku, N., Kojima, M., Sakakibara, H., Kitomi, Y., Yoshikawa, T., Itoh, J., Nagato, Y., 2016. Jasmonate regulates juvenile-to-adult phase transition in rice. *Development* 143: 3407–3416. <https://doi.org/10.1242/dev.138602>.
- Ho, T.T., Murthy, H.N., Park, S.Y., 2020. Methyl jasmonate induced oxidative stress and accumulation of secondary metabolites in plant cell and organ cultures. *Int J Mol Sci* 21: 716. <https://doi.org/10.3390/ijms20102525>.
- Horstman, A., Bemmer, M., Boutilier, K., 2017. A transcriptional view on somatic embryogenesis. *Regeneration* 4: 201–216. <https://doi.org/10.1002/reg2.91>.

- Hoseinpanahi, B., Bahramnejad, B., Majdi, M., Dastan, D., Ashengroph, M., 2020. The effect of different elicitors on hairy root biomass and resveratrol production in wild *Vitis vinifera*. *J Appl Biotechnol Rep* 7: 25–31. <https://doi.org/10.30491/JABR.2020.105915>.
- Hyde, L.S., Pellny, T.K., Freeman, J., Michaelson, L.V., Simister, R., McQueen-Mason, S.J., Mitchell, R.A.C., 2018. Response of cell-wall composition and RNA-seq transcriptome to methyl-jasmonate in *Brachypodium distachyon* callus. *Planta* 248: 1213–1229. <https://doi.org/10.1007/s00425-018-2968-9>.
- Jang, G., Chang, S. H., Um, T. Y., Lee, S., Kim, J. K., Choi, Y.D., 2017. Antagonistic interaction between jasmonic acid and cytokinin in xylem development. *Scientific reports* 7(1): 1-13. <https://doi.org/10.1038/s41598-017-10634-1>.
- Kaminska, M., 2021. Role and activity of jasmonates in plants under in vitro conditions. *Plant Cell, Tissue and Organ Culture (PCTOC)* 146: 425-447. doi:10.1007/s11240-021-02091-6.
- Krishnan, M.L., Roy, A., Bharadvaja, N., 2019. Elicitation effect on the production of asiaticoside and asiatic acid in shoot, callus, and cell suspension culture of *Centella asiatica*. *J App Pharm Sci* 9: 67–74. <https://doi.org/10.7324/JAPS.2019.90609>
- Kumlay, A.M., 2016. The effect of jasmonic acid on the micropropagation of potato (*Solanum tuberosum* L.) under long day conditions. *YYU J Agr Sci* 26: 79–88.
- Lakehal, A., Bellini, C., 2018. Control of adventitious root formation: insights into synergistic and antagonistic hormonal interactions. *Physiol Plant* 165: 90–100. <https://doi.org/10.1111/ppl.12823>.
- Lakehal, A., Dob, A., Rahnesan, Z., Novák, O., Escamez, S., Alallaq, S., Strnad, M., Tuominen, H., Bellini, C., 2020. Ethylene response factor 115 integrates jasmonate and cytokinin signaling machineries to repress adventitious rooting in *Arabidopsis*. *New Phytol* 228: 1611–1626. <https://doi.org/10.1111/nph.16794>.
- Lee, H.J., Lee, J.H., Lee, S.G., An, S., Lee, H.S., C.C.K., Kim, S.K., 2019. Foliar application of biostimulants affects physiological responses and improves heat stress tolerance in Kimchi cabbage. *Hortic Environ Biotechnol* 60: 841–851. <https://doi.org/10.1007/s13580-019-00193-x>.
- Matter, M., Hanafy, M., Aly, U., 2017. Effect of methyl jasmonate and mannitol application on growth and eugenol content incallus cultures of carnation. *Plant Tiss Cult Biotech* 27: 227–240. <https://doi.org/10.3329/ptcb.v27i2.35028>.
- Mira, M.M., Wally, O.S.D., Elhiti, M., El-Shanshory, A., Reddy, D.S., Hill, R.D., Stasolla, C., 2016. Jasmonic acid is a downstream component in the modulation of somatic embryogenesis by *Arabidopsis* class 2 phytoalbumin. *J Exp Bot* 67: 2231–2246. <https://doi.org/10.1093/jxb/erw022>.
- Napoleao, T.A., Soares, G., Vital, C.E., Bastos, C., Castro, R., Loureiro, M.E., Giordano, A., 2017. Methyl jasmonate and salicylic acid are able to modify cell wall but only salicylic acid alters biomass digestibility in the model grass *Brachypodium distachyon*. *Plant Sci* 263: 46–54. <https://doi.org/10.1016/j.plantsci.2017.06.014>.
- Nguyen, H.T., To, H.T.M, Lebrun, M., Bellafiore, S., Champion, A., 2019. Jasmonates – The master regulator of rice development, adaptation and defense. *Plants* 8: 339. <https://doi.org/10.3390/plants8090339>.

- Per, T.S., Khan, M.I.R., Anjum, N.A., Masood, A., Hussain, S.J., Khan, N.A., 2018. Jasmonates in plants under abiotic stresses: crosstalk with other phytohormones matters. *Environmental and Experimental Botany* 145(2): 104–120. doi: 10.016/j.envexpbot.2017.11.004.
- Phillips, G.C., Garda, M., 2019. Plant tissue culture media and practices: an overview. *In Vitro Dev Biol Plant* 55: 242–257. <https://doi.org/10.1007/s11627-019-09983-5>.
- Ruzić, D. J., Vujović, T., Cerović, R., Djordjević, M., 2012. Potential application of jasmonic acid in in vitro rooting of low vigorous pear and cherry rootstocks. In II International Symposium on Horticulture in Europe 1099 (pp. 895-900).
- Siddiqi, K.S., Husen, A., 2019. Plant response to jasmonates: current developments and their role in changing environment. *Bull Nat Res Cent* 43: 153. <https://doi.org/10.1186/s42269-019-0195-6>
- Taheri, Z., Vatankhah, E., Jafarian, V., 2020. Methyl jasmonates improves physiological and biochemical responses of *Anchusa italica* under salinity stress. *S Afr J Bot* 130: 375–382. <https://doi.org/10.1016/j.sajb.2020.01.026>.
- Tayyab, N., Naz, R., Yasmin, H., Nosheen, A., Keyani, R., Sajjad, M., Hassan, M.N., Roberts, T.H., 2020. Combined seed and foliar pre-treatments with exogenous methyl jasmonate and salicylic acid mitigate drought-induced stress in maize. *PLoS ONE* 15(5): e0232269. <https://doi.org/10.1371/journal.pone.0232269>.
- Utsumi, Y., Tanaka, M., Utsumi, C., Takahashi, S., Matsui, A., Fukushima, A., Seki, M., 2020. Integrative omics approaches revealed a crosstalk among phytohormones during tuberous root development in cassava. *Plant Molecular Biology* 1-21.
- Wang, F., Guo, Z., Li, H., Wang, M., Onac, E., Zhou, J., Xia, X., Shi, K., Yu, J., Zhou, Y., 2016, Phytochrome A and B function antagonistically to regulate cold tolerance via abscisic acid-dependent jasmonate signaling. *Plant Physiol* 170 :459–471. <https://doi.org/10.1104/pp.15.01171>.
- Yang, D.L., Yao, J., Mei, C.S., Tong, X.H., Zeng, L.J., Li, Q., Xiao, L.T., Sun, T.P., Li, J.G., Deng, X.W., Lee, C.M., Thomashow, M.F., Yang, Y., He, Z., He, S.Y., 2012. Plant hormone jasmonate prioritizes defense over growth by interfering with gibberellin signaling cascade. *Proc Natl Acad Sci USA* 109: 1192–1200. <https://doi.org/10.1073/pnas.1201616109>.
- Yang, J., Duan, G., Li, C., Liu, L., Han, G., Zhang, Y., Wang, C., 2019. The crosstalks between jasmonic acid and other plant hormone signalling highlight the involvement of jasmonic acid as a core component in plant response to biotic and abiotic stresses. *Front Plant Sci* 10: 1349. <https://doi.org/10.3389/fpls.2019.01349>.
- Yosefi, A., Aa, M., Javadi, T., 2020. Jasmonic acid improved in vitro strawberry (*Fragaria × ananassa* Duch.) resistance to PEG-induced water stress. *Plant Cell Tiss Organ Cult* 142: 549–558. <https://doi.org/10.1007/s11240-020-01880-9>.
- Zare-Hassani, E., Motafakkerzad, R., Razeghi, J., Kosari-Nasab, M., 2019. The effects of methyl jasmonate and salicylic acid on the production of secondary metabolites in organ culture of *Ziziphora persica*. *Plant Cell Tiss Organ Cult* 138: 437–444. <https://doi.org/10.1007/s11240-019-01639-x>.

Zhou, W., Lozano-Torres, J.L., Blilou, I., Zhang, X., Zhai, Q., Smant, G., Li, C., Scheres, B., (2019). A jasmonate signaling network activates root stem cells and promotes regeneration. *Cell* 177: 942–956. <https://doi.org/10.1016/j.cell.2019.03.006>.