Minireview Article

PLANT HORMONES- NATURAL GROWTH REGULATORS

ABSTRACT

Plant hormones ~~or just hormones~~ are compounds that can regulate the overall growth and development of plants and have a great influence throughout the lifecycle.~~ of plants.~~ Various hormones act on the plant at different points of time depending on the vegetative or reproductive state of the plant. The effects of hormones on plants are quite complex to understand and a single plant hormone can have multiple effects on the growth and development of plants. They can help to regulate the homeostasis of plants under stress from both biotic and abiotic factors. Plant hormones have a very complex mode of interaction among themselves and how they influence plant development. There has always been more research done on understanding the individual plant hormone and their mechanism. More recent work focuses ~~more~~ on complex problems like how different hormones work together to regulate the growth of plants.This mini-review article will focus ~~more~~ on the five main hormones, their role in the growth and development of plants and their commercial uses in modern agriculture.

Keywords: *Hormones,Plants, Growth, Development, Natural compounds*

INTRODUCTION

Plant hormones or Phytohormones are organic compounds that regulate the growth of plant structure. These are usually accumulated in small concentrations and are found in all types of plants ranging from lower plants to highly developed plants. Hormones can have different modes of action, some hormones have their site of production as a site of action, and some can have different sites of action (1). These hormones regulate the growth and development of roots, stem, leaves, flower, and fruits. There are many plant hormones but ~~the~~few ~~some of focused~~ hormones such as are auxins, cytokinin, gibberellins, ethylene, and abscisic acid are important for plants. These five hormones are known to control the life cycle of a plant starting from germination to senescence. Some of the recent additions to the list of phytohormones includebrassinosteroids, jasmonates and strigolactones (2). Although the effects of plant hormones are quite complex, a single hormone performs a wide variety of actions with or without combining with different hormones (3).This article and the subsequent paragraphs below mainly focus on the basics of hormones, and how they influence the growth, development and life cycle of a plant.

MAIN HORMONES

Hormones are organic chemicals or compounds released by plants in response to control the physiological process as well as to combat abiotic stress. They can control and coordinate growth, cell development, germination,reproduction, and many more essential functions. Additionally, some hormones are responsible for root production while some of them are responsible for causing the senescence of plants

(4). Auxin is a hormone which is responsible for cell development (5). Cytokinin is a hormone responsible for seed germination (6). Gibberellins are responsible for shoot extension, enhancing leaf growth (7). Ethylene, unlike other hormones, is only one present in the gaseous form. It can act as both a growth promotor and a growth inhibitor depending on the environmental factors (8). Abscisic acid is known to inhibit the growth of plants (4). Some less-researched hormones like Jasmonate and Brassinosteroids also have impacts on the overall growth and development of plants. Jasmonates influence the plant immunity factors. Brassinosteroids are steroidal phytohormones. One of the functions of this hormone is to improve the plant's resistance to sap-feeding insects (9). Plant hormones help the plant to adapt to different environmental stress with the help of complex hormone signalling pathways (10).Plant hormones are now being used in agriculture at a rapid rate to increase crop yields, protect the crop from unfavourable conditions and ripen the fruits (11). Many areas are being studied to understand more about the signalling and stress response of the hormones in plants (12). Cytokinin and auxin in small concentrations can play an important role in tissue culture propagation of plants. With certain combinations of auxins and cytokinins, plants in tissue culture tend to respond in different ways viz.at high auxin and low cytokinin levels the plant will tend to develop more roots, and vice versa athigh cytokinin and low auxinthe plant will tend to develop buds or roots (13). Figure 1 gives a simple classification of plant hormones.

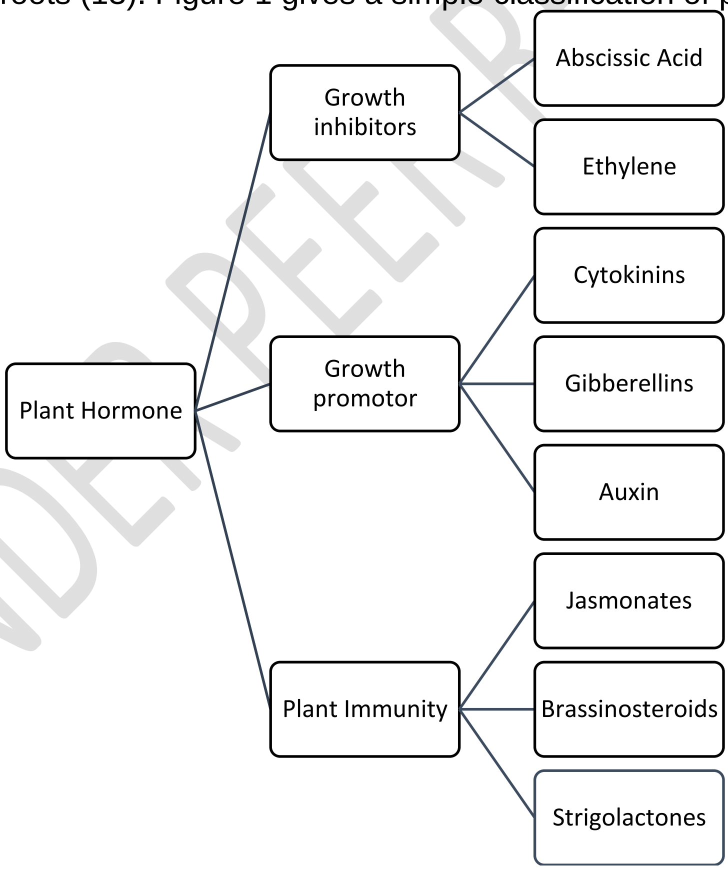

Figure 1: Classification of Plant Hormones based on their role in plant growth and development.

AUXINS

Auxin is a type of hormone which is required for cell division. Naturally found auxins in different plants playvarious important roles in some specific developmental and cellular developments. Auxin is found in the radicle and plumule of seedlings. Auxin is synthesised in plant shoots and roots thus it helps to develop early roots (14). Some most common auxin types are indole-3-acetic acid (IAA), Indole-3-pyruvic acid (IPyA), indole-3-acetaldoxime (IAOx), indole-3-acetonitrile (IAN), indole-3-acetamide (IAM), and indole-3-acetaldehyde (IAAld). Furthermore, studies on auxins have helped develop synthetic auxins and help us understand how hormone plays an important role in the development of plants (15). In modern days, synthetic auxins are produced and widely used as agrochemicals (16).Auxins are also responsible for tropism in plants. It is caused by the redistribution of auxin across the tissues because of light stimulations. This helps to increase the height of the shoot (17). Auxin plays a crucial role in maintaining the plant in environmental stress. Undergoing further investigation, it was observed that they also help to maintain the homeostasis of plants. Although it is believed that auxins are not required for germination, it is necessary for the growth of young seedlings (18). It is also seen that there are some response factors released by auxins that produce mRNA which shows important effects on several factors like plant growth, hormonal signalling, homeostasis and response to environmental stress and nutritional alterations (19). Auxins have been successfully used in modern agriculture for more than 60 years. It is used as an herbicide to control grass weeds (20). Synthetic auxins are mainly used to control broad-leaf weeds in small grain crops like wheat and are also sometimes used to control sedge species. Some of the most commonly used synthetic auxins are 2,4-dichloro phenoxy acetic acid (2,4D) and dicamba (21) to control weeds. Auxincan also be used to control dormancy in seeds and tubers. It can inhibit the germination of seeds;hence the seeds can be stored for a longer time. Potatoes can be stored for 3 years by using auxin. Auxins are known to produce root exudate (22). Auxin plays a crucial role in promoting root growth in plants that can be reproduced through stem cuttings like rose, lemon, bougainvillaea etc.(23). Regular application of synthetic auxins in fruiting plants can have a huge impact on overall yield as it can reduce the production of an abscission layer on a fruit preventing premature dropping of fruit (24).

CYTOKININ

Cytokinin was first discovered ~~in 1955~~ by Miller et al. (1955) and has the ability to enhance plant cell division. Cytokinin is a type of plant hormone that helps regulate a range of functions like cell division, seed germination and many more. The first naturally occurring cytokinin, Zeatin, was isolated from maize seeds in 1964. Cytokininis richly found in liquid endosperm ~~like one~~in coconut (26). It is seen to influence the activities of nitrogen-fixing bacteria in soil (27). Cytokinin mainly is found in development areas in aerial and underground organs of plants. It also helps in controlling the plant response to lighting conditions, stress and nutrition availability thus helping plants to grow in a refined way (28). Cytokinins are usually transported to different locations from their site of production through passive diffusion to the site of action and by the active transport mechanism.One of the roles of cytokinin in the early stages of seedlings is to reprogram the cell life and induce somatic cell production (29). Some of the most recent studies on cytokinin involve understanding to role of cytokinin signalling in plant growth (30). Cytokines are transported from shoot to root through phloem and if produced by root then the xylem is used to transport it to shoot (31). Cytokinin can enhance seed germination if germinated under stress like salinity, heavy metals, etc (32). Cytokinin is believed to control leaf size by manipulating cell division and cell development (33). Cytokinin can both preventand speed up the course of abscission in leaves (34). In recent times there has been a lot of research done on apples to conduct tissue culture and develop a standard protocol. Cytokinin is widely reported to be used for a variety of things in horticultural fruit crops around the world (35).It has also been seen that cytokinins have an effect on fruit softness (36).

	Functions					
Hormones	Cell elongation	Cell division & growth	Seed germination	Fruit ripening	Seed dormancy	Abscission
Auxin	✓	✓	✗	✗	✗	✗
Gibberellin	✓	✓	✓	✗	✗	✗
Cytokinin	✗	✓	✗	✗	✗	✗
Ethylene	✗	✗	✗	✓	✗	✗
Abscisic Acid	✗	✗	✗	✗	✓	✓

c

Figure 2: Overview of the role of five main plant hormones in various stages of a plant's life cycle.

GIBBERELLINS

Gibberellins is a type of plant hormone that induces high vigour in plants. It was first discovered by Takahashi in 1998 when the rice had a disease named Bakanae disease. This disease caused rice to grow unusually tall and it lacked blooming, and no flowers were formed. By 2023, nearly 100 different kinds of gibberellins have been discovered and are designated as GA1,GA2,GA3……GA10, etc (37). Gibberellins are known to induce height in plants thus they can help to increase the height of dwarfsand cancel genetic dwarfism (38). It is also seen that GA3 can encourage germination in seeds, and it is one of the reasons for the bolting of plants as it elongates the plant internodes (39). Some crops like cucumber, eggplant, and other crops, when given doses of gibberellins can produce parthenocarpy fruits (4). Some work on the transport mechanism has been done and it was found that it uses phloem as its carrier (40). It has also been seen that GAs can move inside the plant in both the direction i.e., from root to shoot and from shoot to root. This movement is important for several important functions (41). The discovery of GA import transporters has been confirmed ~~and this confirms~~ the active regulated mechanism of transport of GA throughout the plant (42).Flowering plants are frequently used to understand the mechanism that is involved in regulating the movement of concentrated GA (43). Excess of gibberellins can cause a plant to bolt resulting in early flowering and this can be used to induce flower production in horticultural and floricultural plants (44). This process can be used to get early seeds in some species of plants like onion and mustard. Sometimes this bolting can also cause poor nutritional values incertain root crops like carrots and radish because of early flower production (45). Gibberellins are 500 times better in inducing parthenocarpy in comparison to auxins. Gibberellins can increase the bud size of tea and other essential amino acids in tea plants (46). When GA3 is applied to certain fruits like berries and grapes, it is seen that it can reduce the compactness of the fruit and elongate the size of the bunch. Also, it was discovered that it had an impact on reducing sugars, and other amino acids like tannin in fruits, overall influencing the quality and quantity of the fruit (47). Gibberellins can also delay in ripening of certain fruits like strawberries, pears and tomatoes (46). Applications of GA3 on leaves of soybeans can increase the internodal length of shoots. Also, it can influence the pith of the xylem and phloem (48).

ETHYLENE

Ethylene is the only hormone that is in gaseous form and is known to regulate numerous functions in plants such as ~~like response to~~ biotic and abiotic stress. It is well-known as an indicator of the final stages of plants thus inducting the senescence of the plant (49). Ethylene is also known to regulate some of the important plant growth stages. It also has positive effects on horticultural crops and fruits by helping them to ripen. In leafy green, ethylene in old leaves can indicate disease thus leading it to decrease its nutritional and visual quality (50). Because of its gaseous nature, it is easy for the hormone to move freely thus it is usually synthesised near the site of action (51). Ethylene also influences a lot of different aspects of vegetative growth like leaf emergence, but the effects are mostly suppressed when it comes to leaf expansion (52,53). Ethylene along with jasmonates, salicylate and abscisic acid plays an important role in coping with the stress caused by biotic and abiotic factors (53). Ethylene has been widely used in the fruit ripening industry and ornamental flower industry. Tomato is one of the best fruits to understand the effects of ethylene. The production of ethylene is in very small amounts at the start of fruit production, once the fruits are mature enough there is a boost in the production of ethylene thus ripening the fruit. It is also seen that if ready to ripe fruits are exposed to ethylene there is a boost in production in the fruit thus forcing it to ripe (50).It is observed that ethylene has a direct negative effect on the cut flower industry. Ways to inhibit the production of ethylene have been proven to increase the vase life of cut flowers (54).One of the downsides of excess production of ethylene is it can cause green tissues of leaves and stems to turn yellow lowering the quality of plants as well as causing immature dropping of fruits and vegetables (8). Ethylene is also known to oppose the effects of ABA and GA. It can also enhance seed germination, and root growth and increase oxygen availability in submerged plants (55).

ABSCISIC ACID

Abscisic acid (ABA) is a hormone which inhibits growth. It is also called the stress hormone as it helps the plant to adapt to stressful situations like dehydration, reduction in daylight and many more factors (4). Some of the well-known function of ABA includes stomatal regulation, senescence and weakening of the effect of other hormones. ABA is a messenger that shuts down the stomata during drought helping to reduce water loss (56). Spraying mature leaves with ABA sprays can accelerate the senescence of the leaves (57). ABA is a negative hormone which had the ability to diminish all the work done by other positive hormone-like GAs, Auxin and cytokinin (58). ABA functions in a special way, it gets accumulated in an area causing the plant to activate the stress response when exposed to abiotic stress. Once the stress is reduced the levels of ABA are reduced to normal optimising the growth of plants. The levels of ABA are controlled by metabolism, conjugation, deconjugation and transportation of ABA (59). At normal conditions, it can play a crucial role in tillering, flowering, production, and maturation of seeds (60). ABA is synthesised in vasculature and guard cells of vegetative leaves. Furthermore, studies show that ABA found in roots is produced in the shoot and is later transported when under stress. ABA and auxins are completely different hormones with different functions, but they interact extensively in order to grow the plant in a regulated manner. It is important to know how both hormones interact with each other and how they maintain their homeostasis. ABA is the only hormone that opposes all other hormones and can diminish their effects and interfere with the functioning of other hormones (61). Senescence can show the final stages of leaves. ABA is one of the important hormones which triggers the senescence of the plant. ABA also acts as a negative/inhibiting hormone which can inhibit seed germination and post-germination growth (62).

FUTURE PROSPECTS AND CONCLUSIONS

Plant hormones have been used commercially in agriculture and horticulture for many years. They are being used for various sorts of things ranging from improving quality, increasing yields, increasing shelf life, etc. Each and every plant hormone has its own role in the proper functioning of the plant and getting an optimum result.Some of the hormones go hand in hand with each other like auxins and cytokinin while some might cancel each other effects like auxin and ABA. The effects of plant hormones are more complex than they look. Many times, there is more than one hormone working on a specific part of the plant causing it to either grow or senescence. Hormones are responsible for maintaining the plant's nutritional and physical quality. It is also important to understand the functioning of some negative hormones as they can help to understand the overall health of the plants. When used commercially, farmers usually use a mix of different hormones to target a particular stage of a crop.

However, there are many more areas of focus to completely understand the functioning of hormones and how they work by mixing with each other. In recent times new types of hormones have been added to the five main types of hormones i.e., jasmonate, strigolactones and ~~brassinosteriods~~brassinosteroids. There is not much research done on these hormones and need further investigation to understand their functioning. It can be a good idea to further study these hormones as they can open a huge window for a better understanding of the functioning of plants. Jasmonate is a hormone related to the immunity of the plant, and brassinosteroidsare a hormone also associated with the immunity of the plants from pests and disease. In recent times, strigolactone hormones have been found which are completely opposite to cytokinin. This hormone is responsible for inhibiting shoot and axillary bud branching and also reducing tillering. It also helps microbes like Arbuscular mycorrhizal fungi (AMFs) to communicate with plants and helps in the formation of symbiotic relationships (63). Hence, it requires combining multiple disciplines of physiology, biochemistry and molecular genetics to understand more about the role of hormones in plants and there are many more areas in this field that remain to be explored.

REFERENCES

1. Mander, L. and Liu, H.W., 2010. *Comprehensive natural products II: chemistry and biology* (Vol. 1). Elsevier.
2. Su, Y., Xia, S., Wang, R. and Xiao, L., 2017. Phytohormonal quantification based on biological principles. *Hormone metabolism and signaling in plants*, *13*, pp.431-470.
3. Dilworth, L.L., Riley, C.K. and Stennett, D.K., 2017. Plant constituents: Carbohydrates, oils, resins, balsams, and plant hormones. In *Pharmacognosy* (pp. 61-80). Academic Press.
4. Bharati, A.C., Prasad, B., Mallick, S., Masram, D.S., Kumar, A. and Saxena, G.K., 2023. Animal and plant hormone. In *Handbook of Biomolecules* (pp. 151-175).
5. Davies, P.J., 1995. Plant Hormones Dordrecht. *The Netherlands: Kluwer*.
6. Nikolic, R., Mitic, N., Miletic, R. and Neskovic, M., 2006. Effects of cytokinins on in vitro seed germination and early seedling morphogenesis in Lotus corniculatus LJ Plant Growth Regul. 25, 187-194.
7. Brian, P.W., 1959. Effects of gibberellins on plant growth and development. *Biological reviews*, *34*(1), pp.37-77.
8. Iqbal, N., Khan, N.A., Ferrante, A., Trivellini, A., Francini, A. and Khan, M.I.R., 2017. Ethylene role in plant growth, development and senescence: interaction with other phytohormones. *Frontiers in plant science*, *8*, p.475.
9. Richter, K. and Koolman, J., 1991. Antiecdysteroid effects of brassinosteroids in insects.
10. Verma, V., Ravindran, P. and Kumar, P.P., 2016. Plant hormone-mediated regulation of stress responses. *BMC plant biology*, *16*, pp.1-10.
11. Shi, T.Q., Peng, H., Zeng, S.Y., Ji, R.Y., Shi, K., Huang, H. and Ji, X.J., 2017. Microbial production of plant hormones: opportunities and challenges. *Bioengineered*, *8*(2), pp.124-128.
12. Waadt, R., Seller, C.A., Hsu, P.K., Takahashi, Y., Munemasa, S. and Schroeder, J.I., 2022. Plant hormone regulation of abiotic stress responses. *Nature Reviews Molecular Cell Biology*, *23*(10), pp.680-694.
13. Tanimoto, S. and Harada, H., 1984. Roles of auxin and cytokinin in organogenesis in Torenia stem segments cultured in vitro. *Journal of plant physiology*, *115*(1), pp.11-18.

14. Ljung, K., Hull, A.K., Celenza, J., Yamada, M., Estelle, M., Normanly, J. and Sandberg, G., 2005. Sites and regulation of auxin biosynthesis in Arabidopsis roots. *The Plant Cell*, *17*(4), pp.1090-1104.
15. Sauer, M., Robert, S. and Kleine-Vehn, J., 2013. Auxin: simply complicated. *Journal of experimental botany*, *64*(9), pp.2565-2577.
16. Perrot-Rechenmann, C. and Napier, R.M., 2005. Auxins. *Vitamins & Hormones*, *72*, pp.203-233
17. Muday, G.K., 2001. Auxins and tropisms. *Journal of plant growth regulation*, *20*(3).
18. Hentrich, M., Böttcher, C., Düchting, P., Cheng, Y., Zhao, Y., Berkowitz, O., Masle, J., Medina, J. and Pollmann, S., 2013. The jasmonic acid signaling pathway is linked to auxin homeostasis through the modulation of YUCCA 8 and YUCCA 9 gene expression. *The Plant Journal*, *74*(4), pp.626-637.
19. Miransari, M. and Smith, D.L., 2014. Plant hormones and seed germination. *Environmental and experimental botany*, *99*, pp.110-121.
20. Grossmann, K., 2010. Auxin herbicides: current status of mechanism and mode of action. *Pest Management Science: formerly Pesticide Science*, *66*(2), pp.113-120.
21. Todd, O.E., Figueiredo, M.R., Morran, S., Soni, N., Preston, C., Kubeš, M.F., Napier, R. and Gaines, T.A., 2020. Synthetic auxin herbicides: finding the lock and key to weed resistance. *Plant Science*, *300*, p.110631.
22. Liu, X. and Hou, X., 2018. Antagonistic regulation of ABA and GA in metabolism and signaling pathways. *Frontiers in plant science*, *9*, p.251.
23. Sevik, H. and Guney, K., 2013. Effects of IAA, IBA, NAA, and GA3 on rooting and morphological features of Melissa officinalis L. stem cuttings. *The Scientific World Journal*, *2013*.
24. Cooper, W.C., Rasmussen, G.K., Rogers, B.J., Reece, P.C. and Henry, W.H., 1968. Control of abscission in agricultural crops and its physiological basis. *Plant Physiology*, *43*(9 Pt B), p.1560.
25. Miller, C.O., Skoog, F., Von Saltza, M.H. and Strong, F.M., 1955. Kinetin, a cell division factor from deoxyribonucleic acid1. *Journal of the American Chemical Society*, *77*(5), pp.1392-1392.
26. Amasino, R., 2005. 1955: Kinetin arrives. The 50th anniversary of a new plant hormone. *Plant Physiology*, *138*(3), pp.1177-1184.
27. Murray, J.D., Karas, B.J., Sato, S., Tabata, S., Amyot, L. and Szczyglowski, K., 2007. A cytokinin perception mutant colonized by Rhizobium in the absence of nodule organogenesis. *Science*, *315*(5808), pp.101-104.
28. Werner, T. and Schmülling, T., 2009. Cytokinin action in plant development. *Current opinion in plant biology*, *12*(5), pp.527-538.
29. Pernisova, M., Grochova, M., Konecny, T., Plackova, L., Harustiakova, D., Kakimoto, T., Heisler, M.G., Novak, O. and Hejatko, J., 2018. Cytokinin signalling regulates organ identity via the AHK4 receptor in Arabidopsis. *Development*, *145*(14), p163907.
30. Wybouw, B. and De Rybel, B., 2019. Cytokinin–a developing story. *Trends in plant science*, *24*(2), pp.177-185.
31. Kudo, T., Kiba, T. and Sakakibara, H., 2010. Metabolism and long-distance translocation of cytokinins. *Journal of integrative plant biology*, *52*(1), pp.53-60
32. Peleg, Z. and Blumwald, E., 2011. Hormone balance and abiotic stress tolerance in crop plants. *Current opinion in plant biology*, *14*(3), pp.290-295.

33. Wu, W., Du, K., Kang, X. and Wei, H., 2021. The diverse roles of cytokinins in regulating leaf development. *Horticulture Research*, *8*.
34. Xu, J., Chen, L., Sun, H., Wusiman, N., Sun, W., Li, B., Gao, Y., Kong, J., Zhang, D., Zhang, X. and Xu, H., 2019. Crosstalk between cytokinin and ethylene signaling pathways regulates leaf abscission in cotton in response to chemical defoliants. *Journal of experimental botany*, *70*(5), pp.1525-1538
35. Krishna, H., Alizadeh, M., Singh, D., Singh, U., Chauhan, N., Eftekhari, M. and Sadh, R.K., 2016. Somaclonal variations and their applications in horticultural crops improvement. *3 Biotech*, *6*, pp.1-18
36. Wang, D., Yeats, T.H., Uluisik, S., Rose, J.K. and Seymour, G.B., 2018. Fruit softening: revisiting the role of pectin. *Trends in plant science*, *23*(4), pp.302-310.
37. Takahashi, N., 1998. Discovery of gibberellin. In *Discoveries In Plant Biology: (Volume I)* (pp. 17-32).
38. Yaxley, J.R., Ross, J.J., Sherriff, L.J. and Reid, J.B., 2001. Gibberellin biosynthesis mutations and root development in pea. *Plant physiology*, *125*(2), pp.627-633.
39. Chen, S.Y., Kuo, S.R. and Chien, C.T., 2008. Roles of gibberellins and abscisic acid in dormancy and germination of red bayberry (Myrica rubra) seeds. *Tree Physiology*, *28*(9), pp.1431-1439
40. Hedden, P. and Sponsel, V., 2015. A century of gibberellin research. *Journal of plant growth regulation*, *34*, pp.740-760.
41. Dayan, J., 2016. Gibberellin transport. *Annual Plant Reviews, Volume 49: Gibberellins, The*, pp.95-120.
42. Binenbaum, J., Weinstain, R. and Shani, E., 2018. Gibberellin localization and transport in plants. *Trends in plant science*, *23*(5), pp.410-421.
43. Hedden, P., 2020. The current status of research on gibberellin biosynthesis. *Plant and Cell Physiology*, *61*(11), pp.1832-1849.
44. Chen, C., Huang, W., Hou, K. and Wu, W., 2019. Bolting, an important process in plant development, two types in plants. *Journal of Plant Biology*, *62*, pp.161-169.
45. Jung, H., Jo, S.H., Jung, W.Y., Park, H.J., Lee, A., Moon, J.S., Seong, S.Y., Kim, J.K., Kim, Y.S. and Cho, H.S., 2020. Gibberellin promotes bolting and flowering via the floral integrators RsFT and RsSOC1-1 under marginal vernalization in radish. *Plants*, *9*(5), p.59.
46. Li, H., Wu, H., Qi, Q., Li, H., Li, Z., Chen, S., Ding, Q., Wang, Q., Yan, Z., Gai, Y. and Jiang, X., 2019. Gibberellins play a role in regulating tomato fruit ripening. *Plant and cell physiology*, *60*(7), pp.1619-1629.
47. Xie, S., Liu, Y., Chen, H., Yang, B., Ge, M. and Zhang, Z., 2022. Effects of gibberellin applications before flowering on the phenotype, ripening, and flavonoid compounds of Syrah grape berries. *Journal of the Science of Food and Agriculture*, *102*(13), pp.6100-6111.
48. Shan, F., Zhang, R., Zhang, J., Wang, C., Lyu, X., Xin, T., Yan, C., Dong, S., Ma, C. and Gong, Z., 2021. Study on the regulatory effects of GA3 on soybean internode elongation. *Plants*, *10*(8), p.1737.
49. Kanojia, A., Xu, X. and Dijkwel, P.P., 2023. Ethylene as a plant aging modulator. In *The Plant Hormone Ethylene* (pp. 73-87). Academic Press.
50. Ferrante, A., 2023. Ethylene and horticultural crops. In *The Plant Hormone Ethylene* (pp. 107-121). Academic Press

51. Li, J., Li, C. and Smith, S.M., 2017. *Hormone metabolism and signaling in plants.*
52. Vandenbussche, F., Vaseva, I., Vissenberg, K. and Van Der Straeten, D., 2012. Ethylene in vegetative development: a tale with a riddle. *New Phytologist*, *194*(4), pp.895-909.
53. Van de Poel, B., Smet, D. and Van Der Straeten, D., 2015. Ethylene and hormonal cross talk in vegetative growth and development. *Plant Physiology*, *169*(1), pp.61-72.
54. Reid, M.S., 1985. Ethylene and abscission. *HortScience*, *20*(1), pp.45-50.
55. Hartman, S., Sasidharan, R. and Voesenek, L.A., 2021. The role of ethylene in metabolic acclimations to low oxygen. *New Phytologist*, *229*(1), pp.64-70.
56. Agurla, S., Gahir, S., Munemasa, S., Murata, Y. and Raghavendra, A.S., 2018. Mechanism of stomatal closure in plants exposed to drought and cold stress. *Survival Strategies in Extreme Cold and Desiccation: Adaptation Mechanisms and Their Applications*, pp.215-232
57. Song, Y., Xiang, F., Zhang, G., Miao, Y., Miao, C. and Song, C.P., 2016. Abscisic acid as an internal integrator of multiple physiological processes modulates leaf senescence onset in Arabidopsis thaliana. *Frontiers in Plant Science*, *7*, p.181.
58. Liu, X., Zhang, H., Zhao, Y., Feng, Z., Li, Q., Yang, H.Q., Luan, S., Li, J. and He, Z.H., 2013. Auxin controls seed dormancy through stimulation of abscisic acid signaling by inducing ARF-mediated ABI3 activation in Arabidopsis. *Proceedings of the National Academy of Sciences*, *110*(38), pp.15485-15490.
59. Chen, K., Li, G.J., Bressan, R.A., Song, C.P., Zhu, J.K. and Zhao, Y., 2020. Abscisic acid dynamics, signaling, and functions in plants. *Journal of integrative plant biology*, *62*(1), pp.25-54.
60. Kishor, P.B.K., Tiozon, R.N., Fernie, A.R. and Sreenivasulu, N., 2022. Abscisic acid and its role in the modulation of plant growth, development, and yield stability. *Trends in Plant Science*.
61. Emenecker, R.J. and Strader, L.C., 2020. Auxin-abscisic acid interactions in plant growth and development. *Biomolecules*, *10*(2), p.281.
62. Xie, W., Li, X., Wang, S. and Yuan, M., 2022. OsWRKY53 promotes abscisic acid accumulation to accelerate leaf senescence and inhibit seed germination by downregulating abscisic acid catabolic genes in rice. *Frontiers in Plant Science*, *12*, p.816156.
63. Kowalczyk, A. and Hrynkiewicz, K., 2018. Strigolactones as mediators between fungi and plants. *Acta Mycologica*, *53*