# Could animal hormone regulate plant development? 

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#### Abstract

Hormones play a crucial role both in plants and animals. As we all known, hormones work through specific receptors in different organisms. Therefore, the hormone interaction between plant and animal is an interesting question worth discussing. Recently, food safety has become a common topic concerned by consumers. A widely discussed rumor such as "Fruit bulking agent is some human reproductive hormones" leads us to consider whether animal hormones did regulate plant growth. Based on the large amount of previous research, we demonstrated that animal hormones did affect plant, such as steroid hormones for livestock feed could regulate physiological processes in plant including flowering, senescence and stress resistance after excreted into the environment. Here, we summarize the previous studies and systematically discuss the effects of animal hormones on plant growth and development.


## Animal hormones: potential plant regulators?

Small molecule animal hormone is a kind of regulating substance with high efficiency, which is widely distributed in all parts of body. It plays a critical role in coordinating physiological processes such as metabolism, growth, and development. According to chemical composition, these hormones could be divided into protein hormone containing nitrogen (derived from amino acids, peptides and proteins) and steroid hormone.

As the technology of synthetic animal hormones matures, animal hormones are widely used for medical or agricultural purpose. However, subsequently excreted hormonal waste through defecation and urination could be transferred into environment, which may become a potential threat to plants, especially crops (Ma, \& Yates, 2018).
Can animal hormone regulate plant physiology as new plant growth regulators? Several lines of evidence point to an idea that animal hormones are not unique to animals. Neurohormones indoleamines (melatonin and serotonin) and catecholamines (dopamine, norepinephrine and epinephrine) have all been found in plant. They have great potential to regulate multiple features of physiology and resist environmental stress in plants. For the first, we reviewed the effects of existing small-molecules animal hormones on plants to open a broad prospect for the hormonal application in medicine, agriculture and animal.

## Melatonin regulates plant stress resistance and immune system

Melatonin ( N -acetyl-5-methoxytryptamine) is a kind of hydrophilic and lipophilic hormone with various regulation of circadian rhythm (Behram, Aydin, \& Gorgisen, 2017), which regulates sleep and circadian functions in animals (Radogna, Diederich, \& Ghibelli, 2010). Melatonin also plays crucial role as an antioxidant, anti-inflammatory, immune-modulatory effects on human tissues (Nayak et al., 2019).
Notably, endogenous melatonin has also been found in plants as an effective antioxidant and free radical scavenger (Kang, Lee, Park, Byeon, \& Back, 2013; Murch, Alan, Cao, \& Saxena, 2009). Studies have shown that melatonin can modify the structure of plant hormone carriers and the development pattern of stems and leaves (Arnao, \& Hernández-Ruiz, 2015). Physiological processes including seed and root growth
(Arnao, \& Hernández-Ruiz, 2014; Sarropoulou, Dimassi-Theriou, Therios, \& Koukourikou-Petridou,2012; Byeon, \& Back, 2014; Park, Le, Byeon, Kim, \& Back, 2013), flowering (Huang et al., 2017; Kolář, Johnson, \& Macháčková, 2003), photosynthetic system (Zhao et al., 2015; Arnao, \& Hernández-Ruiz, 2009) and reproductive system could be regulated by melatonin. As antioxidant in plant, previous research has found that melatonin decreased significantly free radicals in barley tissues, which protect chlorophyll from aging (Arnao \& Hernandez-Ruiz, 2009; Wang et al., 2013). Furthermore, melatonin can keep leaf from senescence by regulating the activity of antioxidant enzymes (Zhao et al., 2017). It improves photosynthesis, $\mathrm{CO}_{2}$ uptake and biomass. Accordingly, it can be used to protect plants exposed to strong light from burns and enhance the resistance to strong light (Zhao et al., 2017). Additionally, exogenous melatonin can influence the early stages of flower induction and development.
In addition, melatonin can resist biotic and abiotic stress (Fu et al., 2017; Lee, Byeon, \& Back, 2014; Weeda et al., 2014) and regulate plant physiological ion balance against stress (Wei et al., 2015; Zeng et al., 2018) Plant damage caused by environmental stress including cold, drought, UV irradiation, and chemical stressors (Arnao, \& Hernandez-Ruiz, 2015; Weeda et al., 2014; Mandal, Suren, Ward, Boroujerdi, \& Kousik, 2018) can be mitigated by melatonin. Under bacterial pathogen infection, increased endogenous can induce the transcription of stress-related genes, such as $C B F / D R E B 1 s$ in Arabidopsis thaliana (Shi, Qian, Tan, Reiter, \& He, 2015). Moreover, the rise of soluble sugar caused by melatonin is also responsible for its biological resistance (Yang et al., 2010; Qian, Tan, Reiter, \& Shi, 2015). The overexpression of melatonin and $C B F / D R E B 1 s$ results in the increase of transcription levels of multiple stress response genes, and the accumulation of soluble sugars, such as sucrose (Qian, Tan, Reiter, \& Shi, 2015). It has great potential for melatonin to regulate plant against biotic and abiotic stress. Ideas about melatonin as new plant growth regulator could provide insights into the solution for food security issues (Lee, Byeon, \& Back, 2014).
Furthermore, melatonin can interact with the endogenous plant hormones. Previous research showed that melatonin can stimulate plant to produce ABA and ethylene, which lead to berry ripening (Fu et al., 2017; Qian, Tan, Reiter, \& Shi, 2015). In addition, it could regulate nitrogen oxides and salicylic acid levels by activating plant defense-related genes to relieve the biological pressure (Yin et al., 2013; Li et al., 2018). The effects of melatonin on plants can be used as a plant regulator with potential applications in crop improvement and protection (Arnao, \& Hernandez-Ruiz, 2015).

## The antioxidant regulation of dopamine

Dopamine is a critical neurotransmitter in animals. It has multiple phenolic hydroxyl groups and an amino group which make it antioxidative (Glod, Stanczak, \& Wozniak, 2005). Dopamine acts as a signal in the body to regulate the nervous system and affects the immune function of T cells in the body (Levite, 2016). The content of dopamine in the body is linked to serious human disease like Parkinson's disease, depression.

Individual plants can synthesize dopamine themselves. As early in 1984, scientists found that the leaves of opium poppy, capsule and peduncle have the biosynthetic activity of dopamine for early stage (Kamo \& Mahlberg, 1984). Banana pulp and peel contain a large amount of dopamine. For instance, dopamine levels in peel is between $80-560 \mathrm{mg} / 100 \mathrm{~g}$. In pulp ranging from $2.5-10 \mathrm{mg} / 100 \mathrm{~g}$ (Kanazawa,\& Sakakibara, 2000). The antioxidant activity of dopamine is as even same as the strongest antioxidants gallocatechin gallate and ascorbic acid. This also proves that bananas are antioxidant fruits in some degrees (Kanazawa,\& Sakakibara, 2000).

Moreover, dopamine plays a critical role in response to environmental stimuli including alkali, salt, and drought (Li et al., 2015; Gao et al., 2020; Jiao et al., 2019; Lan, Jiao, Wang, Sun, \& Sun, 2020). These resistances to environmental stress are likely due to its antioxidant capacity. Previous results suggested that dopamine could be used as an exogenous antioxidant to increase the absorption efficiency of nutrients in begonia, to alleviate the stress response caused by the lack of nutrients in begonia. Also, in Rosaceae family, recent research has found that exogenous dopamine could regulate apple's drought resistance and salt tolerance by stomatal behavior ( Li et al., 2015; Gao et al., 2020), as well as alleviate the drought-induced damages, replenishing of K, N, P, S, Cu and other trace elements (Li et al., 2015; Gao et al., 2020). Research
about soybean even demonstrated that dopamine can affect the activity of antioxidant enzymes and the content of reactive oxygen species (ROS) in roots, thus enhancing the antioxidant activity in plants (Gomes et al., 2014).

In addition, dopamine can regulate expression of five SOS pathway genes, which increases the levels of $\mathrm{H}_{2} \mathrm{O}_{2}-$ scavenging enzymes in leaf. The SOD activity has the same tendency (Li et al., 2015). To some extent, this is also an indirect way for dopamine to improve the resistance of plants to adversity. Although previous research and experiments on dopamine have been discovered and carried out, there are many questions which remain unanswered about the role of dopamine in plants.

## Acetylcholine enables the exchange of information between different plant tissues

Acetylcholine (ACh) is a well-known neurotransmitter in the central and peripheral nervous system (Picciotto, Higley, \& Mineur, 2012), which regulates neuronal excitability, presynaptic release of neurotransmitters, synaptic transmission, and coordinates firing of groups of neurons (Lazar, Metherate, \& Kawai, 2007). The ability of acetylcholine to coordinate the neuronal networks makes it an essential mechanism for controlling complex behaviors in animals (Picciotto, Higley, \& Mineur, 2012). We consider acetylcholine here as an animal hormone because of its activity of cholinesterases. This meets all the criteria for an autocrine/paracrine hormone in lung bronchial epithelium (Proskocil et al., 2004).

ACh has been detected in many taxonomic groups throughout plant kingdom (Brenner et al., 2006). Both young leaves and root can synthesis ACh (Tretyn, \& Kendrick, 1991; Bamel, Gupta, \& Gupta, 2015) which regulates various physiological processes in plants. In terms of plant growth and development, previous research showed an increase in the number of secondary roots in tomato and radish caused by exogenous ACh (Bamel, Gupta, \& Gupta, 2015; Sugiyama, \& Tezuka, 2011). Existing evidence has shown ACh can also accelerate the germination of seeds in the control of light (Tretyn, \& Kendrick, 1991) and cause the merging of vacuolar fluorescent reporters to result in an indirect stimulation of cell expansion in vacuolar (Di , Fornaciari, Barozzi, Piro, \& Arru, 2014). Additionally, there have been interactions between Ach and plant hormone, such as auxin to regulate root and interact with phytochrome (Di, Fornaciari, Barozzi, Piro, \& Arru, 2014). From the perspective of reproductive system, ACh could participate in the phytochromecontrolled flowering in plants. ACh affects photoperiodic induction of flowering by altering the bioelectric potentials of leaves (Tretyn, \& Kendrick, 1991).

Moreover, ACh can help plants to cope with abiotic stress. Previous studies suggested that a positive trend on germination traits in soybean under osmotic stress (Braga, Pissolato, \& Souza, 2017). ACh enhances activities of antioxidant enzymes, such as peroxidase and superoxide dismutase, meaning a potential application to alleviate salt-stress damage (Kang, Kim, Park, \& Back, 2009). The control of stomatal movement may also be one of the reasons for ACh against environmental stress. Previous studies showed reduced amount of ATP synthesis in chloroplasts to regulate stomatal movement (Tretyn, \& Kendrick, 1991; Bamel, Gupta, \& Gupta, 2015). The reason stomata are regulated is probably to maximize water use under stress.

## Norepinephrine induces flower-inducing substance

In human, norepinephrine (NE) acts directly on coronary vessels to cause vasodilation and improve blood supply to the heart (Papadopoulos et al., 2010). The noradrenergic system serves multiple brain functions including arousal, attention, mood, learning, memory and stress response (Sofuoglu, \& Sewell, 2009). Moreover, more evidences have even shown the relationship between neuroprotective disease and norepinephrine (Moret, \& Briley, 2011).

High levels of allegedly animal hormone, epinephrine and norepinephrine, have been also detected in peyote (Kulma, \& Szopa, 2007). Lower in oranges, apples, tomatoes, eggplants, spinach, beans, and peas (Feldman, Lee, \& Castleberry, 1987). And they play in corresponding regulation of plant physiology. Flowering is a vital physiological phenomenon of plants. Flower-inducing substance (FIS) could be induced by many factors. Studies have shown that NE could interact with FIS to induce flowering in plant. Lemna paucicostata which had been immersed in NE solution ( 2 mM ) had strong FIS activity (Yokoyama et al., 2000). The
active component in flower-inducing substance is identified as tyrosine, which means FIS is derived from NE upon contact with the lemna(Yamaguchi, 2001). However, the functional and regulatory mechanisms of NE corresponding with FIS remain to be elucidated.
Furthermore, NE and epinephrine have similar physiological effects in plants due to similar chemical structures (Kulma, \& Szopa, 2007). NE in 50 mM and epinephrine in 100 mM are demonstrated to stimulate ethylene synthesis in sugarbeet (Elstner et al., 1976). The same effects were observed in orchardgrass and potato cell culture (Kuklin, \& Conger, 1995; Dai, Michaels, \& Flores, 1993). There may be an interaction between endogenous plant hormones and them. Moreover, norepinephrine is believed to be a precursor for secondary alkaloids, such as berberastine (Szopa, Wilczyński, Fiehn, Wenczel, \& Willmitzer, 2001). However, most of these studies were done decades ago. Further confirmation is necessary with more convincing methods developed recently (Kulma, \& Szopa, 2007).

## Serotonin has a similar effect like auxin inhibitor

Serotonin (5-hydroxytryptamine, SER) is a well-known indoleamine neurotransmitter that regulates mood, sleep and anxiety in mammals (Murch, \& Saxena, 2002). It was initially identified as a vasoconstrictor substance in blood serum, named as 5-hydroxytryptamine (5-HT). It appears to play a role to cope with neuropsychiatric disorders in neuropharmacology (Weele, Anderson, \& Cook, 2000). Plants can synthesize SER themselves, which is abundant in companion and xylem cells. SER may become a central role in maintaining the cellular integrity for facilitating efficient nutrient recycling from senescing leaves to sink tissues (Ramakrishna, Giridhar, \& Ravishankar, 2011).

Plants are capable of taking up exogenous serotonin, which coincided with stimulated root development as a natural auxin inhibitor (Pelagio-Flores et al., 2011). It is essential for signaling and stress mitigating molecules in plant growth (Erland, Shukla, Singh, Murch, \& Saxena, 2018; Erland, Murch, Reiter, \& Saxena, 2015). There has been found a crosstalk between 5 -HT $(0.01-0.03 \mathrm{mM})$ and phytohormones such as SA, ABA, and zeatin (Erland, Shukla, Singh, Murch, \& Saxena, 2018). Moreover, previous research showed that serotonin could regulate growth process including root and shoot organogenesis (Erland, Shukla, Singh, Murch, \& Saxena, 2018), light mediated responses (Leclercq et al., 2002; Erland, Turi, \& Saxena, 2016), maintenance of plant tissues (Erland, Turi, \& Saxena, 2016), and delay of senescence (Erland, Murch, Reiter, \& Saxena, 2015).

In addition, SER acts as an antioxidant to protect plants (Kang, Kim, Park, \& Back, 2009; Kang et al., 2007) and responses to biotic and abiotic stresses such as cold and salt stress (Mukherjee, David, Yadav, Baluška \& Bhatla, 2014). Previous research demonstrated a high level of serotonin accumulated in senescing leaves and roots as the plants aged. Also, pathogenic infection can lead to accumulated serotonin against pathogens by strengthening of the cell wall (Ramakrishna, Giridhar, \& Ravishankar, 2011; Kang, Kim, Park, \& Back, 2009). Absence of serotonin is suggestive of a relatively lesser sensitivity of plant tissues to environmental stress.

Furthermore, there have been interactions between serotonin and other small-molecular regulators, such as melatonin. A balance of the endogenous serotonin and melatonin may modulate plant morphogenesis in vitro (Murch, \& Saxena, 2001). Thus, serotonin is implicated in several physiological roles in plants such as flowering, morphogenesis, and adaptation to environmental changes. However, these physiological functions provide new avenues to consider health effects of plant SER in human.

## Insulin regulates plant immunity and induces polyploids

Insulin, a 6 kDa peptide hormone, produced by beta cells of the pancreatic islets is one of the main anabolic hormones of the body. It is considered to regulate the metabolism of carbohydrates, fats and protein. Decrease in insulin sensitivity causes metabolic disorders such as type II diabetes and metabolic syndrome (Yaribeygi, Farrokhi, Butler, \& Sahebkar, 2019).
There are insulin-like materials in several plants which play essential role in multiple physiological processes. They have the same molecular masses, immunological and bioactive properties with insulin, such as bovine
insulin which was reported to stimulate growth and DNA synthesis in the radicles and the coleoptiles of the embryonic axis in $200 \mu \mathrm{U} \mathrm{ml}^{-1}$ (Avila-Alejandre et al., 2013). Chemically, insulin has a great potential to affect physiology in plant, such as increases of root length and weight in barley (Csaba, \& Katalin, 1982). It was reported that insulin $\left(10^{-8} \mathrm{M}\right)$ enhanced the increase of root in lengths and weights significantly, and had a similarly strong influence on the increase of coleoptile (Oliveira et al., 2004). Qualitative cytological studies even indicated that insulin may induce a polyploidism, associated with the Feulgen-positive bodies in the cytoplasm (Csaba, \& Katalin, 1982). Moreover, the regulation of the cell-cycle restart by bovine insulin is demonstrated in germinating embryonic axes (Avila-Alejandre et al., 2013). This suggests that plant cells also have potential receptors to which hormones of vertebrates could bind (Csaba, \& Katalin, 1982). Molecular mechanism of insulin would be worthwhile avenues to explore.

## Epinephrine releases the inhibition of flowering

Epinephrine (Epi) is a catecholamine secreted by the adrenal medulla which could cause the heart to contract, constricting the blood vessels in the heart, liver, muscles, bones and skin. Abundant evidence indicates that epinephrine modulates memory consolidation in animals (Cahill, \& Alkire, 2013). Simultaneously, Epi, which is known to increase cAMP levels in animals is acknowledged for intracellular signal transduction (Hines et al., 2003).
Similarly, in plants, cAMP takes charge of flowering. It is also associated with epinephrine directly and indirectly. The previous research about inhibition of flowering offer broad views that conducted by Epi, inhibition of flowering Lemna paucicostata in blue light or in short days is partially overcome by increased cAMP and $\mathrm{Ca}^{2+}$ (Ives, \& Posner, 1982). Furthermore, in leaves cultures, Epi at 10-100 $\mu \mathrm{M}$ can stimulate somatic embryogenesis from orchardgrass (Kuklin, \& Conger, 1995). Additionally, previous studies suggested that Epi regulates plant physiology by affecting plant hormone levels, such as stimulating ethylene biosynthesis in suspension cultures (Kuklin, \& Conger, 1995). However, knowledge about the function and regulation of epinephrine in plants is still limited.

## Progesterone and androstenedione involved in plant growth.

Sex hormones are steroid hormones that interact with vertebrate androgen or estrogen receptors. They have been found as messengers to promote the maturation of sexual organs, the development of secondary sex characteristics, regulation on pain perception and maintain sexual function (Bińkowska, \& Woroń, 2015). Various forms of estrogen derivatives have been widely used in contraception, treatment of menopausal syndrome in women, prostatic hypertrophy in men and other endocrine disorders (Maurer, Lissounov, Knezevic, Candido, \& Knezevic, 2016).

Progesterone (PROG) is one kind of mammalian gonadal hormone necessary for the regulation of ovulation and menstruation. It is now detected in a range of plant species (Tarkowská, 2019). It was reported that the PROG contained in some plant tissues even exceeded $2600 \mathrm{ng} / \mathrm{g}$ (dry weight) (Iino et al., 2007). Five secondary steroids as the mammalian gestagen PROG are found in Adonis aleppica and Juglans regia (Tarkowská, 2019; Pauli, Friesen, Godecke, Farnsworth, \& Glodny, 2010). They assume a variety of physiological functions in plants. For instance, the Arabidopsis seedlings were found to be promoted by PROG at low concentrations but suppressed at higher concentrations (Iino et al., 2007). A similar phenomenon is found in sunflowers. High PROG concentration $(0.25 \mu \mathrm{~g}$ per plant) stimulated the elongation of shoots, while a lower concentration ( $0.1 \mu \mathrm{~g}$ per plant) stimulated the growth of sunflower roots (Bhattacharya, \& Gupta, 1981). In addition, PROG can regulate plant mineral management, including calcium, magnesium, phosphorus, sulfur, copper and so on (Dumlupinar, Genisel, Erdal, Korkut, \& Taspinar, 2011). Furthermore, it was reported that PROG (1 and $10 \mu \mathrm{M}$ ) induces the flowering in winter wheat. Same as androstenedione (0.1 $\mu \mathrm{M})$ in Arabidopsis thaliana which leads to more than twice as generative percentage compared to control (Janeczko, Filek, Biesaga-Kościelniak, Marcińska, \& Janeczko, 2003). In terms of environmental resistance, PROG alone ( $0.1 \mu \mathrm{~mol} \mathrm{~L}^{-1}$ ) can alleviate cold stress by modulation of mitochondrial respiratory pathway (Erdal, \& Genisel, 2016). Potential role of PROG in response to oxidative damage $\left(10^{-6} \mathrm{M}\right)$ is demonstrated by influence oxidative enzymes such as SOD, POX and CAT (Erdal, \& Dumlupinar, 2011).

The androstenedione (AN) is another common sex hormone precursor in both sexes and takes charge of the biosynthesis of testosterone (Haring et al., 2012). New result demonstrated the effect of androstenedione $(1 \mu \mathrm{M})$ on winter wheat exposed to low temperature (Janeczko et al., 2018). A key role for AN is to mitigate damages caused by freezing temperatures and enhance frost resistance in wheat. Moreover, there has been found an interaction between animal hormone and plant hormone in wheat. AN triggers an accelerated generative development of wheat via increasing ${G A_{3}}^{2}$ and cytokinins (Janeczko et al., 2018). The frost resistance increases in the process due to AN-induced changes in redox homeostasis. In addition, AN regulates enzyme activity including superoxide dismutase (SOD), peroxidase (POX), catalase (CAT), polyphenol oxidase (PPO) and alpha-amylase against oxidative damage in endosperm of maize seeds (Erdal, 2012). Androstenedione can alleviate drought stress and compensate efficiency of photosystem II in soybean by possible effect on aquaporin functionality and membrane stability (Janeczko, Kocurek, \& Marcińska, 2012). These studies provide new insights into AN as a novel plant growth regulator to improve resistance in crop.

Furthermore, the ability of plants to convert sterols into steroid hormones is found, involving progesterone, testosterone, androstadienedione, androstenedione, and estrogens. This means that plants have endogenous steroid hormones just like animals. However, the biological activity of these hormones remains to be explored (Tarkowská, 2019).

## Oxytocin affects the production of secondary plant constituent in vitro

Oxytocin is a neuropeptide widely used by medical doctors and veterinarians (Perry, 2014). Previous review demonstrated its role in the dynamic function of the social brain, such as result in changes in brain activity and delivery in pregnant mammals (Perry, 2014; Gordon et al., 2013). The oxytocin signaling system is ubiquitous across the animal kingdom.

Oxytocin affects the production of secondary plant constituent in vitro. The influence of oxytocin ( $100 \mu \mathrm{~g} / \mathrm{L}$ ) on biomass accumulation as well as on the production of glycyrrhizin, a key phytoconstituent of liquorice used in the pharmaceutical and food industries (Yu et al., 2017), was observed in the cell cultures of Abrusprecatorius (Karwasara, Tomar, \& Dixit, 2011). Moreover, the article demonstrated the use of oxytocin to increase the growth of pumpkins and cucumbers in India (None, 2009). However, information about the function and regulation of oxytocin in planta is still limited. These would be worthwhile avenues to explore.


|  | Modify the development pattern of stems and leaves | $10^{-4} \mathrm{mM}$ <br> (Arnao \& Hernández, 2015) |
| :---: | :---: | :---: |
|  | Delay chlorophylls lost during leaf-induced senescence | 0.1 mM (Zhao et al., 2015; <br> Arnao \& Hernández, 2009) |
|  | Regulate photosynthetic systems, $\mathrm{CO}_{2}$ uptake and biomass | $\begin{aligned} & 0.1 \mathrm{mM} \\ & \text { (Zhao et al., 2015;Zhao et al., 2017) } \end{aligned}$ |
|  | Function as a chronoregulator in circadian rhythms | $\begin{aligned} & \text { endogenous } 0.25 \mathrm{ng} / \mathrm{g} \\ & \sim 158 \mathrm{ng} / \mathrm{g} \\ & \text { (Arnao \& Hernández, 2015) } \end{aligned}$ |
|  | Affect the different stages of flowering development | $0.02 \mathrm{mM}$ <br> (Huang et al., 2017; Kolář, <br>  <br> Macháčková, 2003) |
|  | Influence the early stages of photoperiodic flower induction | 0.5 mM <br> (Huang et al., 2017; Kolár̆, <br>  <br> Macháčková, 2003) |
| Environmental stress | Improve resistance to biotic and abiotic stress | low temperatures ( $10^{-4}$ mM ) (Fu et al., 2017) salt ( 0.015 mM ) <br> (Zeng et al., 2018), drought |
|  |  | $\begin{aligned} & (0.05 \mathrm{mM}) \\ & \text { (Wei et al., 2015), UV } \end{aligned}$ |
|  |  | irradiation (endogenous $8000 \mathrm{ng} / \mathrm{g}$ ) <br> (Arnao \& Hernández, 2015) |
|  |  | chemical stressors (5 $* 10^{-3} \mathrm{mM}$ ) <br> (Mandal et al., 2018) |
|  | Strengthen the plant immune system by affect defense-related genes | $0.1 \mathrm{mM}^{\sim} 1 \mathrm{mM}$ <br> (Shi et al., 2015; Yang et al., 2010; Qian, Tan, |
|  | Regulate plant physiological ion balance | $\begin{aligned} & 0.03 \mathrm{mM} \\ & \text { (Wei et al., 2015; Zeng et al., 2018) } \end{aligned}$ |
|  | Improve resistance to the fungal pathogen | $0.5^{\sim} 2.1 \mathrm{ng}, \mathrm{g}$ <br> (Lee, Byeon, \& Back, 2014; Yin et al., 2013; Li |
|  | Lead to the accumulation of soluble sugars | $0.02 \mathrm{mM} \text { (Qian, Tan, }$ <br> Reiter, \& Shi, 2015) |

Dopamine (DA)
Molecular: 153.18
Medical: $1.6^{\sim} 7.7 \mathrm{mg} / \mathrm{kg}$ (Schnuelle et al., 2017; Jaja et al., 2020; Lou et al., 2016, Backer et al., 2010) (about $\left.10.5^{*} 10^{-3 \sim} 5.3 \mathrm{mM}\right)$

Acetylcholine (ACh)
Molecular: 146.20
Medical: $10^{-7}-1 \mathrm{M}$
(Kimura et al., 1985; Lee, \& Tsai, 1976; Shibasaki et al., 2009) (about $10^{-4 \sim} 10^{3} \mathrm{mM}$ )

| Environmental stress | Alleviate inhibition of salt by mineral management | $\begin{aligned} & 0.1 \sim 0.2 \mathrm{mM} \\ & \text { (Li et al., 2015) } \end{aligned}$ |
| :---: | :---: | :---: |
|  | Promote alkali tolerance of apple seedlings | $\begin{aligned} & 2^{*} 10^{-4} \mathrm{mM} \\ & \text { (Jiao et al., 2019) } \end{aligned}$ |
|  | Alleviate drought stress in apple seedlings | 0.1 mM (Gao et al., 2020) |
|  | Alleviate nutrient deficiency-induced stress | $\begin{aligned} & 0.1 \mathrm{mM} \\ & \text { (Li et al., 2015, Gao et al., 2020) } \end{aligned}$ |
|  | Maintain photosynthetic capacity in plants | $\begin{aligned} & 0.1_{\sim}^{\sim} 0.2 \mathrm{mM} \\ & \text { (Li et al., 2015) } \end{aligned}$ |
| Physiology | Change stomatal behavior | 0.1 mM (Gao et al., 2020) |
|  | Affect the uptake of K, $\mathrm{N}, \mathrm{P}, \mathrm{S}, \mathrm{Cu}$ and Mn | $\begin{aligned} & 0.1^{\sim} 0.2 \mathrm{mM} \\ & \text { (Li et al., 2015, Gao et al., 2020) } \end{aligned}$ |
|  | Regulate carbon metabolism and nitrogen metabolism | $\begin{aligned} & 0.05 \sim 0.2 \mathrm{mM} \\ & \text { (Lan et al., 2020) } \end{aligned}$ |
|  | Enhance antioxidant activity against ROS | $\begin{aligned} & 0.1^{\sim} 1.0 \mathrm{mM} \\ & \text { (Li et al., 2015; Gomes et al., 2014) } \end{aligned}$ |
|  | Regulate the expression of five SOS pathway genes | $\begin{aligned} & 0.1 \sim 0.2 \mathrm{mM} \\ & \text { (Li et al., 2015) } \end{aligned}$ |
| Physiology | Accelerate seed germination | $\begin{aligned} & 10^{-6} \mathrm{mM} \sim 0.3 \mathrm{mM} \\ & \text { (Tretyn, \& Kendrick, 1991) } \end{aligned}$ |
|  | Accelerate plant growth | $10^{-2} \sim 0.16 \mathrm{mM}$ <br> (Tretyn, \& Kendrick, 1991; <br> Bamel, Gupta, \& Gupta, 2015) |
|  | Inhibit lateral root development of soybean in higher doses | $>10^{-2} \mathrm{mM}$ <br> (Bamel, Gupta, \& Gupta, 2015, Sugiyama, \& T |
|  | Indirect stimulation of cell expansion | $10^{-4} \mathrm{mM}$ <br> (Sansebastiano et al., 2014) |
|  | Affect photoperiodic induction of flowering | $\begin{aligned} & 10^{-2} \mathrm{mM} \\ & \text { (Tretyn, \& Kendrick, 1991) } \end{aligned}$ |
|  | Interact with endogenous plant hormone | $0.1^{\sim} 1 \mathrm{mM}$ <br> (Sansebastiano et al., 2014) |

Alleviate inhibition of salt by mineral management

Promote alkal tolerance of apple seedlings
Alleviate drought stress in apple seedlings Alleviate nutrient stress
Maintain photosynthetic capacity in plants Change stomatal behavior
Affect the uptake of K,
$\mathrm{N}, \mathrm{P}, \mathrm{S}, \mathrm{Cu}$ and Mn
Regulate carbon metabolism and nitrogen metabolism Enhance antioxidant activity against ROS
Regulate the expression of five SOS
pathway genes
Accelerate seed germination
growth

Inhibit lateral root development of soybean in higher doses Indirect stimulation of cell expansion
Affect photoperiodic induction of flowering endogenous plant hormone
$10^{-2} \sim 0.16 \mathrm{mM}$
(Tretyn, \& Kendrick, 1991;
Bamel, Gupta, \& Gupta, 2015)
$>10^{-2} \mathrm{mM}$
(Bamel, Gupta, \& Gupta, 2015, Sugiyama, \& T
$10^{-4} \mathrm{mM}$
(Sansebastiano et al., 2014)
$10^{-2} \mathrm{mM}$
(Tretyn, \& Kendrick, 1991)
$0.1^{\sim} 1 \mathrm{mM}$
(Sansebastiano et al., 2014)


Epinephrine (Epi)
Molecular: 183.20
Medical:0.000045-
$0.016 \mathrm{mg} / \mathrm{kg}$ (Perkins et al., 2018; Carpenter, Smith, \& Bridenbaugh, 1989; Tai-Cherng et al., 2006) (about 0.024 $\left.\sim 8.7^{*} 10^{-5} \mathrm{mM}\right)$

Progesterone (PROG)
Molecular: 314.46
Medical:3.34-7.62 mg/ kg
(Coomarasamy et al., 2015; Tosun et al., 2019;
Milivojevic, Sinha, Morgan, Sofuoglu, Fox, 2014; Fox, Sofuoglu, Morgan, Tuit, \& Sinha, 2013; Evans, \& Foltin, 2006) (about10.6
$\left.{ }^{\sim} 24.2^{*} 10^{-3} \mathrm{mM}\right)$

Norepinephrine (NE) Physiology
Molecular: 169.18
Medical: 806.4-16000 $\mu \mathrm{g} /$
kg (Venet et al., 2015;
Permpikul et al., 2019;
Backer et al., 2010)
(about $4.76{ }^{\sim} 95^{*} 10^{-3}$
mM )
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| Increase roots in |  |
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| lengths and weights | Katalin, 1982) |

Table 1. The existing functional regulation of animal hormones on plants. Plants could respond to external stimuli by animal hormones. The dose of physiological regulation produced by the corresponding hormone on the plant has been listed. The clinical concentration of animal hormones is noted below the corresponding hormones based on previous research. In some calculations, the average weight of adult and child are considered 60 kg and 25 kg , respectively if not mentioned in the article. Considering the proportion of water in human body, we approximate the weight of 1 kg human to 1 L , so as to reflect intuitively the safety when using these hormones in plants on animals.

## Concluding Remarks and Future Perspectives

In summary, there has been multiple regulatory effects for animal hormones on plants. Here, we summarized existing discovery about the effects of animal hormones on plants (Table 1) to show explored physiological functions of animal hormones on plants.

It is well established that some allegedly animal hormones are not unique to animals (Pasko, SulkowskaZiaja, Muszynska, \& Zagrodzki, 2014; Hano et al., 2017). Many of them have been found naturally on plants. These animal hormones could regulate stress resistance, reproductive and photosynthetic systems in plant. Notably, some of them, such as melatonin and serotonin even have been used to improve agricultural or horticultural production and resist biotic and abiotic stress (Jiang, \& Asami, 2018; Zhang et al., 2018; Debnath et al., 2019). Hopefully, it has great potential to see new approaches about them appeared to meet human demands for ornamental plants and crops. However, it is necessary to ensure the safety of animal hormones contained in these plants to the human body. We referred to clinical concentrations of some animal hormones (Table 1). Some animal hormones used in plants could reach medical concentrations theoretically in humans. This means the use of animal hormones on plants could have a potential effect on humans through food. We should be aware of possible health threats if we use animal hormones on plants in the future. But the functional and regulatory mechanisms of plants in response to animal hormones remain to be elucidated. We only draw these conclusions from theoretical clinical data with the lack of direct evidence. More research should be carried out to study the application of animal hormones in agriculture. And we are looking forward to understanding the hormonal networks systematically and the molecular mechanism of them in both plant and animal.

## Conflicts of interest

The author declares no conflict of interest.

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