LITERATURE REVIEW PACLOBUTRAZOL POTENTIAL AND PHYSIOLOGICAL ROLE IN TUBER CROPS AS FOOD DIVERSIFICATION

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ABSTRACT
Tuber as one of the vegetative organs of plants, can be utilized as a complementary food or a substitute for rice. Tuber productivity depends on the amount and rate of assimilation, so growth regulators are needed that can increase the productivity of tuberous plants, such as paclobutrazol. Paclobutrazol is a growth regulator that has a major role in inhibiting the vegetative phase of plants. Paclobutrazol will inhibit the rate of gibberellin biosynthesis thus inhibiting plant height growth. Paclobutrazol, containing triazoles, boosts cytokinin biosynthesis, supporting chloroplast separation and chlorophyll biosynthesis whereas anticipating debasement. This comes about in delayed photosynthetic action, expanding acclimatize aggregation for tuber arrangement. At ideal measurements, paclobutrazol keeps up shoot biomass, chlorophyll substance, morphogenesis, photosynthetic capacity, and phytohormone adjust, driving to physiological and morphological changes in plants.
Kewords: accumulation, biosynthesis, photosynthesis, retardants

ABSTRAK
Umbi sebagai salah satu organ vegetatif tanaman, dapat dimanfaatkan sebagai makanan pelengkap atau pengganti nasi. Produktivitas umbi bergantung pada jumlah dan laju asimilasi, sehingga diperlukan zat pengatur tumbuh yang dapat meningkatkan produktivitas tanaman umbi-umbian, seperti paklobutrazol. Paklobutrazol merupakan zat pengatur tumbuh yang memiliki peran utama dalam menghambat fase vegetatif tanaman. Paklobutrazol akan menghambat laju biosintesis giberelin sehingga menghambat pertumbuhan tinggi tanaman. Paklobutrazol, yang mengandung triazol, meningkatkan biosintesis sitokinin, mendukung pemisahan kloroplas dan biosintesis klorofil sekaligus mengantisipasi pembusukan. Hal ini terjadi dalam aksi fotosintesis yang tertunda, memperluas agregasi aklimatisasi untuk pengaturan umbi. Pada pengukuran yang ideal, paklobutrazol menjaga biomassa tunas, zat klorofil, morfogenesis, kapasitas fotosintesis, dan fitohormon menyesuaikan diri, mendorong perubahan fisiologis dan morfologis pada tanaman.

Kata Kunci : akumulasi, biosintesis, fotosintesis, penghambat

Introduction

Rice could be a staple nourishment for over half the global population, with around 90% delivered and expended in Asia (Bandumula, 2014). In some areas, food security is difficult to realize when people's consumption is inversely proportional to the planning done by the government. Therefore, food diversification is needed by not completely replacing rice as the staple food, but rather changing and improving people's consumption patterns to have a wider variety of foods with better nutritional quality (Singha et al., 2014). One alternative that can be used is by consuming tubers. Major tuber crops include cassava, sweet potato, yam, and aroids. Minor ones comprise Amorphophallus konjac, wild Dioscorea, Coleus, Costus, Typhonium, Tacca, arrowroot, canna, Chinese potato, cocoyam, Ceropegia, Alocasia, winged bean, yam bean, swamp taro, giant taro, and starchy Curcuma species (Parra et al., 2005; Neviani et al., 2005).

Tubers are agricultural commodities that contain high carbohydrates as food substitutes for rice. Tubers also make a significant contribution to food diversity and nutritional adequacy of the community because they contain vitamins, minerals, and fiber (Estiasih et al., 2017). Therefore, it is necessary to cultivate tuberous plants to produce quality products, one of which uses growth regulators so that plants can be stimulated, inhibited, or modified in their physiological processes to obtain the expected production. One of the growth regulators is paclobutrazol. Paclobutrazol is an inhibitor that play a role in allocating nutrients and plant energy directed to reach the generative phase faster to increase production (Saputra et al., 2017).

Paclobutrazol as a growth regulator can shorten plant stems, increase leaf chlorophyll content Dewi et al., (2018) and enhance the activity of enzymes that transport sucrose from source to sink and accumulate for tuber formation so that the time needed to form sweet potatoes is also relatively faster by focusing photosynthate flow for tuber formation and enlargement (Zheng et al., 2012).

Tuber productivity depends on the amount and rate of assimilation from the crown to the lower part of the plant. If shoot growth is greater, it will result in smaller tubers (Sasvita et al., 2013). The application of growth regulators can be done to modify plant growth physiologically, namely by regulating vegetative and generative growth. PBZ is one of the growth regulators of the retardant type that is capable of inhibiting gibberellin biosynthesis, vegetative growth is inhibited and assimilates will be transferred to the reproductive parts of the plant or the accumulation parts, such as tubers and stems (Desta et al., 2021). Therefore, the right concentration of PBZ is needed for optimal growth of each type of tuber crop.

RESEARCH METHODS

The method used in this article is a descriptive method obtained through a literature review of 48 articles that have been analyzed in depth. The articles selected cover a wide range of sources relevant to the research topic, and through a systematic review of each article, the authors were able to identify key themes, trends, and important findings that provide a comprehensive overview of the topic. The selection process of the articles was conducted by considering the credibility of the sources and the relevance of their content to the research objectives, so as to produce valid and reliable conclusions.

RESULTS AND DISCUSSION

Chemical formula of paclobutrazol

Paclobutrazol was registered in 1985 (cultar, ICI Americas, Goldsboro, NC) (Davis et al., 1991). PBZ officially recorded in India in November 2009 by the Central Insecticides Board & Registration Committee as a plant growth regulator under section 9(3) of the Insecticides Act, 1968 Kegley et al., (2010) and has since been sold under various trademarks (Kishore et al., 2015). PBZ is one type of growth inhibitor used in plants and is widely known and widely used at an affordable price. PBZ is a pyrimidine derivative that has the empirical formula C15H20CIN3O (Wattimena, 2006).

Paclobutrazol as a growth regulator

The growth regulators are natural compounds of nutrients that can stimulate development and growth that work actively in a plant. A growth regulator is usually made from chemicals or synthetics that have pure content, but it can also come from organic or natural materials that have content that almost matches growth regulators made from chemicals or synthetics (Asra et al., 2020). A growth regulator is a non-nutrient organic compound that is active in low concentrations and can cause biochemical, physiological, and morphological responses. The growth regulator plays a role in regulating the growth acceleration of each tissue and integrating these parts to produce the desired shape (Lestari, 2011).

Furthermore, a growth regulator as organic compounds produced by plants can be used in other parts of the plant, the location of production and work in various sections of the plant, and actively working at low concentrations are criteria that must be owned by growth regulators (Cokrowati, et al., 2019). Endogenously produced growth regulators consist of five groups: auxins, gibberellins, cytokinins, ethylene, and abscisic acid (Salisbury et al., 1959). Besides promoting plant growth, growth regulators can also inhibit it or suppress plant growth which is classified as a retardant substance. The retardants are divided into two categories: natural retardants and synthetic retardants. Examples of natural retardants are benzoic acid, coumarin, and cinnamic acid. Examples of synthetic retardants are daminozide, chlormequat (*cystocele*), paclobutrazol (*bonzi*), and maleic hydrazine. Some synthetic retardants are commonly used in horticultural cultivation. The function of these retardants is to inhibit internode elongation, forming a more compact and attractive plant (Acquaah, 2002). PBZ is more effective in suppressing gibberellin synthesis than other retardants, such as CCC (*chlorocholine chloride*) [Hamdani et al., 2016).

The application of PBZ with higher concentrations in *Solanum tuberosum* L. influences plant growth and metabolism in the subapical meristem, leading to the inhibition of cell elongation., resulting in inhibited stem internode elongation, and stimulate the growth of new shoots (Sambeka et al., 2012). PBZ can inhibit stem height growth increase stem thickness in young plants and accelerate rooting in *Lycopersicon esculentum* shoots. PBZ physiologically plays a role in suppressing stem elongation due to PBZ activity that can inhibit gibberellin biosynthesis through inhibition of ent-kaurent oxidation to kaurenoic acid in the second stage of gibberellin biosynthesis (Soumya et al., 2017). In addition to being used to inhibit plant growth, PBZ can also increase yield in plants, for example in potatoes (Karmelia et al., 2018). PBZ increases the activity of sucrose-transporting enzymes that play plays a role in moving sucrose from the source to the sink (Dewi, 2018). PBZ can be used to create plants that are not too tall, have compact flowering, and have many fruits and faster flowering plants (Saputra et al., 2017). The use of PBZ in other words can be a solution to overcome the potential for dwarfism in sunflower pot plants. PBZ can encourage flowering, encourage pigment formation, prevent etiolation, and extend the rooting of cuttings, and in low concentrations can increase plant resistance to disease (Novi et al., 2017.

Tuberous plant variety and morphology

Tubers are plant organs that undergo changes or modifications in the form of other organs in plants that function as storage of certain substances. The formation of tubers consists of several stages of a complex process starting from the formation and growth of stolons, induction of tuberization, tubers initiation, and tubers growth (Ewing et al., 2010). Tubers are swollen bodies, round, cone-like, or irregular shapes, food storage, can be an incarnation of the stem, and can also be an incarnation of the roots. Therefore, tubers are divided into stem tubers (*tuber caulogenum*) and root tubers (*tuber* *rhizogenum*). Stem tubers generally have no remnants of leaves, so the surface is smooth, stem books and internodes are not clear or called bare tubers (*tuber nodes*) as in potatoes (*Solanum tuberosum* L.) and sweet potato (*Impoema batatas* Poir.). Stem tubers are still visible from the presence of buds on these tubers, which will be able to sprout to produce new plants. Some tubers lie on the part of the plant that is above the ground, namely on the stem or in the leaf axils referred to as *tuber caulinare*, for example, yam (*Dioscorea alata* L.), gembili (*Dioscorea aculeata* L.). Root tubers are tubers that are the incarnation of roots and never have leaves. Root tubers can be the incarnation of taproots for example in radish (*Raphanus sativus* L.), jicama (*Pachyrrhizus erosus* Urb.), and fibrous roots for example in cassava (*Manihot utilissima* Pohl.), dahlia (*Dahlia variabilis* Desf.). Root tubers are not as likely to be used as breeding tools as stem tubers (Tjitrosoepomo, 2020).

Solanum tuberosum L. is an herbaceous annual of the *Solanaceae*, whose tubers are edible and are called potatoes, sweet potatoes, sleigh bells, etc. It ranks as the world's fourth most important food crop (Zhang et al., 2016). Potato is a herbaceous and annual plant with fibrous roots and tubers that are enlarged parts of underground stems. It has angular, branched stems and pinnately compound leaves up to 30 cm long. Inflorescence is a cyme featuring flowers that vary in colors, such as white, blue, purple, red, pink, and yellow (Rice et al., 1990).

Sweet potato (*Ipomoea batatas* Poir.) is a globally important crop for human nutrition, it is rich in carbohydrates (mainly starch) and serves as a key energy source. It also contains essential minerals (potassium, manganese, copper, iron, and zinc) and proteins that provide necessary amino acids for metabolism (Neela et al., 2019). Sweet Potato is a herbaceous habitus plant, creeping on the soil surface reaching 3-5 m. Fibrous, brownish-white roots that will form tubers. Tubers are round to long, slightly hard, skin color white, yellow, and purple, flesh color purple, white, yellow, yellow, purple, 7 to 25 cm in length and 3 to 8 cm in diameter. Sweet potato stems are round, woodless, smooth, green, and purple in color. Sweet potato leaves are single, stalked, rounded stalks, some are round, and some resemble a heart, green and purple fingered bones, tapered ends, flat and notched bases, and edges vary, some are flat and some are incised (Lende et al., 2020).

Cassava (*Manihot esculenta* Crantz) is a terna, perennial, 1- 4 m tall, taproot plant. Tubers are elliptical, dark brown epidermis color, rough epidermis surface, white and yellow layer skin color, and white and yellow tuber flesh. Stem woody, erect, rounded, branched, stem pith white and yellow, young green and old greyish brown to yellowish brown. Leaves are single, stalked, dark red and yellowish red, the arrangement of leaves on the stem is alternate, and round in shape, the edges share a finger into 5-6 nicks, and the depth of the nicks is between 6-12 cm, the reinforcement is fingered and light green in color, the length is between 8-15 cm, the width is between 2-7 cm (Lende et al., 2020).

Effect of paclobutrazol on the growth of tuberous plants

PBZ is a growth retardant that can shorten plant stems, PBZ application increases the function of sucrose transporters. involved in sucrose translocation from sources to sinks (Dewi, 2018). One of the important sinks is the tuber. Some studies show that tuber formation, number of tubers, tuber size, and tuber weight increase with increasing concentration of paclobutrazol with a concentration of 7.5 mg-1 (Suharjo et al., 2019).

Tubers are one of the organs in plants to store starch, which is the main source of energy reserves for growth. Starch can be broken down into sucrose which is transported and utilized for vegetative growth and inflorescence formation (Zheng et al., 2012). PBZ has a significant effect on the morphology of potatoes. It suppresses vegetative growth by reducing the height and total weight of shoots.

PBZ inhibits plant growth by blocking gibberellin synthesis, affecting the isoprenoid pathway, altering hormone levels, and increasing cytokinin, which reduces stem elongation. PBZ also showed dark green leaf and stem colors, indicating high chlorophyll content (Husen et al., 2024). PBZ increased tuber yield by preserving shoot biomass duration (SBD) and chlorophyll content while positively affecting the growth rate of the tubers (Elizani et al., 2019). PBZ inhibits gibberellin production in the terpenoid pathway by blocking enzymes involved in metabolic reactions. Since gibberellins stimulate cell elongation, their inhibition allows cell division to occur without elongation, resulting in shorter branches. This substance is transported through the xylem to the shoot buds (Sambeka et al., 2012). PBZ works opposite to the action of the hormone gibberellin so that it can inhibit GA3 biosynthesis, besides that PBZ can reduce upward growth, especially reducing internode length depending on the type of potato species and cultivar. PBZ halts plant growth, leading to increased carbohydrate reserves in the roots and allowing for earlier flowering and fruiting. The application of PBZ in small doses is useful for stimulating simultaneous flowering and fruiting (Lolaei et al., 2013). PBZ has an effect on root development in sweet potatoes which can be seen from the increased storage root number and yield of sweet potatoes (Ribeiro et al., 2021).

Effect of paclobutrazol on the physiological response of tuberous plants

Chlorophyll content

Paclobutrazol (PBZ) is a growth inhibitor that induces dwarfism, boosts chlorophyll content, enhances photosynthesis, and inhibits gibberellin synthesis, leading to increased production (Salisbury et al., 1959). Chlorophyll aids photosynthesis by capturing sunlight at specific wavelengths (Elizani et al., 2019).

Ponders on PBZ application appear it altogether influence potato plant tallness when connected 4-6 weeks after planting, hindering stem internode development and expanding leaf chlorophyll. This upgrades photosynthesis, coordinating vitality toward carbohydrate arrangement in tubers (Sambeka et al., 2012). When PBZ is used as a foliar spray, it is absorbed by the petiole and stem, and then transported to the growing tip through the xylem. When applied as a soil drench, it is taken up by the roots and delivered to the apical meristem via the xylem (Desta et al., 2021). PBZ increases leaf chlorophyll content, enhancing photosynthesis and directing energy to tuber carbohydrate formation, significantly boosting tuber weight. It also inhibits gibberellic acid synthesis, halting shoot growth and elongation (Ni'mah et al., 2014). PBZ increases leaf chlorophyll content by diverting the gibberellin pathway, leading to the formation of compounds like phytol, a precursor of chlorophyll (Husen et al., 2024). The results of research related to the effect of PBZ application on tuberous plants are presented in Table 1 below.

Table 1 List of effects of paclobutrazol (PBZ) treatments on tuberous plants

Scientific name	PBZ dosage	Application Site	Effects on Plants				Reference
			Leaves	Stem	Root	Tuber	
Solanum tuberosum L.	125 ppm	Root-Shoot	+ Cl	+SH	-RN	+ TW	Sambeka et al., 2012
Solenostemon rotundifolius Poir.	10 ppm	Root	+Cl	-	-	-	Kishorekumar et al., 2006
Amorphophallus onchophyllus P.	200 ppm	Root	+Cl	-SH	-	+TW	Hidayah et al., 2022
Ipomoea batatas L	200 $L.ha^{-1}$	Leaf	+Cl +L	-SH	+RN	+TW	Ribeiro et al., 2021
Manihot esculenta crantz	400 ppm	Shoot Buds	0	-SH	-RN	+TW	Ardian et al., 2019

Notes :
+ = Increase
- = Decrease
0 = No effect
(-) = Not Delivered
Cl = Chlorophyll
L = Leaves

SH = Stem height
RN = Root Number
TW = Tuber Weight
TT = Tuber Tiller

Paclobutrazol is effectively applied through leaves and soil, translocating via the xylem to shoot buds. It increases leaf chlorophyll content, enhancing photosynthesis and directing energy toward tuber carbohydrate formation, significantly boosting tuber weight.It also inhibits gibberellic acid synthesis, halting shoot growth and elongation (Wieland et al., 1988).

Leaf senescence

Leaves are the main photosynthetic organ and the main source of carbon assimilation and plant growth. Chlorophyll, the main photosynthetic pigment in leaves, enhances the photosynthetic process by effectively utilizing solar energy, promoting continuous plant growth (Anjum et al., 2011). However, once the plant reaches the reproductive stage, chlorophyll levels in the leaves gradually decline due to leaf senescence, significantly diminishing photosynthetic capacity (Wang et al., 2018). Senescence is a process of declining conditions and metabolic activity that accompanies aging and leads to the death of organs or organisms. Where all these processes are controlled by space and time, the senescence process is usually followed by abscission. The process of senescence begins with a reduced nutrient supply to an organ, decreased metabolic activity, and decreased growth. The process of leaf senescence can be suppressed by applying paclobutrazol (Firdaus et al., 2006).

Paclobutrazol is a retardant that inhibits gibberellin biosynthesis, reducing cell division and vegetative growth by blocking kaurene oxidation. This leads to slower leaf growth and extends leaf wilting time at certain concentrations. The application of PBZ was shown to delay leaf senescence and maintain higher chlorophyll content in potatoes compared to control plants. PBZ can stimulate plant synthesis of cytokinin (Husen et al., 2024).

Effect of paclobutrazol on the action of other growth hormones

Paclobutrazol is a type of retardant from the class of triazole compounds that play a role in inhibiting gibberellin biosynthesis by blocking ent-kaurene oxidation (Desta et al., 2021). Gibberellin can accelerate cell division and growth, and encourage adventitious root growth. Gibberellin can delay the process of tuber formation in plants so that the provision of growth inhibitors such as PBZ can increase tuber production (Falcon et al., 2006). The decrease in gibberellin content by PBZ can increase abscisic acid (ABA) production. High endogenous ABA content can trigger bud dormancy, thus inhibiting budding during storage. At the time of PBZ application, ABA hormone will decrease considerably in the tubers at all growth periods. The amount of IAA hormone will increase during the vegetative period (Zheng et al., 2012). So that the application of PBZ is in line with what is needed, taken also from other plant species, and other hormones. PBZ also enhances the production of ABA and cytokinins, which help accumulate biomass and store it in specific plant organs, thereby indirectly boosting plant production (Assuero et al., 2012).

Effect of paclobutrazol on the assimilation of bulbous plants

PBZ applied can be directly absorbed by plants through stomata and can direct the supply of photosynthate from the photosynthetic process in the leaves (Nurmala et al., 2017). PBZ blocks gibberellin production on the terpenoid pathway. When GA production is blocked, cell division continues, but new cells remain unelongated, resulting in branches with shorter lengths. The substance moves through the xylem and reaches the shoot buds (Sambeka et al., 2012).

The application of PBZ can increment the action of sucrose transporter proteins that play a part within the translocation of sucrose from the source to zinc. PBZ contains triazoles that can increment cytokinin biosynthesis which plays an imperative part in chloroplast differentiation, and chlorophyll biosynthesis additionally avoids chlorophyll degeneration (Husen et al., 2024). High chlorophyll content and slow degradation enhance photosynthetic activity, allowing plants to sustain photosynthesis longer. This extended activity boosts the accumulation of assimilates for tuber formation. The inhibition of gibberellin biosynthesis stimulates cytokinin synthesis, which aids in the bulking process [Ni'mah et al., 2014). This indicates that the application of PBZ helps preserve leaf greenness and stimulates cytokinin production in plants. Cytokinin enhances chloroplast differentiation and production and prevents the breakdown of chlorophyll. Enhanced chlorophyll content and reduced degradation boost photosynthetic activity (Nurmala et al., 2017). Optimal doses of PBZ promote shoot biomass, leaf surface area, chlorophyll levels, and overall root and plant development (Husen et al., 2024). PBZ increases the chlorophyll content of lily leaves due to chlorophyll and enhances the transport and utilization of photoassimilates (Zheng et al., 2012).

CONCLUSION

Besides being useful as vegetative organs of plants, tuber can be utilized as a companion food or a substitute for rice. Considering that the productivity of tubers depends on the amount and rate of assimilation, a growth regulator is needed that can increase the productivity of assimilation results. Paclobutrazol is a growth regulator that has a major role in inhibiting the vegetative phase of plants. This growth inhibition will inhibit the rate of gibberellin biosynthesis, thus inhibiting the growth of plant height, and the assimilate will be transferred to the reproductive part of the plant to be accumulated, in this case, the tuber. Paclobutrazol (PBZ) contains triazoles that boost cytokinin biosynthesis, supporting chloroplast separation and avoiding chlorophyll corruption. This leads to drawn out photosynthesis, expanding acclimatize collection for tuber arrangement. PBZ upgrades carbohydrate collection by changing morphogenesis, photosynthetic capacity, and phytohormone adjust, making strides the dissemination of acclimatizes between plant organs. PBZ is promising for expanding tuber trim yields but assist investigate is required to decide its affect on tuber quality and its potential to move forward planting materials for tuberous plants.

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