Advancements in Understanding Auxin's Role in Starch Production

Rida Fatima[1*], Bushra Sadia[2], Zakia Parveen[1] and Arslan Muhammad Ali Khan[3]

1. Department of Botany, University of Agriculture Faisalabad, Pakistan
2. Centre of Agricultural Biochemistry and Biotechnology, University of Agriculture Faisalabad, Pakistan
3. Department of Parasitology, University of Agriculture Faisalabad, Pakistan

*Corresponding Author: **rida86001@gmail.com**

ABSTRACT

Starch is a vital nutrient and the main source of carbohydrates for plant growth. While starch is essential for plants' energy source, a network of hormonal signals controls growth and development and auxin is especially important in this case. According to current research, auxin is a plant hormone that affects gene expression and enzyme activity and leads to enhanced starch production. This review includes research on auxin synthesis and regulatory mechanisms, including its impact on starch synthase expression and interactions with cytokinin's and gibberellins. The article covers the role of auxin in starch deposition across major crops like rice, maize, and peas as well as its impact on grain filling and kernel development. This review also discusses future ideas for altering auxin pathways to increase crop yields. The promise of auxin-based interventions to enhance agricultural productivity and global food security as well as future research is highlighted.

Keywords: Auxin, Starch production, Gene expression, Enzymatic activity, Hormonal interaction, Auxin's biosynthesis pathway

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Introduction

Starch is an insoluble, non-structural carbohydrate composed of α-glucose polymers. It is produced by plants and algae to store energy in a dense and osmotically inert form. It is primarily found as granules in seeds, tubers, and roots. It provides essential energy to plants for growth, development, and metabolism [1]. Starch also has significant importance for humans because it is the primary carbohydrate source in a balanced diet. It constitutes 60%-75% of the weight in cereals and is vital for energy supply in human diets. Modified starches are increasingly utilized in food products for their thickening and stabilizing properties, enhancing food quality and a renewable raw material for industry [2]. While starch is essential for plants' energy source, a network of hormonal signals controls growth and development and auxin is especially important in this case.

Auxins are plant hormones that play an important role in regulating plant growth and development under various environmental conditions. It is necessary for embryo development because it establishes the polar axis needed for the development of proper plant structure. Auxin is biosynthesized and metabolized through numerous parallel pathways, and it is detected and transmitted by both normal and atypical pathways [3]. Auxin's involvement in plant growth and development, as well as in stress response, is primarily determined by its synthesis, catabolism, and signal transduction pathways. Even at low concentrations, auxins can affect gene expression through particular transcription factors and proteins that are regulated to environmental reactions in the signaling pathway. Auxins are produced in tissues with high cell division activity and distributed by specialized transmembrane proteins that regulate efflux and influx [4].

According to recent studies, auxin affects the expression of genes that are involved in the production of starch. Auxin inhibits starch accumulation via down-regulating genes such as AGPS, GBSS, and SBE. The functional characterisation of two auxin responsive factors in tomato (SlARFs) revealed that auxin signaling regulates sugar metabolism throughout fruit development. In tomato, ARF4 suppresses auxin-dependent gene expression, resulting in altered starch biosynthetic gene expression and high sugar and starch levels in fruits [5].

Auxin Biosynthesis and Regulation

Biosynthesis of auxin requires multiple pathways and regulatory system because it's a complex process. It can be synthesized from the precursor molecule tryptophan using a variety of mechanisms, including intermediates, or through a tryptophan-independent pathway. The tryptophan-dependent pathway includes indole-3-pyruvic acid (IPA), YUC flavin monooxygenase, indole-3-acetamide (IAM), and tryptamine (TAM) pathways [6].

The Indole-3-Pyruvic Acid (IPA) Pathway

The most extensively explored is the IPA pathway, which consists of three steps. It starts with the oxidative transamination of tryptophan to IPA, then decarboxylates IPA to indole-3-acetaldehyde (IAAld) by indole-3-pyruvate decarboxylase and then changes IAAld to IAA as the final product via the enzymatic process of IAAld dehydrogenase. The flavin monooxygenase-like proteins (YUC family) enzymatically convert IPA to IAA via the YUC flavin monooxygenase route, which is thought to be 'the primary auxin synthesis pathway in Arabidopsis'. IAAld is a crucial step for two other IAA biosynthesis pathways and can be produced directly from tryptophan or through the intermediate molecule tryptamine [7].

Other Biosynthesis Pathway of Auxin

Although IPA pathway is believed to be the major auxin production pathway, some other pathways have also been recognized.

Tryptamine pathway: This pathway converts tryptophan to tryptamine, which is subsequently oxidized to produce IAA. This pathway is not as well understood, but it can be involved in certain tissues or under particular environmental conditions.

Indole-3-Acetamide Pathway: This pathway converts indole-3-acetamide to IAA through the enzyme indole acetamide hydrolase. This pathway is particularly important in certain plant species and tissues.

Phenylalanine pathway: Recent studies have discovered a metabolic interaction between auxin biosynthesis and phenylalanine biosynthesis. Phenylpyruvate, a phenylalanine biosynthesis intermediary, can serve as an amino acceptor in the TAA1/TAR-catalyzed reaction, increasing auxin biosynthesis [8].

Regulatory Mechanisms

Auxin levels in plant tissues are strictly regulated to promote optimal growth and development. The regulation is a compilation of biosynthesis, conjugation, degradation, and transport processes:

Biosynthesis: Auxin biosynthesis is geographically and temporally regulated at both the transcriptional and post-transcriptional levels. For instance, TAA1 and YUCCA gene expression are tissue-specific and environmentally regulated by stimuli [9].

Conjugation: Inactivation of auxin is also achieved by conjugating sugar or amino acids, forming storage forms that are inactive like IAA-glucose and IAA-aspartate. The conjugates are cleaved to give free active IAA when it is required.

Degradation: Breakdown of auxin is catalyzed by enzymes like IAA oxidase, which degrade IAA into inactive products. The process is tightly regulated in order to maintain auxin homeostasis.

Transport: Auxin transport, both locally and over long distances, is crucial for creating auxin gradients inside tissues. Tropisms and organogenesis rely on this transport, which is facilitated by specialized carrier proteins [10].

Auxin and Starch Synthesis

Plant tissue auxin levels are strongly related to starch production, especially in growing grains. Auxin promotes the differentiation of starch-storing tissues in cereal grains, including the endosperm and aleurone layers. For example, in wheat, the expression of the auxin biosynthesis genes TaTAR2-B3 and TaYUC9 correlates favourably with starch content and grain size. Auxin modulates important enzymes that are involved in starch metabolism for the deposition of starch. Auxin also modulates the genes that encode ADP-glucose pyrophosphorylase and starch synthase for starch synthesis [11].

Molecular Regulation of Auxin in Starch Production

Various molecular mechanisms have been involved in the production of starch by auxin. These include modification of gene expression, interaction with other enzymes like cytokinin and gibberellins and increased enzyme activity.

Gene Expression Modulation

The expression of genes involved in starch biosynthesis is altered by auxin to control starch production. For example, auxin deficiency increased the expression of ADP-glucose pyrophosphorylase small subunit (AgpS) and granule bound starch synthase to promote starch synthesis in tobacco plant cells. However, increased concentration of auxin lowers the expression of these genes which demonstrate that auxin plays a vital role in the deposition of starch under certain conditions [12]. The expression of auxin biosynthesis genes such as TaTAR2.3-1B, TaYUC9-A1, TaYUC9-B, TaYUC9-D1, TaYUC10-A, and TaYUC10-D are all linked to starch synthesis in developing grains of wheat [11]. There are some transcription factors in maize such as ZmDOF36 and ZmICIE1 that have been activated by auxin to produce starch [13].

Enhancement of Enzymatic Activity

Certain enzymes are involved in the production of starch. The activity of those enzymes has been increased by auxin to boost up starch synthesis. For example, the activity of α- and β- amylase is boosted up in sorghum which breaks down and synthesize starch. Similarly, auxin increases the activity of sucrose synthase. It is an enzyme that metabolizes sucrose and produces substrate for starch production [14].

The treatment of rice with auxin also increases the activity of starch synthase which in turn increases starch content in grains [15]. Similarly, auxin modifies the activity of ADP-glucose pyrophosphorylase which limits the production of starch. All these studies demonstrate that auxin plays an important role in modifying enzymatic activity for starch production [16].

Hormonal Interaction

The interaction of auxins with cytokinin and gibberellins control the production of starch in plant cells. Gibberellins interact with auxin to increase the breakdown of starch in rice during salt stress and promote starch mobilization during seed germination. Since auxin treated seed produces more gibberellins so this link can be explained by change in endogenous hormone levels. On the other hand, auxin and cytokinin work antagonistically to regulate the production of starch. Cytokinin amplifies the genes involved in starch synthesis whereas auxin suppresses it. So, the production of starch in plants significantly depends on the interaction between cytokinin and auxin [17]. The contribution of auxin in starch production across major crops is illustrated in table 1.

Table 1: summary of Auxin's role in Starch deposition across major crops

Crop	Auxin role in starch deposition	Significant finding	References
Rice	Regulates starch deposition by modulating the expression of biosynthetic genes.	Increased auxin levels during grain filling promote starch accumulation through *OsYUC11* and *OsTAR1*.	[18]
	Auxin control sugar transporter expression for starch storage	*OsTIR1* and *OsARF25* regulate *OsSWEET11*, affecting starch synthesis	[19]
	Auxin interact with ABA for grain filling	*qPE9-1* gene regulates auxin and ABA level to enhance starch production	[15]
Maize	Auxin promote starch deposition via carbon metabolism	Auxin regulate the gene cell wall intvertase (*CWIN*) for starch production	[20]
Pea	Mutation in auxin biosynthesis gene	mutation in gene tryptophan aminotransferase related2 (*TAR2*) is linked with impaired starch synthesis	[21]

Future directions

The role of Auxin in the production and storage of starch requires more investigation. A detailed investigation of the complex interaction of genes and biochemical interactions along with ideas of hidden pathways can explain how auxin influences starch metabolism. If future study focuses on modifying these auxin pathways to increase starch deposition then maybe we end up with crops with significantly improved features [22]. Plant physiology, biochemistry, and genetics can all work together to produce unforeseen benefits. Combining the viewpoints of experts from different fields frequently leads to a new understanding of how auxin may influence starch accumulation. The only way to transform those controlled results into useful and applicable insights is to go outside of the lab and do field experiments [23].

Conclusion

Auxin helps plants produce and accumulate starch, which is crucial for growth and development. It regulates gene expression in endosperm, starch production, and tissue differentiation. It also aids in stress management by regulating genes involved in the stress response. Gibberellins and auxins stimulate starch production in staple crop grains. The role of auxin in starch formation in plants can be studied by altering the auxin biosynthesis pathways. Collaboration between plant research, agronomy, and government can be useful in this area.

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