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Molecular Basis of Dormancy in Wheat: A Path to Enhancing Crop Resilience and Productivity: a review article

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Abstract: Wheat (Triticum aestivum.) is one of the most important cereal crops in the world and a staple food for billions of people. Despite this, wheat production is hindered by several factors such as climate change, pest incidence and the decrease of arable land. Molecular dormancy, a poorly understood but critical feature of wheat, is key to seed vigour and yield. This review further delves into molecular dormancy in wheat which could be a significant target for modulating crop resilience and productivity. This review covers the genetic and epigenetic basis of dormancy in wheat, including an insight into the regulatory networks behind it. Focus on environmental signals and signalling pathways that activate or release dormancy of seeds or plants in wheat/respectively Knowledge of the molecular basis of dormancy presents exciting avenues for crop improvement, including the modification of germination timing and the development of stress-resilient crops in a sustainable manner. Such approaches can transform wheat production to meet the demands of climate variability, new pests and diseases, and shifting global food requirements.

Keywords: Dormancy, Crop Resilience, Molecular, Productivity, Wheat.

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Introduction

Wheat (Triticum aestivum L) constitutes a significant cereal cultivation on a global scale as reported by FAOSTAT (1). It is categorized based on growth habit, kernel color, and texture of the ripened grain according to Briggle and Reitz (2). For example, hard wheat comprises four primary subclasses, namely hard red spring, hard red winter, hard white, and durum (amber color). Soft wheat is additionally categorized into soft red winter and soft white cultivars. In general, Winter wheat necessitates a specific duration of cold temperatures, known as vernalization, in order to initiate grain production, unlike spring wheat (3). Multiple studies have also demonstrated that white-kernel wheats generally exhibit increased susceptibility to pre-harvest sprouting in comparison to red wheats. The correlation observed between preharvest sprout tolerance and red pigmentation is believed to stem from the pleiotropic influence of the genes that regulate grain colour, as described by Kumar *et al*. (4). In the year 2015. It is the process that prevents viable seeds from sprouting under ideal environmental circumstances(5).

It is crucial to wheat production since it essentially controls preharvest sprouting and seed germination (6). Improvements areas that made in various are crucial to cultivar development have produced lines with few problems with seed dormancy. Therefore, as long as the conditions are right, the majority of lines germinate with ease. Moreover, the farming community readily adopts the technology since the cultivar offers seed treatment options in the event that dormancy problems with the line are discovered. Researchers, however, believe dormancy may be a when cultivar underway or that seed problem development is when attempting to regenerate some old lines from seed stored in gene banks. Some unwanted genes might be passed into the elite lines, for example, when crossing The genes from the wild relatives. that encourage seed dormancy might be among them. Breeders must remove genes linked to seed dormancy, which could slow the development of new due to linkage drag down cultivars (7). The development of cultivars that remain dormant until harvest in order to prevent pre-harvest sprouting is therefore one of the objectives of the wheat breeding program; however, the dormancy end after harvest. should swiftly end after harvest.

Influence of Environment on Seed Dormancy in Wheat

Environmental factors during grain development and maturation, as well as during grain storage, can also affect the degree of dormancy at harvest and its subsequent maintenance, despite the fact that it is a (8). After the grain maximum size, which heritable trait reaches its occurs about three to four weeks after flowering. embryo dormancy is initiated and maintained. After the ninety-day ripening period, a significant portion of the seeds in heavily dormant wheat sprout. However, depending on the genotype and storage conditions, the majority of wheat genotypes can have seed dormancy for anywhere between 20 and 60 days. As a result, the degree of seed dormancy at maturity varies among seeds of different genotypes. According to Rodriguez *et al*. (9), for instance, low seed dormancy at maturity is typically linked to high temperatures, short days, drought, and nutrient availability during seed development (2011). Moreover, the environmental factors have been documented to have a profound impact on seed dormancy in the field, particularly during the grain maturity phase. include Factors high temperatures, short days; Drought and nutrient availability during seed development are positively associated with low seed dormancy at the onset of maturity (9). Exposure of seeds to environmental factors such as cold, nitrate and light, as well as post-ripening, which refers to the duration of dry storage, can disrupt seed dormancy in wheat seeds (10). Producers play a crucial role in seed production. You must use recommended cultural practices such as: B. the timely application and the required amount of nitrate-containing fertilizers to the crop SO that there is sufficient nitrate fertilizer during grain development until ripening. Storage conditions are crucial for seeds. Poor storage conditions can affect seed dormancy.

Understanding Seed Dormancy: Mechanisms, Types, and Environmental Influences

According to Black *et al*., (11) seed dormancy is an evolutionary adaptive mechanism that keeps seeds from germinating in unsuitable environmental conditions, which would normally provide a low chance of seedling survival. As a result, under specific environmental conditions that typically encourage the germination of non-dormant seeds, dormant seeds do not germinate within a given time frame (12). The physiological mechanis m that postpones seed germination is seed dormancy, which is distinct from actual germination. Due to extemal environmental factors like being too cold, dry, or warm, seeds do not germinate when they are dormant (13). Numerous species exhibit a seed dormant period ranging from months to years, according to studies (14, 15). In one study, a Silene stenophylla that was thought to be over 31,000 years old and buried in Siberian permafrost was transformed int 0 a plant from tissue. This suggested that seed seed viability was maintained in part by seed dormancy (16).

The classification of true dormancy depends on the part of the seed that causes germination failure. The two classes are broadly both exogenous and endogenous. Under exogenous conditions, conditions outside the embryo trigger a dormant phase. In addition, there are three main factors among exogenous factors, namely physical, chemical and mechanical. Impermeable seed coats cause the seeds to have a physical dormancy period. Therefore, during the seed or fruit development and ripening phases, one or more impermeable layers form that limit water absorption and gas exchange (17). The above conditions prevent seeds from germinating until the layer is broken. Factors such as high temperatures, fluctuating temperatures, fire, freezing and thawing. The drying and passage of seeds through the animal's digestive tract helps break the physical dormancy period (18). The challenge with physical stillness is that once it is broken, it cannot be undone. Mechanical rest is another group within the exogenous class. Mechanical dormancy occurs in situations where the seed coat becomes too hard for the developing embryo to expand during the germination process (19). Finally, chemical rest is the last group in the exogenous classification. The elements involved in chemical dormancy include the growth regulators present in the covering tissue of the embryo. Once they are washed out of the tissue by soaking or washing the seed or other mechanisms that deactivate the chemicals. Rainwater or snowmelt can contain chemicals that leach from the seeds and can trigger chemical dormancy (19).

Seed dormancy in the second class is caused by endogenous factors. The embryo's internal conditions cause seed dormancy. The endogenous class is divided into three subgroups: physiological, morphological and combined dormancy. Physiological dormancy embryos and limits the growth of germination of environment seeds until the seed have chemical changes.

Gibberellic acid (GA3), when applied to seeds after ripening or during dry storage, speeds up germination in comparison to a control and may indicate physiological rest. Cutting out dormant seeds is another tactic to eventually create healthy seedlings.

Other research also backs up the application of scarification. A physiological dormant period is present in the seed sample if the process promotes germination (19). Because it inhibits growth, the amount of abscisic acid in the sample must be kept to a minimum during storage (20).

Because they are underdeveloped undifferentiated during the or morphological dormant phase, embryos are unable to fully develop into seedlings. Depending species, some on the crop seeds might contain fully developed embryos that need to develop before they can sprout.

In certain instances, the embryos might not develop into particul ar tissues when the fruit is ripening (21).

Lastly, when morphological physiological factors and are present, combined dormancy takes place, resulting complex dormant phase. physiological components in a Thus, also are present in seeds with immature embryos. Consequently, they need time to develop fully developed embryos and treatments to break dormancy (12). Both endogenous (physiological) and exogenous (physical) factors contribute to complex seed dormancy. A seed might, for instance, have a physiological dormant period and a hard, impermeable seed coat (22)

Seed Dormancy: Balancing Survival Benefits and Agricultural Challenges.

It is impossible to categorize seed dormancy as either good or bad in a cross-sectional scenario. Depending on the circumstances, seed dormancy is either deemed good or bad. When the right circumstances for germination are present, seed dormancy serves to postpone germination. All seeds may germinate less frequently as a result of this. This might be useful if there is minimal grain germination prior to harvest, as long as there has been consistent rainfall in the area. Grain quality is lowered by sprouting prior to harvest (23, 24), and it may become more vulnerable to fungal diseases (25). In order to manage pre-harvest germination and preserve grain quality, seed dormancy may be advantageous in the aforementioned situation. In situations where germination occurs gradually, seed dormancy may also be appropriate. This prevents seeds and seedlings from being harmed or, in severe situations, killed by unjustified periods environmental passing herbivores. of unfavorable conditions or by.

In temperate regions, where dormancy helps plants withstand extremely cold that may be detrimental to temperatures their reproductive and vegetative organs, this may be the case. Seed dormancy ensures that germination only occurs under favorable conditions. On the other hand, dormancy induced by inhibitors in seed coats is useful in desert plants. In other parts of the world, particularly in tropical regions, the dormancy period associated with impermeable seed coats guarantees high chances of survival under water-stressed conditions. Seed dormancy can also support artificial storage of seeds, particularly in gene banks, particularly for cereals and legumes (26). Seed dormancy also plays a crucial role in seed dispersal to distant locations from unfavourable environments. This is common in herbivorous animals when they feed on pastures containing seeds, and in birds when they feed on fruits containing seeds. The seed normally survives the gastric juices and germinates once released into the soil. Dormancy also helps seeds stay alive in the soil for several years, providing a continuous source of new plants even when all mature plants in the area have died due to natural disasters. A good example is bushfires in natural forests or grasslands. One of the disadvantages of seed dormancy is that it has implications for weed control. As long as some seeds remain dormant in the soil, it presents enormous challenges to completely eliminate the weed problem in the region (27).

The regulatory Genes involves in wheat dormancy

Dormancy in wheat is regulated by a complex network of genes that control the transition from the dormant to the active growth phase. Recent advancements in molecular genetics have enabled researchers to identify and characterize several key regulatory genes that play a fundamental role in the dormancy-to-germination transition.

Wheat breeders and researchers are interested in the influence of regulatory genes on dormancy that helps in controlling preharvest sprouting and enhancing the seed quality. It is observed that Delay of Growth of Germination 1 (DOG1) which is a quantitative trait locus responsible for regulating the response of seeds to phytohormones abscisic acid (ABA) and gibberellin (GA), which have opposite functions in dormancy and germination (28). Many seed maturation regulators such as LEAFY COTYLEDON1, LEC2, and FUSCA3 (FUS3) which tend to act as transcription factors in charge of seeds development and seeds storage tissues, affect the expression of DOG1 (29). The relationships between DOG1 and different seed maturation regulators and the connections of these regulators with ABA and GA metabolic genes are quite intricate and depend on the genotype and environment of wheat seeds as well. These studies also help to delineate the molecular mechanisms of loss of dormancy and seed germination in wheat (30).

A different set of genes encoding transcription factors, receptors, and hormones regulates together the complex signalling cascades associated with wheat dormancy (31). It was found that one of the most prominent regulatory genes of the wheat dormancy gene is the transcriptional factor TaABF1 (32). It is known that TaABF1 regulates the abscisic acid (ABA) signalling pathway that is vital in the maintaining dormancy status of the plant (33). This transcription factor is responsible for the upregulation of genes which further enforce seed dormancy by blocking its germination. Its identification made possible the creation of new wheat genotypes that can stay dormant for a longer period of time than previous similar genotypes. This is important because farmers will now be able to plant them expectedly when weather becomes favourable for agriculture.

Another active component of this regulatory network is the ABA receptor gene TaPYL. As the name suggests, this receptor has binding sites for ABA which stimulates dormancy and other downstream molecular events to prevent germination (34). It is important to determine the functions of TaPYL and their relations with other components of the ABA pathway to gain crucial knowledge about the molecular aspects of dormancy regulation. Moreover, attention must be given to the functioning of gibberellin (GA)-associated genes including TaGA2ox in the processes of breaking dormancy and initiating seed germination (35). These genes counterbalance ABA, enabling germination since they promote the breakdown of GAs, which are hormones that encourage growth. Effective control over the timing of dormancy emergence and the onset of germination requires a balance between ABA and GA signaling, and the discovery of TaGA2ox helps to complete part of this picture (36).

More recently, work has also addressed the gene participants in reactive oxygen species (ROS) metabolism, such as TaSOD and TaCAT, which are important in the process of breaking seed dormancy. Also, regulation of ROS production can lead to changes in redox environment in seeds, which subsequent determines seed dormancy and germination processes (37, 38). Among the various key regulatory genes of wheat dormancy, emphasis can be placed on TaVrn1 gene. TaVrn1 is responsible for vernalization response, which is the promotion of flowering following exposure to cold (39). The TaVrn1 gene is one of those members which control expression of other genes related to the vegetative and reproductive growth stage transition and thus length of dormancy.

Another important regulatory gene in wheat dormancy is the gene TaMFT (40). TaMFT is homologous to the Arabidopsis gene MOTHER OF FT AND TFL1 (MFT) (41). It is also involved in the processes of flowering time and dormancy by regulating the gene expression of these events. A teleological effect is observed in TaMFT in the sense that it responds to cold and switches the plant from dormancy to the active state. In Wheat, TaMORC1 residing in the satellite II is upregulated during dormancy and appears to facilitate the maintenance of dormancy to some extent by targeting chromatin organization (42). Similarly, it is involved in an epistatic interaction in the regulation of other genes associated with dormancy including TaABI3. TaABI3 gene is believed to be an important regulatory gene in wheat dormancy (42). In wheat, TaABI3 is known to regulate some genes that are associated with the aba signalling pathway and or stress response which are crucial for the maintenance of dormancy (43). Other major regulatory genes associated with dormancy include, TaSdr, TaBMY and TaSPL15. TaSdr is believed to be a homolog SLEEPLER (SLP) gene of wheat which has been established to be associated with the regulation of seed dormancy.

The effect of epigenetics on wheat dormancy gene regulation

In wheat, preharvest sprouting leads to serious grain yield and quality losses (44); it is also a characteristic of seed dormancy. Hence, it is highly important to explore the epigenetic regulation of seed dormancy in wheat for enhanced crop production and quality.

Histone acetylation is one of the epigenetic mechanisms that are proposed to be involved in the regulation of seed dormancy. One example of a histone modification is acetylation, which is reversible and modifies the chromatin structure to impact gene expression. As commitment to seed dormancy occurs at embryogenesis for wheat, the level of histone acetylation is dynamically altered (45). A permissive chromatin environment for expression of large number of genes and patterning cell fates in the early embryo, and a repressive state restricting totipotency and preventing organogenesis at late embryonic stages is suggested by H3K27ac fluctuations during early and late mammalian development for example, terminal embryos already displaying signs of organogenesis show decline in overall levels of active chromatin states across all developmental systems (46). In addition, H3K27ac is associated with the transcription of the hormonal pathways including ABA as well as GA which regulate seed dormancy and germination (47).

Another epigenetic regulator of seed dormancy has been identified as DNA methylation. The DNA methylation in wheat is different for different genotypes and tissues and is influenced by environmental conditions (48). High temperatures at the time of seed development, for example, decrease DNA methylation and seed dormancy in wheat (49). In addition, DNA methylation mediates ABA signalling genes, including PKABA1 and TaABF1, which are suppressed by DNA methylation in the embryo of sown wheat seed (50). They are also suppressed by H3K27me3, another marker of suppressive chromatin suggesting that DNA methylation and histone methylation might collaborate to regulate seed dormancy (51).

Conclusion

Molecular genetics of wheat dormancy is a fast-growing and dynamic research field, with big implications for crop improvement and food production. Recent findings about regulatory genes, epigenetic alterations and environmental triggers made it possible to develop novel wheat genotypes that are more dormant. With the increasing demands of agriculture due to climate change, such research is now more important than ever, presenting a promising and safer prospect for the world's wheat crops.

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