Combing of early maturity and aromatic traits in rice (*Oryza sativa* L.): A review

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Abstract. Rice (Oryza sativa L.) is the main food crop in Indonesia, and it's still highly consumed, indicating that its daily nutrient uptake relies on its grain. Flowering time of Rice is a crucial agronomic trait for seed production. It is mainly controlled by genes associated with photoperiod sensitivity, particularly in short-day plants. Aromatic or fragrant Rice is considered the best quality due to its desirable characteristics and global identity. The volatile compound 2-acetyl-1-pyrroline (2AP) is recognized as a vital component of the aroma of fragrant Rice. The variation in grain 2AP content among fragrant varieties is associated with the expression of the badh2 gene, with 19 alleles identified. This review paper focuses on the genetics of early maturity of aromatic traits, variability of both early and aromatic characteristics simultaneously.

1. Introduction

Rice (Oryza sativa L.) is the second-most significant cereal crop in the world, and 90% of people in Southeast Asia use Rice as a staple diet [1]. Rice grains contain 75% to 80% starch, 12% water, and 7% protein [2]. Over 25 species of the genus Oryza, but only two species, namely Oryza sativa and Oryza glaberrima, are cultivated globally [3]. It is a third of the world's population's stable food next to corn and wheat, and It is widely grown in tropical and subtropical regions; besides its position among the highly rated cereals, Rice feeds more than half of the world's population [4]. The total rice production worldwide in 2023 is about 523.9 million tons [5]. The main source of genetic variability in Rice originates in Asia; nevertheless, Rice is farmed and consumed across almost 90% of the world [6, 7]. The world's population is expected to require twice as much Rice by 2050 to fulfill their demands; thus, rice demand is expected to rise faster than produce [8]. Indonesia's traditional rice cultivars are part of the tropical japonica subspecies, occasionally called javanica [9]. Indonesia is the origin of Rice. There are still plenty of locations in Indonesia where indigenous Rice may be produced [10]. Plant breeders focused on two key factors, high yield, and early maturity, to

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increase rice production sustainably for food security and self-sufficiency [11]. As a result, raising rice production has always been a primary concern in meeting humanity's increasing needs [12]. Genetic variation in the population under study determines genetic improvement [13]. The variation among every genotype (and hence the features) within a population and the speed at which a particular genotype might vary in response to hereditary or environmental influences are known as variability [14]. Breeding techniques that focus on enhancing quantitative traits are designed and implemented differently depending on the level of genetic variation [15]. Many scientists have come to understand the importance of variation in test materials, giving up the possibility of improving the current genotypes [16]. Breeding efforts to enhance genetic variation for agronomic qualities are essential for expanding the gene pool of Rice [17]. In addition, high heritability and genetic progress are required for the qualities selected to create high-yielding cultivars [18]. Genotypic and phenotypic coefficients of variation, which separate genetic and environmental variance, can be used to evaluate the available genotype variability [19]. To achieve genetic improvement, one must understand the kind and extent of genetic variation that controls the transmission of quantitative traits like yield and its constituents [20]. Plant breeders have not correctly used the ample supply of valuable genes collected throughout rice germplasm, even though many genes responsible for the desirable qualities have been accumulated [21]. Genetic features that indicate the degree of variability in the germplasm include the genotypic and phenotypic coefficients of variation [22]. Studying the genetic behavior and background of all the genotypes' desirable traits is necessary to enhance and generate new kinds successfully [23]. The degree of genetic variety in the population is the primary determinant of gene improvement [24]. The degree of variability in genes and the heritability of economic variables determine the effectiveness of breeding programs [25]. Any crop breeding effort must take into account the degree of diversity. A broad range of diversity across germplasm has been demonstrated in previous work [26]. Utilizing new methods in rice breeding has the potential to produce genotypes that are more competitive than conventional ones. However, the option of creating rice hybrids still exists using traditional breeding techniques [27]. Genetic variation and divergence are necessary for plant breeders since they are essential to a successful breeding program. Generally, genetically different parents are used to get the desired recombinants in segregating generations [28]. Through breeding programs and agronomic management, this knowledge will be useful for enhancing the early maturity and scent of the grain in fragrant rice to satisfy customer needs.

2. Genetic of early maturity trait

Genetic variances are the basis for significant plant breeding from the decisions; they provide a more comprehensive range of genotypes from which new varieties or breeding materials can be selected [29]. Plant breeders aim to develop high-yielding varieties with wide adaptability [30]. In contrast to environmental differences, which often result in only transient, non-heritable phenotypic alterations, variation in genetics is the emergence of people with various genotypes or the presence of genotypically distinct individuals [31]. Therefore, creating cultivars with increased yield and other desired agronomic traits is of interest to rice breeders [32]. Flowering time is a significant limiting factor influencing rice grain yield and is strongly regulated by environmental factors such as temperature and day length [33, 34]. Numerous genes and alleles regulate photoperiod sensitivity and the duration of the rice fundamental vegetative growth ("BVG"), per multiple genetic studies [35]. To date, as many as 12 heading-time (flowering-time) loci controlling photoperiod sensitivity (PS) have been identified in rice [36]. The last ten years have seen a substantial clarification of the genetic and molecular underpinnings of heading dates, particularly via the improvement of resources obtained from rice genome study [37]. Many mapping populations have been used to identify QTLs controlling heading [38]. Due to a reduction in photoperiod sensitivity, an earlier heading date could have been crucial in extending the range of rice [39]. The growing focus on creating short-lived plant species that can provide food for extended periods under various circumstances suggests that breeding trials are essential [40]. It is still challenging to overcome the negative connection that results in early maturing cultivars having a yield penalty from reduced vegetative development periods despite many relevant genes being loaned and functionally described up to this point [41]. Genetic variety has been lost due to the selection of high-yielding, early-maturing Rice, among other factors [42]. Generally speaking, early-maturing cultivars outperform late-maturing kinds in terms of productivity, determined by water usage, insect-induced probability, and the possibility of generating a lucrative crop of ratoons [43]. Therefore, it would be very beneficial to accelerate research on rice heading date genes to determine the molecular process of plant blooming and cultivate early-maturing Rice with high yield in a steady manner to solve the future high demands of this vital crop [44]. The earlier heading restorer line is crossed with the regular sterile line to produce earlier heading hybrids, which lack the dominant early maturity genes (DEMG) [45].

Additionally, the heading date is influenced by internal and external signals and is strongly linked to the geographical adaptation of rice types[46]. Most Rice yield-contributing traits depend on one another to increase grain production. Furthermore, both heritable and non-heritable variability exist, with most yield components being quantitative [47].

Table 1. Growth duration and growth stage of early, medium, and late rice crops by phase.

Rice Type	Vegetative Phase (day)	Reproductive Phase (day)	Ripening Phase (day)	Growth Duration (day)
Early maturity rice	35-55	35	30	120
Medium maturity rice	55-75	35	30	120-140
Late maturity rice	75-95	35	30	140-160

2.1. Heritability of Early Maturity

Heritability is a critical component of the production formula for computing the expected response to selection since it is based on the phenotypic variance [48]. Heritability estimates combined with genetic advance are frequently more informative than heritability estimates alone when identifying the gene under selection [49]. In general, the amount of genetic variation, heritability, genetic advancement, and character association all play a major role in the success of a crop improvement program [50]. Research revealed that for every characteristic tested in every cross combination, intermated progenies exhibited greater heritability (h2) and genetic progress compared to F2 and F3 generations [51]. More investigation suggests a few characteristics have a high to moderate heritability value. The 21 rice genotypes' attributes have a high degree of heritability, as mentioned [52]. Plant height, effective tillers, and grain yield showed high heritability and higher genetic advance as a percentage of the mean recorded [53]. Moderate to medium heritability, high GCV, and significant genetic progress as a percentage of means were observed for plant height, biomass yield, grain production, and number of unfilled grains per panicle [54]. The qualities with the highest genetics advance and wide sense heritability were those that indicated they would be selected for because of their strong genetic transmissibility and variability [55]. Plant height and days to maturity were shown to have high estimates of heritability. High genetic development was seen in the days of maturity and seed vigour [56].

3. Genetic Aromatic Trait

Civilization worldwide places excellent emphasis on aromatic Rice as an essential quality. Various volatile organic compounds (VOCs) are emitted when Rice is cooked, giving Rice its distinctive aroma; for example, the scent of basmati rice is nutty and aromatic, but the aroma of jasmine rice is sweet and floral [57]. In this sense, aromatic rice varieties are becoming increasingly well-liked in South and Southeast Asia, and they have been well-accepted in East Asia, Europe, and the United States of America [58]. Aroma plays an essential role in rice's sensory properties, and the quality of rice aroma directly influences consumers' desire to purchase and their acceptability [59]. Palatability, or pleasant taste, is a feature of rice that is impacted by its aroma, appear, texture, and taste [60]. The aroma of the delicate flavor of cooked Rice is composed mainly of formaldehyde, ammonia, and hydrogen sulphide [61]. The demand throughout aromatic rice has been steadily rising in both local and international markets over the past half-century due to its strong aroma [62, 63]. However, this is a valuable resource for breeding and enhancing aromatic rice cultivars to meet the varied expectations of global customers owing to the preferred flavor and a few other prominent grain quality traits [64]. Aromatic rice has long been grown in Indonesia. When cooked, it has a light, fluffy texture with a fragrant, nutty flavor [65]. However, these local varieties have long maturity (more than 125 days). They are susceptible to significant pests and diseases [66]. However, because of the apparent genetic similarity between the aromatic and japonica varieties and the implicit belief that the aromatic is a subtype of the japonica, less focus has been placed on the origin of aromatic rice [67]. More than 300 volatile chemicals have been found to contribute to rice's fragrance, and 2-acetyl-1-pyrroline (2AP) is a crucial component regulating aromatic qualities in fragrant rice and many other crops [68]. Aromatic rice is a small and unique type of rice that is thought to be of the highest quality and is typically used to prepare special dishes [69]. Genetic differentiation among populations is also helpful for breeding new aromatic rice cultivars with desired traits [70], [71]. A non-functional betaine aldehyde dehydrogenase 2 (BADH2) in aromatic germplasm produces fragrance and is also the cause of reduced grain production [72]. The development of high-yielding varieties of aromatic rice requires genetic analysis of the local germplasm, but this research has not yet been done [73]. While the analyst's ability to identify an aroma or related tastes varies greatly, sensory assessment is still a practical and suitable way to test the mode of inheritance of this characteristic [74]. The value of aromatic Rice in the international market is enhanced by its aromatic quality [75]. The genetic differences are the leading cause of the variation in 2-AP contents. Additionally, the contents of 2-AP are influenced by storage conditions, harvesting methods, and evaluation methods [76]. Hybrid technology, which enhances the genetic potential of crop species, has been widely recognized and accepted in various species [77]. Plant breeders are attempting to capitalize on the superior genetic stock through system testing and evaluation of germplasms to select and produce cultivars with high yield potential [78]. There is an excellent opportunity to earn foreign currency by exporting aromatic Rice, as the consumption area worldwide is large, with a high price and price [79]. Aromatic rice, sometimes referred to as fragrant or scented rice, is widely available in Asia and is regarded as premium rice in markets around the world, including Ghana and many other African nations [80]. The unique aroma of this type of rice is a significant trait many appreciate, contributing to its high value-added qualities [81]. Aromatic rice gets its name from the chemical ingredient that gives it a nut-like flavor and scent. 1-pyrroline 2-acetyl [82]. Among these traditional rice varieties, aromatic rice landraces bear special significance because of their unique flavor and economic value in the present globalized era [83]. Volatile organic compounds are responsible for the characteristic features of aromatic rice varieties [84]. Aromatic Rice constitutes a small but particular group of Rice considered of the best quality [85]. Also, it constitutes a particular group of rice accessories well known for their aroma and non-grain quality [86]. It is a critical commodity worldwide and fetches premium prices over non-aromatic varieties in the local and international markets due to its superior grain quality and pleasant aroma [87]. As is already well established, the loss of function of the betaine aldehyde dehydrogenase 2 (badh2) gene on chromosome 8 causes rice to become more aromatic via increasing 2-AP production [88].

Various authors have reported monogenic, di-genic, and transgenic control of aroma. However, some authors believe aroma is imitatively inherited [89]. Some aromatic rice varieties are traditional cultivars grown in minimal areas and are known for their unique fragrance [90]. People in the country have a strong predilection for short-grain fragrant rice. In addition to working hard on their categorization and upkeep, they have underlined the need of conserving native aromatic rice [91]. The current aromatic rice varieties can now be improved, and aromatic rice can now be distinguished from non-aromatic rice types thanks to developments in plant biotechnology and genome editing technologies [92]. Nowadays, other scientists have been researching genetic traits related to the aromatic rice varieties.

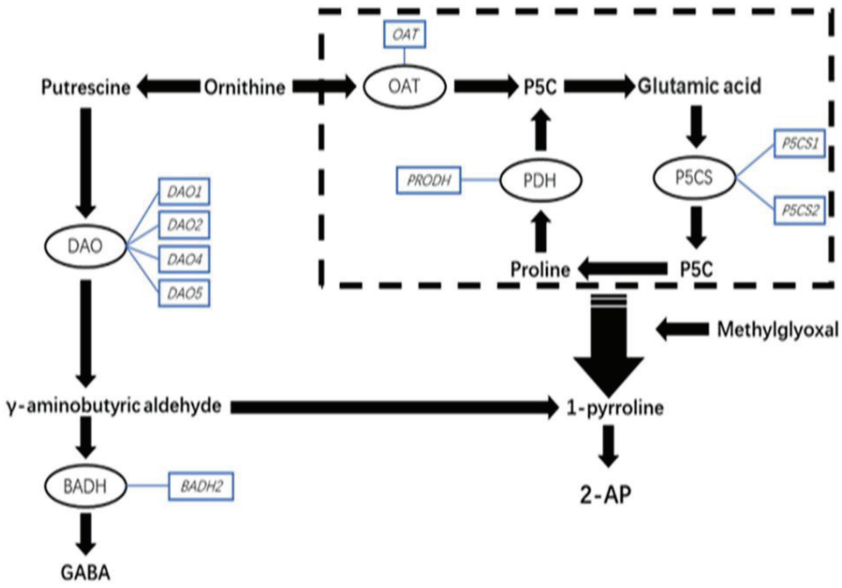

Fig. 1. The possible 2-AP production process in fragrant Rice is shown systematically. GABA, ornithine transaminase; P5CS, 1-pyrroline-5-carboxylate synthetase; PDH, proline dehydrogenase; DAO, diamine oxidase; OAT, ornithine transaminase; BADH, betaine aldehyde dehydrogenase; Pyroline-5- carboxylic acid, or P5C, Source: [93] - modified

Table 2. List of aromatic varieties.

No	Variety	Country
1	Basmati-370, Basmati-386, Dehradun	India
2	Hawm Klong Luang, Hawm Supanburi, Jasmine	Thailand
3	Can Duoc, Di Huong, Hai Hau	Vietnam
4	A-201, Della, Dellamont	USA
5	Congjiangxixiangmi, De Chang Xiang Mi, Ganwan-xian 22	China
6	Batang Gadis, Bengawan Solo, Gunung Perak	Indonesia
7	Haginokaori, Hieri, Izayoi, Jakou	Japan

8	Basmati 50021-1, Basmati Pak, Basmati-185	Pakistan
9	Ahalami tarom, Anbar-boo, Champa, Domsiah	Iran
10	Badshabhog, Banshful, Basmati-D	Bangladesh
11	Bahra, Bala, Germa Bala	Afghanistan

3.1. Heritability of Aromatic Trait

Heritability is the heritable aspect of phenotypic diversity. It has the potential to precisely ascertain whether genes are transferred from parents to their progeny [94]. Heritability's primary goal is to increase yield by using the heritable components of genotypes [95]. In addition to other selection techniques, hybridization may be advantageous for characters with a high heritability [96]. Heritability estimates and genetic advance are frequently more useful than heritability estimates alone when predicting the gene under selection [97]. The findings showed that all the traits were highly heritable in F1s; however, for the variables reported by [98]. The phenotypic expression of days to maturity and panicle length was shown to be influenced by non-additive gene action, as indicated by their low genetic advance (GA) percentage and moderate to high heritability [99]. High estimates of overall heritability were generally seen for most of the variables under study, including grain dimension, with a considerable genetic advance in the mean percentage [100]. Days to 50% blooming were shown to have a sluggish genetic advancement and a high heritability. These characteristics appear to be in charge of both additive and non-additive gene actions [101]. Between high heritability and genetic advancement, there were notable variations in the percentage of mean for grain yield, 1000 grain weight, tillers per plant, panicle length, flag leaf length, and plant height [102, 103].

4. Breeding of Early Maturity and Aromatic Rice

The domestication of rice dates back around 8,000 years, and it likely happened separately in southern China and northeastern India. Constant human selection for better features has altered domesticated rice types to the point that they are no longer able to live in the wild [104]. High production and rice survival will be improved by an increasing number of novel molecular and cellular biology approaches, such as molecular marker-assisted selection, genetic engineering, and alternative cultures [105]. Because Japanese food is often preferred by consumers over Indian food when it comes to eating and cooking, there is an increasing demand for Japanese rice [106]. The two most common subspecies of rice that are grown in Asia are Japonica and Indica, yet their biological and ecological traits are quite dissimilar [107]. Based on genomic investigations, Oryza sativa has been genetically differentiated into subspecies or varietal groupings [108]. The three main techniques of selection utilized in Indonesian rice breeding are bulk, modified bulk, and pedigree. These techniques rely on the desired traits naturally building up in a plant or line from the parents [109]. The life cycle of a plant is impacted by variations in the growth period's duration; for instance, a plant may mature earlier if the vegetative or reproductive development phases are shortened [110]. Depending on the breeding goals, heterosis, both positive and negative, can assist enhance crops. Negative heterosis is often preferred for early maturity and positive heterosis for yield [111]. Scientists have stressed the value of multidisciplinary teams doing applied research and on-farm diagnostics since the 1980s [112]. This approach involves farmers in all phases of the rural problem-solving process. Thanks to the development of several radiation mutagens and better treatment techniques, it is now possible to create desirable changes in a variety of traits through induced mutations. These alterations can then be utilized on their own or in conjunction with recombination breeding [113]. Because the dosage of this ion beam irradiation is modest, the amount of mutation induction is higher, making it safer and not damaging to the endosperm [114]. Nine Genomic Selection (GS) methods were compared in a simulation study to predict eight traits in a collection of 110 Asian cultivars. The results showed that accuracy depended heavily on the characteristics targeted and that reliability decreased when only a small number of cultivars were used for validation [115]. The goal of current rice breeding initiatives is to increase the economic value of rice through the cultivation of fragrant rice [116].

5. Conclusion

Genetic variation in rice varieties is wide-ranging. Early maturity reduces the crop period to adapt to the environment and lessens damage from pests and diseases, which can lead to the potential of growing multiple crops in a season. Aromatic traits are popular choices for consumers because they have good quality and are considered to have a higher marketing value. To provide breeders with desirable traits and identify genes that control them can be done through Genetic variability of early maturity and aromatic traits in rice genotypes, Identifying the relationship between characters of early maturity and aromatic traits and yield of genotypes, and Studying heritability and genetic variability of yield and essential traits in rice genotypes.

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