

Genetic Diversity of Agronomic Characters in Rice Plants (*Oryza sativa* L.) Using Several Colchicine Concentrations

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Abstract

*This study aimed to evaluate the effects of various colchicine concentrations on the genetic diversity of agronomic characters in rice plants (*Oryza sativa* L.). The experiment was conducted at the Agricultural Modernization Application Center (BRMP) Gorontalo from January to April 2025, employing a two-factor factorial completely randomized design (CRD). The first factor was rice variety, comprising two levels: V1 (Inpago 13 Fortis) and V2 (Inpari Nutri Zinc), while the second factor was colchicine concentration with four levels: P0(control/0 ppm), P1 (750 ppm), P2(1000 ppm), and P3 (1250 ppm). Each treatment combination was replicated three times, resulting in 24 experimental units. Observed parameters included both vegetative and generative phases. Results indicated that colchicine did not exert a significant overall effect on either vegetative or generative traits; however, certain concentrations induced an increase in the number of spikelets in the Inpago 13 Fortis variety. In contrast, Inpari Nutri Zinc exhibited higher tolerance to colchicine, maintaining stable growth and morphology across all concentrations. These findings highlight that colchicine effectiveness is highly dependent on dosage and genotype response, emphasizing the need for optimal concentrations to induce mutations without causing toxic effects, thereby providing a foundation for rice mutation breeding.*

Keyword: *Generative phase, vegetative phase, selection character, mutation, effective treatment.*

INTRODUCTION

Global food security represents a critical issue confronting the contemporary world. With the escalating population, the demand for stable and sustainable food sources has become

673

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increasingly urgent. Rice (*Oryza sativa* L.) serves as a primary food commodity for more than half of the world's population, including Indonesia, where it constitutes the staple food in the form of cooked rice. According to data from the Central Statistics Agency (BPS, 2023), rice production in Gorontalo Province exhibited an upward trend from 2020 to 2023, with figures of 227,627 tons, 234,392 tons, 240,134 tons, and 251,431 tons, respectively. However, in 2024, production declined to 218,781 tons, indicating a 12% reduction compared to the previous year (BPS, 2024). Amidst the rising national food demands aligned with population growth, efforts to develop superior varieties that are adaptive to environmental conditions and nutritionally enriched are essential.

The development of superior rice varieties constitutes a primary strategy for enhancing national food security. Ideally, these varieties should exhibit high productivity, tolerance to abiotic stresses such as drought and suboptimal soils, and improved nutritional content. The Inpago 13 Fortis variety is an upland rice cultivar rich in zinc and protein, with high yield potential and resistance to various pests, diseases, and suboptimal land conditions (Subekti & Umar, 2023). Conversely, Inpari IR Nutri Zinc is a new superior variety (NSV) rice enriched with sufficiently high zinc content. Zinc is a vital nutrient for both human health and plant physiology, playing a crucial role in cell growth and development (Brown et al., 2002; Priyadi, 2021). The elevated zinc content in Nutri Zinc rice can enhance the zinc levels in the produced grain, thereby aiding in the improvement of human health through its consumption.

A primary challenge in developing superior rice varieties lies in the limited genetic diversity, particularly in key agronomic traits such as plant height, tiller number, panicle length, and grain yield. Nevertheless, the advancement of modern rice varieties heavily relies on the availability of genetic diversity derived from local varieties selected naturally by farmers over generations, as well as from wild species (Boy & Soeharsono, 2013). To broaden genetic diversity, mutagenesis techniques have been extensively applied, including the use of chemical mutagens such as colchicine (Husain et al., 2022). Colchicine operates by inducing mutations in cell division during mitosis, resulting in polyploid plants with superior traits. Optimal concentrations of colchicine application can lead to increased chromosome numbers and cell sizes, consequently producing plants with diverse morphological variations (Sabana et al., 2022). The application of colchicine to rice plants can generate novel individuals with morphological and agronomic characteristics differing from the original population, potentially serving as genetic sources for further selection.

Research on the influence of colchicine on genetic diversity and agronomic traits in rice varieties remains relatively scarce, especially concerning the Inpago 13 Fortis and Inpari Nutri





Zinc varieties. These varieties possess distinct advantages, rendering them suitable for further enhancement through induced mutation approaches. Evaluating the diversity of agronomic traits post-colchicine application is a critical step in selecting individuals exhibiting superior performance (Yamin et al., 2023).

Accordingly, this study aims to assess the genetic diversity of agronomic traits in the Inpago 13 Fortis and Inpari Nutri Zinc rice varieties following treatment with various colchicine concentrations. It is anticipated that the findings of this research will contribute scientifically to the development of adaptive and nutritious superior rice varieties through directed and systematic artificial mutation approaches.

METHOD

This study was conducted over three months, from January to April 2025, at the Greenhouse of the Gorontalo Agricultural Modernization Implementation Center (BRMP), located at Jl. Van Gobel No. 270, iloheluma Village, Tilongkabila Distric, Bone Bolango Regency, Gorontalo Province. The research utilized tools such as shovels, analytical balances, calipers, rulers, buckets, banners, seated scales, Erlenmeyer flasks, bottles, labels, cameras, and office stationery, along with materials including rice seeds of Inpago 13 Fortis and Inpari Nutri Zinc varieties, colchicine powder, NaOH solution, soil, husk, and cow manure fertilizer. The experimental design employed a factorial Completely Randomized Design (CRD), with the first factor being rice variety (two levels: V1 for Inpago 13 Fortis and V2 for Inpari Nutri Zinc) and the second factor being colchicine concentration (four levels: P0 as control, P1 at 750 ppm, P2 at 1000 ppm, and P3 at 1250 ppm), resulting in eight treatment combinations, each replicated three times for a total of 24 experimental units.

In this study, observed parameters were divided into two observation phases: the vegetative phase, encompassing germination age, plant height, leaf number, leaf length, leaf width, vegetative tiller number, leaf area, and stem diameter; and the generative phase, including flowering age, generative tiller number, panicle length, and spikelet number. Data analysis was performed using SAS software for variance analysis and Excel for graphical representation.

RESULTS AND DISCUSSION

Agronomic Characteristics of Rice Plants

Based on the variance analysis results presented in Table 1, it was determined that the variety factor exerted a highly significant influence ($\alpha = 1\%$) on several vegetative traits, namely



leaf number and vegetative tiller count. Additionally, the variety factor showed a significant effect ($\alpha = 5\%$) on leaf length and stem diameter. For generative traits, the variety factor demonstrated a highly significant impact ($\alpha = 1\%$) on flowering age, panicle length, and generative tiller number.

Table 1. Recapitulation of variance analysis of various agronomic characters of rice in response to colchicine treatment

Character	Middle Square			KK (%)
	Varieties	Cholchicine	V*P	
Vegetative				
Age of Germination	0,42tn	0,15tn	0,15tn	9,45
Plant Height	918,84tn	172,37tn	86,51tn	59,98
Number of Leaves	24832,67**	91,00tn	355,44tn	58,25
Leaf Length	1855,04*	141,71tn	75,60tn	54,56
Leaf Width	1,26tn	0,20tn	0,12tn	57,43
Leaf Area	1307,44tn	314,37tn	154,67tn	59,74
Stem Diameter	0,22*	0,01tn	0,02tn	50,76
Number of Vegetative Shoots	888,17**	8,94tn	27,83tn	52,38
Generative				
Flowering Age	9600,00**	783,89tn	1093,67tn	67,79
Panicle Length	793,50**	80,61tn	14,39tn	67,30
Number of Spiklets	477,04tn	416,26tn	206,82tn	84,99
Number of Generative Offspring	84,38**	1,82tn	2,38tn	76,89

Explanation: * = significantly different at the 5% significance level; ** = highly significant at the 1% significance level; ns = not significant.

The variance analysis results indicate that colchicine treatments and varietal differences elicited diverse responses in the agronomic traits of rice plants during both vegetative and generative phases. Traits such as leaf number, leaf length, stem diameter, and vegetative tiller count exhibited significant influences due to varietal differences, suggesting notable genetic diversity among varieties for these characteristics. Suhartini and Sutoro (2007) state that inter- and intraspecific diversity arises from genetic differences, encompassing morphological variations, genomic structures, and relatedness levels. Morphological distinctions, as observed

in rice vegetative traits, often directly reflect genetic variations among varieties or individuals within the same species (Ezward et al., 2020).

Leaf number and vegetative tiller count are traits highly influenced by varietal differences, indicating that morphological adaptations to environmental conditions and external treatments like colchicine are more pronounced in specific varieties. Leaf length and stem diameter also showed significant differences, implying that elongation and secondary growth responses in rice have specific genetic underpinnings across varieties. According to Kumar et al. (2014), highly significant genetic variations were detected among genotypes for all observed traits, including plant height, panicle length, flag leaf length and width, grain length and width, and grain yield. Furthermore, Hattori et al. (2009) demonstrated that identifying Quantitative Trait Loci (QTL) controlling stem elongation and related traits provides a robust genetic foundation for regulating responses to submergence conditions, potentially accelerating the development of superior rice varieties adaptive to flooding stress. This underscores that extensive genetic diversity in populations is a crucial foundation for plant breeding. Septiningsih et al. (2009) also emphasize that genetic variation for submergence tolerance in rice germplasm opens opportunities for enhancing tolerance through breeding and marker-assisted selection.

Jordan and Wilson (2004) state that low concentrations of colchicine tend to inhibit microtubule dynamics without causing extensive depolymerization or drastic cellular morphological changes, as required to halt mitosis. In agreement, Wang et al. (2016) explain that effective inhibition, yielding tangible biological effects such as morphological alterations or antimitotic activity, requires sufficiently high levels of polymerization inhibition, typically unattainable at low colchicine concentrations. Bhattacharyya et al. (2008) further affirm that low colchicine concentrations merely inhibit microtubule dynamics without significant depolymerization, whereas high concentrations can trigger total depolymerization and clear cellular morphological changes, such as cell rounding. Based on this, the insignificance of the interaction between variety and colchicine treatment ($V \times P$) indicates that colchicine does not exert a specific influence on particular varieties but produces a uniform general response across varieties to the treatment.

In the generative phase, varieties showed a highly significant influence ($\alpha = 1\%$) on flowering age, panicle length, and generative tiller number. This reflects the critical role of genetic factors in regulating the reproductive phase of plants, directly linked to yield potential and adaptability to growing conditions. Conversely, spikelet number and panicle number did not exhibit significant differences among treatments, likely due to environmental influences or limitations in mutagenic effects on generative traits within a relatively short cropping cycle. In

the context of mutation-based plant breeding, Agrawal et al. (2001) argue that mutagenic effects tend to be limited in influencing generative traits over a short period, as the phenotypic expression of new mutations often requires several generations to stabilize and become evident. Additionally, the mutagen dose employed may not have been sufficient to induce measurable changes in quantitative traits like spikelet and panicle number within a single growing season. Therefore, the absence of significant differences in these traits could stem from inadequate treatment duration or suboptimal mutagen intensity in producing quantifiable alterations during the limited observation period.

The relatively high coefficient of variation (CV) for most parameters (>50%) indicates substantial variability among experimental units (Table 1). This reinforces the indication that certain traits are highly influenced by microenvironmental conditions or genetic variability within experimental plots. The highest CV values were observed for spikelet number (84.99%) and generative tiller number (76.89%), suggesting that these two traits are particularly sensitive to environmental changes and treatments, although not all showed statistically significant influences.

Comparison of Morphological Characters Between Two Rice Varieties

Based on the results of the analysis of variance, it was found that the treatments using the Inpago 13 Fortis and Inpari Nutri Zinc varieties had a significant effect on the observed parameters, namely the number of leaves (JD), leaf length (PD), panicle length (PM), and stem diameter (DB) (Table 2). The following table presents the mean values of the number of leaves, leaf length, and leaf width between the two rice varieties.

Table 2. Mean values of the number of leaves, leaf length, and leaf width between the two rice varieties

Varieties	Parameter			
	JD (Strands)	PD (cm)	PM (cm)	DB (mm)
Inpago 13 Fortis	29,00b	26,92b	8,34b	0,24b
Inpari Nutri Zinc	93,33a	44,50a	19,84a	0,43a

Explanation: Values not followed by the same letter differ significantly at the 5% level based on the Statistical Analysis System (SAS) test.

Statistical analysis revealed a significant difference ($\alpha = 5\%$) across all observed morphological parameters between the Inpago 13 Fortis and Inpari Nutri Zinc varieties. The Inpari Nutri Zinc variety consistently exhibited superior agronomic performance, as indicated by the highest number of leaves (93.33 leaves), leaf length (44.50 cm), leaf width (19.84 cm), and stem diameter (0.43 mm). Conversely, the Inpago 13 Fortis variety showed the lowest values for all morphological parameters, with 29.00 leaves, a leaf length of 26.92 cm, a panicle length of 8.34 cm, and a stem diameter of only 0.24 mm. These differences not only reflect genetic variability between the varieties but also indicate a strong interaction between genetic potential and the applied colchicine concentration.

In the Inpari Nutri Zinc variety, colchicine treatment at an optimal concentration likely induced stable polyploidy, thereby enhancing cell division and cell enlargement activity in vegetative tissues. This resulted in the development of larger and more abundant leaves, as well as thicker stems. Such positive effects are consistent with the findings of Dwimahyani and Dewi (2010), who reported that colchicine treatment at moderate concentrations can increase the size of vegetative organs in several rice varieties due to an elevated chromosome number that enhances the expression of growth-regulating genes. On the other hand, the Inpago 13 Fortis variety demonstrated a lower morphological response, which may be attributed to several factors. First, the genetic potential of this variety may be less responsive to colchicine treatment, leading to changes in ploidy that do not significantly affect vegetative organ development. Second, if the colchicine concentration applied was relatively high for this variety, it could have induced cytotoxic effects, damaging meristematic tissues, inhibiting cell division, and ultimately reducing the rate of vegetative growth (Adil et al., 2019). Colchicine toxicity at elevated concentrations has been reported to cause tissue necrosis and a decline in plant viability, resulting in lower morphological characteristics compared to control or optimal treatment levels.

The finding of a larger stem diameter (DB) in the Inpari Nutri Zinc variety (Table 2) is presumed to contribute to enhanced lodging resistance, given the positive correlation between stem thickness and mechanical stability. Singh (2022) identified stem diameter as one of the key morphological traits significantly and positively associated with lodging resistance in direct-seeded rice genotypes. A stem diameter of ≥ 0.40 mm has been shown to improve mechanical stability through the thickening of sclerenchyma tissues and an increase in lignin density. This aligns with the findings of Gui et al. (2018), who reported that the stem breaking index is highly and negatively correlated with sclerenchyma thickness and lignin content, highlighting their role in strengthening stem structure. Similarly, Wu et al. (2017) noted that stem diameter and wall

thickness are closely associated with mechanical strength, as reductions in lignin content under shading conditions weaken stem structure. Nevertheless, the vegetative advantages of the Inpari Nutri Zinc variety may also introduce a potential trade-off, namely competition in photoassimilate allocation between vegetative and reproductive organs.

The results of the analysis of variance further indicated that the Inpago 13 Fortis and Inpari Nutri Zinc varieties had a significant effect on the parameters of flowering age (UB), number of vegetative tillers (JAV), and number of generative tillers (JAG). The following table presents the mean values of flowering age, number of vegetative tillers, and number of generative tillers between the two rice varieties (Table 3).

Table 3. Mean values of flowering age, number of vegetative tillers, and number of generative tillers between the two rice varieties

Varieties	Parameter		
	UB (Hst)	JAV	JAG
Inpago 13 Fortis	26,33b	5,84b	1,84b
Inpari Nutri Zinc	66,33a	18,00a	5,58a

Explanation: Values that are not followed by the same letter indicate a significant difference at the 5% level according to the Statistical Analysis System (SAS) test.

The analysis results indicated a significant difference ($\alpha = 5\%$) in all phenological and tiller production parameters between the Inpari Nutri Zinc and Inpago 13 Fortis varieties. The Inpari Nutri Zinc variety consistently exhibited superior agronomic performance compared to Inpago 13 Fortis. Regarding the flowering age parameter, Inpari Nutri Zinc reached flowering earlier, at 66.33 days after transplanting (DAT), whereas Inpago 13 Fortis flowered much later, at 126.33 DAT, showing a striking difference. In addition, Inpari Nutri Zinc produced a higher number of vegetative and generative tillers, with averages of 18.00 and 5.58, respectively. Conversely, Inpago 13 Fortis produced only 5.84 vegetative tillers and 1.84 generative tillers. These differences suggest that Inpari Nutri Zinc possesses greater adaptive capacity and productivity potential under the tested environmental conditions, as well as more stable phenological characteristics that support higher yield performance.

The concentration of colchicine applied varied widely, and each concentration exerted different effects on plant growth and development. Research conducted by Prabawa and Purba (2019) on black rice (*Oryza sativa* L.) var. Cempo Ireng revealed that colchicine treatment at a concentration of 750 ppm was effective in inducing mutations that led to phenotypic changes in

most plant traits. At this concentration, a significant increase was observed in the number of tillers, number of productive tillers, percentage of filled grains, and total grain weight per plant. The increase in tiller number aligns with the findings of Ghosh (1949), who also reported a rise in tiller production in rice plants treated with colchicine at a concentration of 500 ppm. These findings indicate that relatively high colchicine concentrations, such as 750 ppm, can stimulate vegetative growth in rice plants, thereby potentially enhancing yield.

However, it is important to note that increasing colchicine concentration does not always correlate positively with the enhancement of desirable agronomic traits. Higher concentrations, such as 1000 ppm and 1250 ppm, can be toxic or even lethal to plants. Ghosh (1949) reported that colchicine concentrations of 0.1% (1000 ppm) and 1% (10,000 ppm) resulted in no surviving seedlings. Similarly, Prabawa and Purba (2019) observed a decrease in plant survival percentage with increasing colchicine concentration, where at 750 ppm, only 55% of the plants survived. Concentrations higher than 750 ppm, such as 1000 ppm and 1250 ppm, are likely to cause even greater mortality rates and may induce undesirable morphological abnormalities. Sumiasih (2014) also found that colchicine treatment can enhance several yield components; however, inappropriate concentrations may instead lead to adverse effects on plant growth and productivity.

Descriptive Analysis of Two Rice Plant Varieties and Colchicine Concentration on Observed Characters

Germination age is one of the early physiological indicators of plant growth, reflecting the viability and ability of seeds to actively initiate the vegetative phase. Based on Figure 1, it can be observed that colchicine treatments with varying concentrations produced differing effects on the germination age of both rice varieties, although these differences appeared to be relatively subtle when viewed visually.

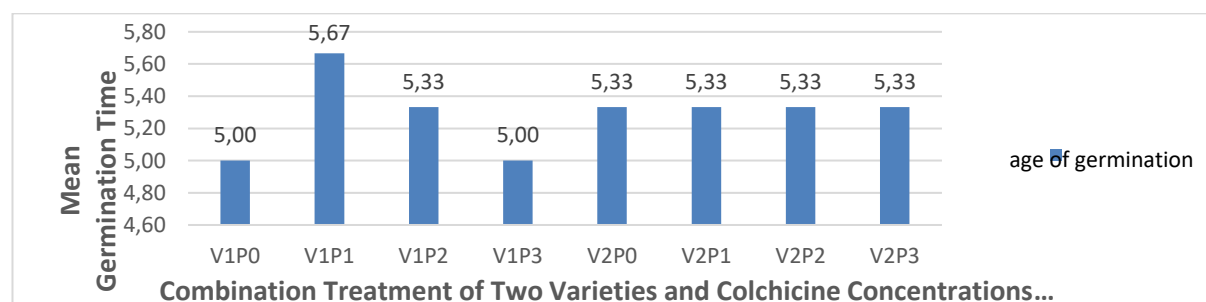


Figure 1. Graph of the mean germination age of rice varieties under different colchicine treatments



The Inpago 13 Fortis variety (V1) exhibited greater variation in germination age compared to the Inpari Nutri Zinc variety (V2) (Figure 1). The V1P1 treatment (Inpago 13 Fortis with 750 ppm colchicine) showed the longest mean germination period, averaging 5.67 days, which was the highest among all treatment combinations. The delayed germination observed in this treatment is likely due to the physiological effects of colchicine on the early stages of mitosis, particularly in actively dividing meristematic root cells during the imbibition phase. This finding is consistent with the report of El-Latif et al. (2018), who stated that colchicine can slow down mitotic processes and reduce seed germination due to its cytotoxic effects on meristematic tissues. Similarly, Hu et al. (2014) noted that colchicine treatment significantly inhibited rice seed germination by delaying the transition between mitotic phases, especially from metaphase to anaphase, in root tip meristem cells.

In contrast, both the control treatment and the Inpago 13 Fortis treatment with a colchicine concentration of 1250 ppm showed the same germination age of 5.00 days. This identical value to the control indicates that, in the Inpago 13 Fortis variety, the 1250 ppm colchicine concentration did not produce stronger effects than the 750 ppm and 1000 ppm treatments. This may suggest the presence of tolerance or compensatory physiological mechanisms that allow seeds to germinate within the same period despite exposure to high mutagenic stress. This observation aligns with El-Latif et al. (2018), who reported that although higher colchicine concentrations can be toxic, certain seeds do not exhibit delayed germination, possibly due to physiological thresholds or compensatory responses that mitigate mitotic inhibition.

Meanwhile, the Inpari Nutri Zinc variety (V2) demonstrated stable germination age across all treatments, with an average of 5.33 days, including the control (V2P0). This consistency indicates a higher level of physiological tolerance to colchicine, even at high concentrations (V2P3). Such stability in germination age can be interpreted as one of the genetic advantages of Inpari Nutri Zinc, enabling optimal metabolic activity and effective dormancy breaking during early germination, even under mutagenic treatment. According to Chiara Forti (2020), successful germination in cereals largely depends on the activation of early metabolism, and some genotypes possess resistance to abiotic stress and heavy metals such as Zn and Cd without experiencing a decline in germination rate. Similarly, Ara (2019) emphasized that colchicine can effectively induce polyploidization, and several rice accessions have demonstrated the ability to maintain normal germination parameters under moderate doses, suggesting potential mutagenic tolerance and metabolic stability in certain genotypes.



The physiological resistance of the Inpari Nutri Zinc variety to colchicine can be interpreted as an indication of its adaptive response to chemical stress. High survival rates following mutagenic treatment are crucial in mutation breeding to ensure the availability of sufficient mutant progeny. Low survival rates may indicate excessive genetic damage or insufficient physiological recovery (Shu, 2009). This is supported by Ara (2019), who reported that a positive response to colchicine is an indicator of varietal tolerance. Genotypes capable of surviving and maintaining normal growth are likely to possess stable, heritable mutations beneficial for plant breeding programs.

Observations of rice plant morphological parameters revealed variation in responses between the two varieties (Inpago 13 Fortis and Inpari Nutri Zinc) to different colchicine concentrations, particularly in plant height, leaf width, and leaf area (Figure 2). In general, the Inpari Nutri Zinc variety (V2) tended to exhibit superior morphological performance compared to the Inpago 13 Fortis variety (V1) across all colchicine concentrations, especially under the control (P0), P1, and P2 treatments (Figure 2).

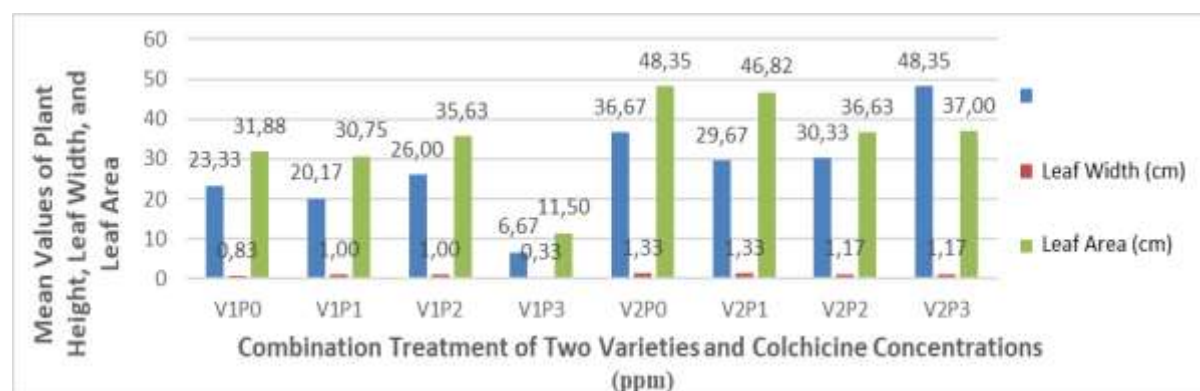


Figure 2. Graph of the mean plant height, leaf width, and leaf area of rice varieties under different colchicine treatments

Figure 2 shows that the highest plant height was achieved in the Inpari Nutri Zinc treatment with a colchicine concentration of 1250 ppm (48.35 cm), followed by the control treatment (36.67 cm), indicating that the Inpari Nutri Zinc variety (V2) possesses a greater vertical growth capacity compared to the Inpago 13 Fortis variety (V1). This finding suggests that Inpari Nutri Zinc has a higher genetic potential and responsiveness to external stimuli, including mutagenic treatments. Conversely, the V1P3 treatment exhibited the lowest plant height (6.67 cm), indicating a possible toxic effect of high colchicine concentration on this variety or limited tolerance of V1 to mutagenic stress. Aliyu et al. (2016) reported that high colchicine

concentrations significantly reduce plant height, particularly in sensitive varieties, due to toxicity or inhibition of mitotic cell division. This observation is consistent with the findings of Zeinullina et al. (2023), who noted that several rice accessions exhibited up to a 50% reduction in plant height under high colchicine treatments, reflecting genotypic sensitivity to mutagenic stress.

Leaf width across all treatments (Figure 2) showed relatively low variation, particularly in Inpago 13 Fortis treated with 1250 ppm colchicine and Inpari Nutri Zinc under the control condition, ranging between 0.33 and 1.33 cm. This indicates that leaf width tends to remain stable under colchicine treatment or requires a longer period to exhibit significant phenotypic changes. Nevertheless, the slight increase in leaf width observed in V2P0 and V2P1 treatments (1.33 cm each) suggests that, in the Inpari Nutri Zinc variety, this morphological trait can still be modulated by environmental factors or mild mutagenic exposure. Barus et al. (2024) stated that Inpari Nutri Zinc exhibits physiological variations, including changes in leaf width and chlorophyll content, when cultivated under different soil amendment conditions, indicating its potential adaptability. Furthermore, Zeinullina et al. (2023) added that low colchicine concentrations can induce phenotypic variability without causing severe growth inhibition, reinforcing that mutagenic modification capacity largely depends on the genotype used.

Leaf area (Figure 2) demonstrated a more dynamic response to the treatments (variety and colchicine) compared to other morphological traits. The largest leaf area was observed in the Inpari Nutri Zinc variety under the control treatment (48.35 cm²) and with 750 ppm colchicine (46.82 cm²), indicating that this variety is capable of maintaining its photosynthetic capacity even under mild colchicine stress. In contrast, the smallest leaf area was recorded in Inpago 13 Fortis treated with 1250 ppm colchicine (11.00 cm²), reinforcing that high colchicine concentrations negatively affect leaf expansion, particularly in Inpago 13 Fortis. The ability of V2 to sustain a large leaf area, even under moderate colchicine concentrations (750 and 1000 ppm), suggests its positive potential for selection in mutagenic breeding programs. According to Aliyu et al. (2016), the reduction in leaf area due to mutagenic exposure is more pronounced in sensitive varieties, highlighting the importance of genotypic tolerance differences and the role of traits such as leaf area and plant height as key selection markers in mutation breeding. Sahoo (2018) also emphasized that under moderate colchicine concentrations, some varieties can still maintain leaf area and shoot length, suggesting that the LD₅₀ range can serve as an early selection indicator in mutation-based breeding programs.

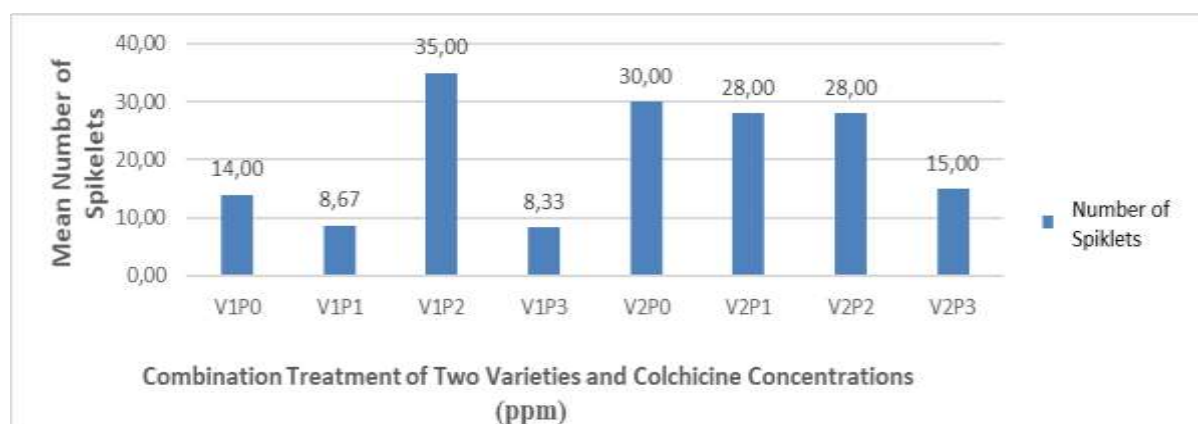


Figure 3. Mean number of spikelets across rice varieties and colchicine immersion treatments

The number of spikelets per panicle is a critical yield component in rice production, as it directly contributes to the potential grain yield (Figure 3). The presented data indicate a significant difference in response between the two rice varieties to colchicine treatment, observed at low, medium, and high concentrations.

The Inpago 13 Fortis variety (V1) exhibited notable variability in the number of spikelets produced. The P2 treatment (1000 ppm) generated the highest spikelet count, reaching 35.00, which was markedly greater than the control (V1P0) that produced only 14.00 spikelets. These findings suggest that colchicine at a concentration of 1000 ppm can enhance panicle formation in this variety. It is very likely that colchicine at this level induces advantageous genetic mutations, particularly in genes involved in floral development or spikelet primordia formation. According to Sujipuli et al. (2021), colchicine application leads to polyploidy and increases the expression of the BmoOSC gene, which plays a role in shoot organogenesis and floral trait variability.

Conversely, in the Inpago 13 Fortis variety treated with colchicine at 750 and 1250 ppm, the spikelet number decreased sharply to 8.67 and 8.33 spikelets, respectively. This indicates the presence of a colchicine dose-threshold effect, wherein concentrations that are too low or too high can be inhibitory to spikelet formation. The negative effect at the high concentration (1250 ppm) can also be attributed to disruptions in cell division and toxicity to the plant's reproductive tissues. As reported by Manzoor et al. (2019), high colchicine concentrations interfere with chromosome separation and microtubule dynamics, primarily affecting the development of reproductive organs and pollen viability.

The Inpari Nutri Zinc variety (V2) demonstrated a more stable response across all treatments, with spikelet numbers ranging from 15.00 to 30.00. The highest value was observed



in the control treatment (V2P0) at 30.00 spikelets, followed by treatments V2 with colchicine at 750 and 1000 ppm, which yielded an identical count of 28.00 spikelets. This indicates that the Inpari Nutri Zinc variety possesses higher morphogenetic stability compared to Inpago 13 Fortis under colchicine treatment. This consistency affirms that V2 has a genetic regulatory system more resilient to mutagenic stress, thus not experiencing significant disruption in spikelet initiation and development processes.

Interestingly, the highest colchicine treatment on the Inpari Nutri Zinc variety (1250 ppm) reduced the spikelet count to 15.00, a figure nearly equivalent to the control value in the V1 variety. This decline reinforces the evidence that high-dose colchicine has the potential to cause universal toxic effects, not only in sensitive varieties but also in those generally more tolerant.

Therefore, the concentration of 1000 ppm appears to be the optimum point capable of inducing positive mutagenic effects without eliciting phytotoxic consequences, at least for the Inpago 13 Fortis variety.

CONCLUSION

Genotypic differences between the varieties resulted in pronounced diversity in agronomic characteristics, with the Inpari Nutri Zinc variety consistently demonstrating superior performance compared to Inpago 13 Fortis, as reflected in its enhanced morphological and phenological parameters. Furthermore, Inpari Nutri Zinc exhibited a more stable response to colchicine treatments, achieving optimal performance at low to medium dosages. Conversely, the applied colchicine concentrations did not induce significant phenotypic alterations, and the highest concentration (1250 ppm) suppressed growth in both varieties, indicating a toxicity threshold. These findings lead to the conclusion that the inherent genetic superiority of the variety is the primary determinant, and the application of colchicine in breeding programs requires more precise concentration optimization to circumvent inhibitory effects and elicit the desired morphological responses.

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