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Exploration, Analysis of Zinc (Zn) And Iron (Fe) Content in Local Rice Genotypes from West Sumatra: An Initial Step toward Biofortification for Stunting Mitigation

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ABSTRACT

Stunting in children under five remains a significant public health issue in Indonesia, particularly in West Sumatra, where prevalence rates exceed the national average. Addressing this challenge requires improving nutritional intake, focusing on essential micronutrients like zinc (Zn) and iron (Fe). Biofortification is a promising agricultural strategy to enhance the nutritional quality of staple crops such as rice. This study aims to explore and evaluate the Zn and Fe content of local rice genotypes from West Sumatra, which hold potential for biofortification programs. Twenty-eight rice genotypes, including 27 local genotypes and one control (Inpari Nutri Zinc), were analyzed for Zn and Fe content. The results showed that the control variety, Inpari Nutri Zinc, exhibited the highest Zn (31.30 ppm) and Fe (19.85 ppm) content. Among the local genotypes, Puluik Mutia (Zn: 28.40 ppm, Fe: 18.30 ppm), Kuning Aro (Zn: 27.60 ppm, Fe: 18.20 ppm), and Rampai Kuning (Zn: 26.20 ppm, Fe: 18.05 ppm) displayed the highest Zn levels, while Manggung (Fe: 18.85 ppm) had the highest Fe content. These findings highlight the significant variability in micronutrient content among local genotypes, emphasizing their potential as germplasm for biofortification breeding programs. This research represents the first systematic exploration of Zn and Fe levels in local rice genotypes from West Sumatra. The novelty lies in identifying high-Zn and Fe genotypes, particularly those with firm texture preferences, which could support biofortification efforts and provide a sustainable solution to combat stunting. Future research should focus on environmental interactions and agronomic practices to further optimize the micronutrient content in local rice varieties.

INTRODUCTION

Stunting in children under five is a significant public health issue, particularly in developing countries. It arises from chronic malnutrition and recurrent infections during the critical First 1,000 Days of Life, a period from conception to a child's second birthday. This phase is essential for a child's growth and development, and nutritional deficiencies during this time can cause irreversible damage, impacting the quality of future generations [1]. Stunting remains a pressing nutritional challenge in Indonesia. According to the 2022 Indonesian Nutritional Status Survey (SSGI), the national stunting prevalence was 21.6%, down from 24.4% in 2021, but still above the National Medium-Term Development Plan (RPJMN) target of 19% by 2024 [2]. In West Sumatra, stunting prevalence rose to 25.2% in 2022 from 23.3% in 2021, with the highest rates in Pasaman Barat (35.5%), Kepulauan Mentawai (32.0%), Solok

Selatan (31.7%), and Sijunjung (30.0%) [3]. The consequences of stunting in children are profound, including hindered physical growth, impaired mental development, speech difficulties, and increased susceptibility to infections [4]. Short-term effects include reduced learning and cognitive abilities, while long-term impacts involve shorter stature in adolescence, a higher risk of obesity, diminished reproductive health, and reduced work productivity [1].

Stunting in children is influenced by multiple factors, including socioeconomic conditions, maternal nutrition during pregnancy, and deficiencies in essential nutrients like zinc (Zn) and iron (Fe) [5]. Zinc is vital for cellular function, supporting over 300 enzymes involved in carbohydrate, fat, protein, and nucleic acid metabolism. It plays a crucial role in cell growth, division, immune function, and child development. Zinc deficiency can lead to growth failure and tissue loss [6]. Similarly, iron is critical for oxygen transport, electron transfer within cells, red blood cell formation, and enzymatic reactions in body tissues [7].

Addressing stunting requires an integrated and sustainable approach, with improving community nutrition as a key strategy. Nutritional adequacy must focus not only on quantity but also on quality, emphasizing nutrient enrichment in food products. Enhancing the nutritional value of crops through breeding whether conventional or biotechnological is a pivotal step toward achieving national food security [8]. Plant breeders must prioritize producing crop varieties enriched with Zn and Fe through plant breeding programs, which include biofortification. Biofortification involves enriching crops with essential nutrients like vitamins and minerals through agronomic practices (fertilization) or genetic improvements [9]. This agricultural innovation addresses malnutrition and public health issues by enhancing the nutritional content of staple crops like rice, the primary food source for most Indonesians. The Indonesian Ministry of Agriculture, through the Rice Research Center has successfully developed biofortified rice varieties via conventional breeding. For instance, the Inpari IR Nutri Zinc, released in 2019, contains 29.54 ppm Zn, while the Inpago 13 Fortiz, released in 2020, contains 34 ppm Zn [9].

These initiatives highlight the potential of exploring Zn-rich local rice genotypes in West Sumatra to support breeding programs, particularly for biofortification. Understanding Zn and Fe content in various local rice genotypes, particularly those with firm textures, can optimize efforts to improve public health and nutrition through more nutritious rice consumption. Multiple plant breeding methods have been employed for biofortification across crops. For example, genetic engineering has demonstrated its effectiveness in enhancing nutrient content. Liang *et al.* (2019) [10] showed that cloning two genes increased folate content by 4.2 and 2.3 times in transgenic corn and wheat, respectively. Similarly, Corrales-Lerma *et al.* (2022) [11] improved the nutritional profile of Natal grass (*Melinis repens*) through gamma irradiation, achieving crude protein content of 19.5% and lignin reduction to 1.6%.

In Indonesia, rice biofortification has included exploring nutrient-rich local rice varieties. Gumelar *et al.* (2023) [12] evaluated six local rice types in North Timor Tengah, reporting Zn levels between 20.4–29.4 ppm and Fe levels between 13.0–15.1 ppm. Suwanto *et al.* (2010) [13] investigated environmental interactions with 10 rice genotypes and found that the Barumun genotype had the highest Fe content (36.75 ppm). Environmental factors accounted for 66.55% of Zn content variation, emphasizing the influence of growing conditions. Hybridization has also been used to enhance nutrition, as shown by Fitriyah *et al.* (2020) [14], who analyzed the β -carotene content in transgenic Golden Rice, ranging from 231.61 ppm to 920.52 ppm in different lines. Research on Fe and Zn content in local rice genotypes has been conducted extensively.

Despite extensive research on Fe and Zn content in local rice genotypes, no systematic exploration or identification of Zn and Fe levels in West Sumatra's local rice varieties with firm textures has been conducted. This represents a novel approach in the current study. By focusing on these local rice genotypes, this research aims to provide crucial data to support biofortification breeding programs. It is

a significant initial step toward achieving sustainable solutions for stunting reduction through improved nutrition in Indonesia.

EXPERIMENTAL SECTION

The research aimed to explore and analyze the zinc (Zn) and iron (Fe) content of rice genotypes in West Sumatra, Indonesia, using a combination of field exploration and advanced laboratory analysis. The exploration phase employed a survey method to document the diversity of rice genotypes cultivated by local farmers. Data were collected through direct field visits and structured interviews with farmers to obtain information on the origin, cultivation practices, and perceived nutritional value of the rice varieties. Sampling locations were purposively selected to represent different agroecological zones, including lowlands, midlands, and highlands. Collaboration with local agricultural extension officers ensured comprehensive coverage of potential rice genotypes. Data recorded during interviews included genotype names, planting area, and farmer perceptions of grain quality and yield.

Representative seed samples were collected from each identified genotype based on uniqueness, local popularity, and availability. These samples were properly labeled and transported in airtight containers to maintain their integrity. Upon arrival at the laboratory, the seeds underwent preliminary processing. Approximately 25 g of paddy rice (unhulled rice) from each genotype was husked using a Satake THU Testing Husker to obtain brown rice (unpolished rice), which was used for Zn and Fe content analysis. The analysis was conducted at the BSIP Rice Laboratory, Ministry of Agriculture, Sukamandi, West Java, using an X-Ray Fluorescence (XRF) spectrometer (Oxford Instrument X-Supreme 8000). This instrument, validated with the Inductively Coupled Plasma (ICP) method for accuracy, offers a reliable and non-destructive approach to trace element analysis in agricultural samples. The processed brown rice samples were sorted to ensure only whole and clean grains were used. The XRF spectrometer was calibrated using the “Rice15” program, optimized for brown rice analysis, and the Zn and Fe content of Inpari IR Nutri Zinc (Inpari IR NZ) was used as the benchmark reference. Inpari IR NZ is a widely cultivated biofortified rice variety in Indonesia known for its high Zn and Fe content, serving as an ideal standard for comparison.

Each 25 g brown rice sample was placed in the XRF sample chamber and analyzed in triplicate to ensure accuracy and reliability. Zn and Fe concentrations were recorded in parts per million (ppm). To maintain data accuracy, periodic validation of the XRF results was performed by cross-referencing with ICP measurements. Strict adherence to standardized operating procedures and quality control measures further ensured the reliability of the findings. Data from the exploration and laboratory analysis were statistically analyzed to determine the nutrient profiles of the rice genotypes. Descriptive statistics, including mean and standard deviation for Zn and Fe content, were calculated. Comparative analysis was performed against the benchmark Inpari IR NZ to identify promising genotypes with potential for biofortification or nutritional enhancement.

RESULTS AND DISCUSSION

Zinc (Zn) Content

Zinc is another essential micronutrient that plays a critical role in various biological processes in humans. Zinc acts as a cofactor for more than 300 enzymes involved in diverse metabolic pathways, including protein synthesis, DNA replication, and carbohydrate metabolism. In addition, zinc is key in supporting immune function, growth, and tissue repair. In the present study, the zinc content in local rice genotypes from West Sumatra showed significant variability. The fortified varieties Inpari IR Nutri Zinc had the highest zinc content (31.30 ppm). Other genotypes such as Puluik Mutia (28.40 ppm), Kuning Aro (27.60 ppm), and IR42 Tinggi (27.65 ppm) showed zinc content that is close to the control, indicating their substantial potential for further development.

Zinc deficiency, though often less apparent than iron deficiency has serious health consequences particularly in children. Zinc is vital for supporting normal growth and development. Zinc deficiency during childhood can lead to stunting (Sharif *et al.*, 2020) [15], a major nutritional issue in Indonesia. Stunting not only affects height but also impairs cognitive development and immune function. Moreover, zinc plays a vital role in supporting the immune system. Zinc enhances the activity of immune cells like T lymphocytes and neutrophils, which are responsible for fighting off pathogens. Zinc deficiency increases the risk of infections, including diarrhea and pneumonia, which are the leading causes of morbidity in children in developing countries [16]. Therefore, rice varieties with high zinc content, such as Inpari IR Nutri Zinc or local genotypes like Puluik Mutia, can be a crucial solution to improving public health.

At the molecular level, zinc is required for protein structure stability and cell membrane function [17]. Zinc also exhibits antioxidant properties, protecting cells from oxidative damage caused by free radicals [18]. In metabolism, zinc is involved in regulating hormone activities, such as insulin, which is essential for controlling blood sugar levels [19]. Globally, zinc deficiency has been linked to increased mortality in children due to infectious diseases and related complications. Increasing zinc content in rice also has significant relevance for the agricultural sector. Enhancing zinc content can be achieved through agronomic biofortification practices, such as applying zinc-based fertilizers or through genetic breeding approaches. Local genotypes like Kuning Aro that show relatively high zinc content present good prospects for environmental adaptability, making them suitable candidates for further development using modern breeding technologies.

Table 1. Zn and Fe content (ppm) of several rice genotype in West Sumatra

No.	Genotype	Zn Content	Fe Content
1	Inpari Nutri Zinc	31.30	19.85
2	Anak Daro	20.80	11.20
3	Bujang Marantau	21.80	15.75
4	Rampai Kuning	26.20	18.05
5	Bawaan	23.85	15.90
6	Caredek Putih	20.30	14.75
7	Banang Pulau	23.65	14.25
8	Cisokan	17.40	14.30
9	Kuriak Kusuik	20.95	13.75
10	Caredek Merah	18.95	12.85
11	Manggung	20.55	19.40
12	Sungkai	20.40	14.60
13	Kahayan	21.35	15.60
14	Tongga	23.75	18.85
15	Junjungan	24.10	17.80
16	Kuning Aro	27.60	18.20
17	IR 42 Tinggi	27.65	16.85
18	Randah	23.70	15.15
19	Batang Piaman	25.65	15.25
20	Redek Merah	24.25	14.10
21	Anam Pulau	18.55	15.45
22	Redek Sirah	21.65	15.30
23	Puluik Merah	23.20	18.80
24	Puluik Hitam	20.10	18.10
25	Puluik Tulang	19.05	16.05
26	Puluik Mutia	28.40	18.30
27	Ketan Merah	20.10	12.50
28	Ketan Hitam	22.15	17.30

However, it is important to consider the bioavailability of zinc in plant-based sources. Zinc in rice is often bound with phytic acid, which reduces its absorption in the intestine. Therefore, in addition to increasing zinc content, efforts to reduce phytic acid levels or enhance bioavailability through complementary compounds are essential [20]. From a public health standpoint, developing rice varieties with high zinc content has a significant potential to address the issue of hidden hunger, a condition caused by micronutrient deficiencies. Biofortification programs like these have been successfully implemented in several countries to reduce stunting rates and enhance overall immune function. Therefore, local genotypes like Puluik Mutia and Kuning Aro can serve as a strategic choice for supporting food security and improving the nutritional status of the population.

Iron (Fe) Content

Iron is an essential micronutrient that plays a fundamental role in various physiological processes and metabolism in humans. It is primarily involved in oxygen transport through hemoglobin and myoglobin. Hemoglobin, a protein found in erythrocytes, is responsible for carrying oxygen from the lungs to tissues, while myoglobin stores oxygen in muscles to support cellular activity. Iron deficiency often leads to iron-deficiency anemia, which can negatively impact cognitive function, energy levels, and productivity [21]. In the data obtained from the study, the iron content of local rice genotypes from West Sumatra showed significant variation. The fortified variety Inpari IR Nutri Zinc had the highest iron content at 19.85 ppm. This genotype serves as a benchmark for comparison with other tested genotypes. Some local varieties, such as Puluik Mutia (18.30 ppm) and Junjungan (17.80 ppm), showed iron content that is comparable to the control, indicating the substantial potential of these varieties in improving iron intake for the population if further developed.

Iron content in local rice varieties is highly relevant to the Indonesian population, where rice is a staple food. In rural and urban areas with limited access to diverse foods, adequate iron intake from plant-based sources becomes crucial. Globally, iron deficiency affects an estimated 2 billion people, with Southeast Asia showing particularly high prevalence. In this context, the development of local rice varieties with high iron content, such as Puluik Mutia, could contribute significantly to addressing iron deficiency. Iron also plays an essential role in energy metabolism through its involvement in the electron transport chain in mitochondria. Proteins like cytochrome contain iron as a cofactor, allowing electron transfer to generate adenosine triphosphate (ATP), the primary energy molecule of the body. Iron deficiency can reduce ATP production, affecting stamina and physical activity [22]. In addition, iron is necessary for DNA synthesis, cell differentiation, and immune function [23]. A lack of iron can impair immune function, making individuals more susceptible to infections. Children with iron-deficiency anemia, for example, are at greater risk of acute respiratory infections and diarrhea, two major causes of morbidity in developing countries [24]. Therefore, increasing iron content in staple foods like rice is a strategic step toward improving public health.

The data also indicate that local genotypes such as Caredek Merah and Ketan Hitam have relatively lower iron content at 12.85 ppm and 17.30 ppm, respectively. Although their iron content is lower compared to fortified varieties, these genotypes still have potential advantages in other areas, such as environmental adaptability or nutritional properties. Further studies could explore methods for enhancing iron content through agronomic techniques, such as soil and fertilizer management, or through plant breeding. On a molecular level, the bioavailability of iron in rice is a key challenge. Iron in plant-based sources is usually bound in the non-heme form, which has lower bioavailability compared to heme iron from animal sources. The presence of phytic acid in grains like rice can inhibit iron absorption in the intestine. Therefore, in addition to increasing iron content, it is important to reduce phytic acid levels or add bioavailability-enhancing compounds, such as ascorbic acid, through biofortification [25].

Biofortification programs have proven successful in increasing iron content in rice in various

countries. For example, genetically modified rice, such as Golden Rice, has successfully enhanced iron and other vitamins, though its adoption still faces social and economic challenges. Local West Sumatran varieties with high iron content, such as Puluik Mutia, could serve as a basis for further development through conventional and modern breeding approaches. From a public health perspective, developing local rice varieties with high iron content could significantly reduce the prevalence of anemia, particularly in vulnerable groups such as pregnant women, children, and the elderly. Iron deficiency in pregnant women, for example, increases the risk of preterm births, low birth weight, and maternal mortality [26].

CONCLUSION

This study systematically explored and evaluated the Zn and Fe content of 28 rice genotypes, including 27 local genotypes from West Sumatra and a control variety (*Inpari Nutri Zinc*). The control variety exhibited the highest Zn (31.30 ppm) and Fe (19.85 ppm) levels. Among local genotypes, *Puluik Mutia*, *Kuning Aro*, and *Rampai Kuning* showed the highest Zn content, while *Manggung* had the highest Fe content. These findings highlight the potential of local rice genotypes as germplasm for biofortification programs. This research provides a foundation for sustainable efforts to address malnutrition and stunting in Indonesia through improved rice nutrition.

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