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Article

# Whole Maize Flour for Better Food and Nutrition Security in Malawi

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**Abstract:** Maize is the staple cereal in Malawi, with a daily per capita consumption of 383g (dry matter basis), primarily consumed as dehulled maize flour used to cook *nsima*, a thick porridge. However, the extent of mass and nutrient loss during dehulling remains unclear in this food-insecure country, where the household maize harvest typically lasts only 6–7 months. In the current study, a milling experiment to determine yield and micronutrient losses was conducted. Milling batches (30 kg) of four maize grain varieties were dehulled at three abrasive disk dehullers under controlled conditions. Mass losses ranged from 18.8% to 42.7%, with a mean of 28.2±5.7%. Maize variety and dehuller significantly affected mass loss ( $p < 0.05$ ). Initial protein, iron, and zinc concentrations were 8.8 ±1.0 g/100g, 20.5±2.0 µg/g, and 18.2 ±2.6 µg/g, respectively. Post-dehulling nutrient true retention varied for protein (49.7% to 75.6%, mean=64.7±7.0%), iron (18.7% to 71.6%, mean=37.6±12.0 %), and zinc (11.0% to 46.2%, mean=27.9±8.7 %). Maize variety significantly influenced mass and protein loss ( $p < 0.05$ ), while dehuller influenced mass, iron, and zinc losses. However, no significant difference ( $p > 0.05$ ) was found in the interaction between dehullers and variety on mass and nutrient losses, respectively. Given Malawi's precarious food insecurity situation, transitioning from dehulled maize flour *nsima* to whole maize flour or less refined *nsima*, is imperative. Our study findings can have food and nutritional savings for other southern Africa countries where the dehulling practice is rampant.

**Keywords:** Dehulled maize flour; maize grain dehulling; mass and nutrient loss; food and nutrition security

## 1. Introduction

Food insecurity continues to be a significant challenge in Malawi, with the country ranking 105th out of 113 nations on the Global Food Security Index [1]. Typically, households only have food, particularly maize, the country's staple, lasting 6 to 7 months from each crop production season [2]. Despite the food shortage, most households consume maize after undergoing a dehulling process that may result in significant mass and nutrient losses [3]. This practice has the potential to exacerbate malnutrition.

Dehulling involves separating the pericarp and germ from the endosperm, often achieved through machinery like abrasive disk dehullers or traditional methods such as using a mortar and pestle [4]. The extent to which the pericarp and germ are separated varies significantly. Some methods remove the aleurone layer, which is rich in proteins, minerals, phytochemicals and antioxidants, along with the pericarp, while others retain part of it attached to the endosperm [5–8]. This variability may be influenced by factors such as gain moisture, the type of dehuller used and the

maize variety, ultimately impacting the nutrient density of the refined flour produced. Consequently, there are notable differences in mass loss and yield.

It has been estimated that 57% of households in Malawi produce their own maize flour [3]. In contrast, a recent study conducted in Lilongwe, Malawi's capital, found that 89% of households utilize local abrasive disk dehullers and grinding mills for maize processing (Ngoma et. al., unpublished data). However, the effectiveness of these methods and their impact on mass and nutrient retention are uncertain. Milling generally leads to micronutrient losses [9,10], with significant reductions in zinc content reported in maize meal from Malawi and Uganda [3,10]. Although dehulling may not affect provitamin A carotenoids, it can decrease zinc and amino acid levels [8,11].

The current study investigated the extent of mass and nutrient losses during maize grain dehulling across various maize varieties and dehullers in Malawi, with specific focus on proteins, iron, and zinc. We hypothesized that significant differences in mass losses occur among varieties used in Malawi (Hypothesis 1). Additionally, we expected a nuanced relationship between maize variety and nutrient losses, particularly concerning protein, iron, and zinc content (Hypothesis 2). The study's findings have the potential to guide policy development and targeted interventions aimed at mitigating physical and nutrient losses, thus contributing to enhanced food and nutrition security in Malawi and other Southern African countries where dehulling practices are prevalent.

## 2. Materials and Methods

### *Experimental Details*

To evaluate the physical and nutrient losses during maize dehulling, as well as identify factors contributing to variations in losses, an experiment was conducted. The experiment involved dehulling triplicate 30kg batches of four distinct maize varieties (including an unspecified local variety obtained from a farmer in Lilongwe District as well as *Kanyani*; *Njobvu*; *Pro Vit A* varieties procured from Chitedze Agricultural Research Station using three randomly selected abrasive disk dehullers in Lilongwe District. The weights of raw maize, maize grits, and bran produced post-dehulling and winnowing were recorded to calculate physical losses. Iron (Fe) and zinc (Zn) concentrations were determined using inductively coupled plasma optical emission spectroscopy (ICP-OES), while protein content was measured using a near-infrared spectrophotometric method (NIRs), both as described by Palacios-Rojas et al [12]. The results obtained for raw maize grain and flour was then used to calculate the percentage of nutrient concentration losses and apparent retention (AR) by comparing the concentration of the nutrient in the maize flour to that of the maize grain, in a fresh basis. True retention (TR) percentage was also reported and it was calculated by multiplying the apparent retention (AR) by the proportion of flour obtained from the grain. Maize hardness characterization was not conducted due to logistical challenges.

### *Statistical Analysis*

Shapiro-Wilk test and Bartlett's test were used to test normality and equal variance assumptions. All assumptions were satisfied and therefore, a two-way ANOVA was used to examine the effects of variety and dehuller type on mass and nutrient loss, among the experiment samples, at a significance level of 5%. Post-hoc mean separations were conducted using Tukey's honestly significant difference test where ANOVA model revealed significant differences. All statistical analyses were conducted using XLSTAT (ver 2023; Addinsoft, New York, NY).

## 3. Results

The mass losses observed in the dehulling experiments ranged from 18.8% to 42.7%, with a mean loss of  $28.1 \pm 5.7\%$ . Analysis of the experimental data showed that the variety of maize ( $F_{3,32} = 13.74$ ,  $p = 0.000$ ) and dehuller ( $F_{2,33} = 9.73$ ,  $p = 0.001$ ) had significant effects on mass loss. Two of the four varieties had significantly lower mass losses (Figure 1). These two varieties were classified as being

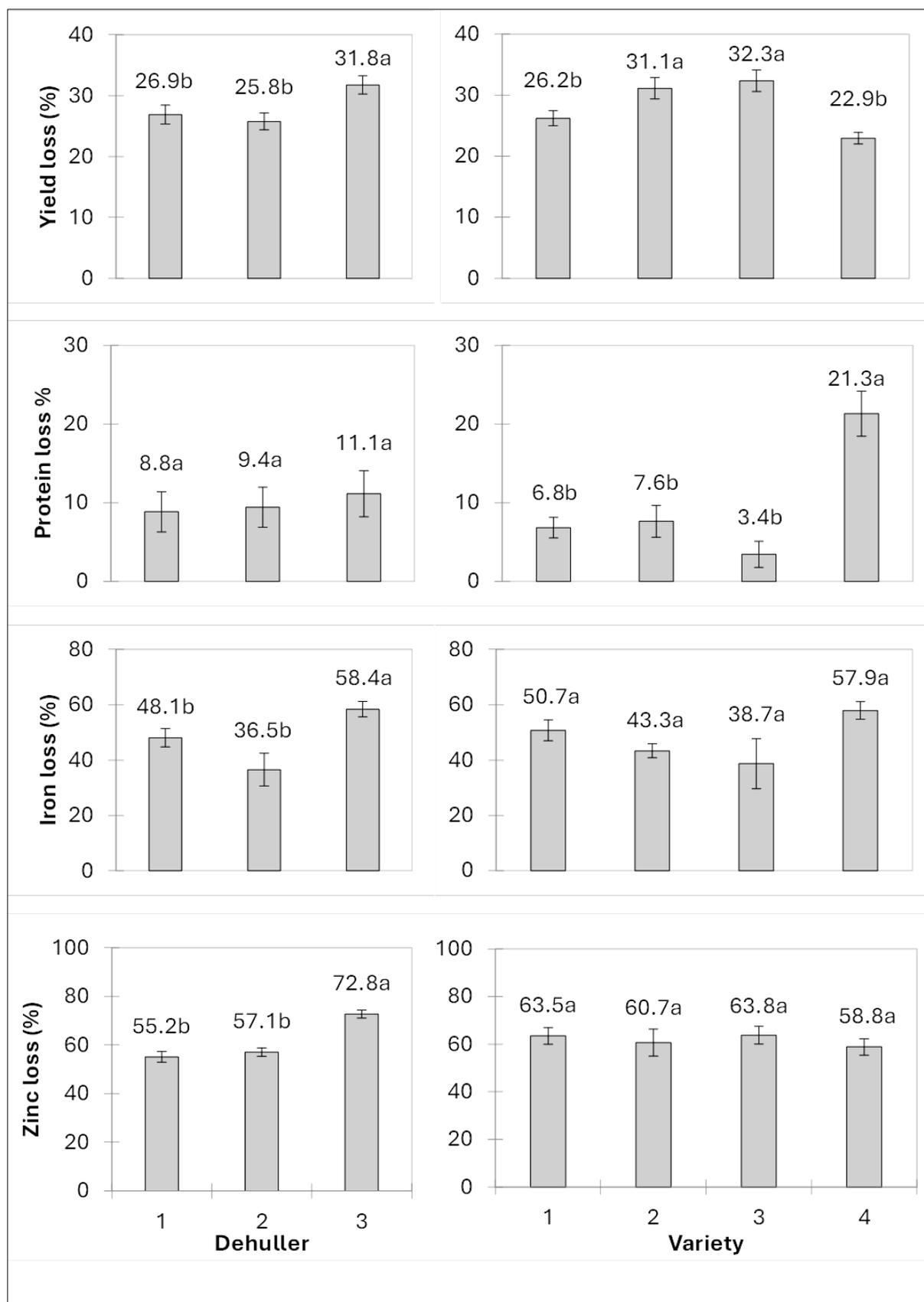
of hard endosperm, but due to damage of the analytical sample, the actual hardness for the samples was not measured.

The initial concentrations of protein, zinc and iron in whole maize grains ranged 7.5–9.8 g/100g, 16.7–21.1 µg/g and 18.7–22.5 µg/g, respectively. Following the dehulling process protein concentration ranged 7.3–8.4 g/100g, zinc was 6.1–7.7 µg/g and iron was 9.4–12.4 µg/g (Table 1). Varying degrees of concentration losses were observed: protein concentration loss ranged from 0% to 32.3% (mean= 9.8±9.1 %), iron loss from 0% to 71.8% (mean=47.7±16.9 %), and zinc loss from 41.5% to 80.9% (mean=61.7±10.2 %). Results revealed that maize variety significantly influenced protein loss ( $F_{3,32} = 14.95, p = 0.000$ ) whereas the dehuller had a significant impact on both iron and zinc losses, as depicted in Figure 1. However, the interaction between dehullers and variety did not show a significant effect on protein, iron, or zinc losses. Due to the low milling yield, the resulting TR values for protein (TR% ranged 49.7–75.6%, mean=64.7%), zinc (TR% ranged 11.0–46.1%, mean=27.9%) and iron (TR% ranged 18.7–71.6%, mean=37.6%) were significantly lower than AR in each milling batch (Supplementary Figure 1).

**Table 1.** Mean (± SEM) protein, zinc and iron concentrations in maize grain and flour of four varieties produced in Malawi.

Variety	Protein G		Protein F		Zinc G		Zinc F		Iron G		Iron F (µg/g)
	(%)		(%)		(µg/g)		(µg/g)		(µg/g)		
	9.	0.	8.	0.	21.	1.	7.	2.	19.	0.	2.
Local*	1 ± 7		4 ± 6		1 ± 8		7 ± 2		2 ± 3		9.4 ± 2
Kanyan	8.	0.	7.	0.	16.	3.	6.	1.	21.	0.	12.
i	6 ± 5		9 ± 3		7 ± 8		4 ± 5		8 ± 7		4 ± 8
	7.	0.	7.	0.	16.	0.	6.	1.	18.	2.	11.
Njobvu	5 ± 9		3 ± 9		8 ± 7		1 ± 9		7 ± 3		6 ± 9
Pro Vit	9.	0.	7.	0.	18.	0.	7.	1.	22.	0.	2.
A*	8 ± 2		7 ± 9		0 ± 7		4 ± 9		5 ± 9		9.5 ± 2

\*unspecified variety.



**Figure 1.** Effect of dehuller and maize variety on yield loss, and protein, iron, and zinc concentration losses (%)(n = 3). (Varieties: 1=Unspecified local variety; 2=Kanyani; 3= Njobvu; 4=Pro Vit A). Error bars denote SEM.

#### 4. Discussion

By replacing refined maize flour (*woyera*) with whole grain flour (*mgaiwa*), which avoids milling losses associated with dehulling, the availability of maize grains at the household level could potentially be extended from the 6 to 7 months, by approximately 2 months of availability. While the bran generated from the dehulling process is traditionally given to livestock it is noteworthy that a significant proportion of the food-insecure population, particularly the less privileged, does not keep livestock or keep it as free-range [13,14]. Paradoxically, they continue the culturally ingrained practice of dehulling maize, resulting in the aforementioned loss.

Transitioning to whole maize flour can also contribute to alleviate the prevalent zinc deficiency problem, which currently affects 60-66% of the Malawi population across all demographic groups [15]. The 72.1% average zinc loss reported in the current study during maize dehulling is concerning considering *nsima*'s significance (maize flour-based staple food in Malawi) as a potential zinc source. With an average zinc content of 18.2 µg/g in maize and assuming daily per capita consumption of 383g of maize (dry matter basis) as whole meal *nsima* [16], it can be hypothesized that this dietary source could contribute 87.1% and 63.4% to the recommended daily zinc intake for adult females (8mg) and males (11mg), respectively, according to the Institute of Medicine [17].

However, because of the dehulling process, which averages a reduction of 72.1% in zinc content, *nsima* can contribute only approximately 33.4% for females and 24.3% for males towards fulfilling the recommended daily zinc intake. This leads to a substantial deficit unlikely to be addressed, particularly given the monotonous nature of the Malawian diet and the limited economic access to alternative zinc-rich sources [18]. While these calculations may be conservative, considering that *nsima* may contain phytates, which can inhibit zinc absorption and affect bioavailability, these calculations nonetheless serve as an indicator of the losses associated with maize dehulling. Moreover, this loss not only contributes to zinc deficiency but also exacerbates the protein and iron deficiencies already prevalent in Malawi [19,20]. Additionally, households not only lose mass and nutrients during the dehulling process but also incur additional expenses, a significant burden considering the majority of the population is poor.

Despite the significant consumption of *mgaiwa* flour by the rural population in Malawi, in urban populations, dehulled maize *nsima* is a long-standing staple, consequently, transitioning to more consumption of whole maize may initially pose challenges. Global examples, like the Irish adoption of potatoes [21] and the introduction of maize in Africa by colonialists [22], illustrate that communities can modify dietary preferences through effective promotion despite potential cultural resistance. Emphasizing health benefits, such as reduced diabetes risk and increased dietary fibre from whole maize meal *mgaiwa* [23], or semi refined is important. While phytochemicals and antioxidants in whole grains receive less attention than those in fruits and vegetables, they are linked to decreased risks of chronic diseases, including cardiovascular disease, type 2 diabetes, cancers, and overall mortality [24]. While it is widely acknowledged that dehulling reduces mycotoxins [25–27], reassuring consumers about readily available alternative mycotoxin prevention methods, such as sorting and preharvest measures [28,29], would alleviate concerns regarding to mycotoxin risk associated with whole grains and facilitate the transition to consumption of whole maize. Notably, Malawi's boarding secondary schools already primarily serve whole maize meal *nsima*, supplemented with beans and vegetables, showing adaptability to this dietary norm. Furthermore, disadvantaged households sometimes blend bran with *mgaiwa* flour to produce *madeya* flour for *nsima* preparation, with the intention of augmenting its volume [30].

While promoting the adoption of whole maize meals is important, the significant variability in mass loss observed in the current experiment highlight the urgent need for promoting more efficient milling practices. Introducing, efficient milling technologies as an intermediate strategy is equally crucial to address both mass and nutrient losses through precision engineering [31]. Furthermore, the current results underscore the importance of prioritizing micronutrient fortification of refined maize-based end-products to complement genetic maize biofortification, given the significant nutrient losses that may occur during the dehulling process. Additionally, promoting the consumption of whole grain maize, particularly high-zinc varieties, is encouraged to maximize nutrient intake.

## 5. Conclusions

Our investigation provided significant insights into our hypotheses. Firstly, we observed no significant difference in mean mass loss percentages among dehullers, suggesting widespread high mass losses across various mechanical dehulling methods. Secondly, our analysis unveiled a nuanced relationship between maize variety and nutrient losses (specifically protein, iron, and zinc content). Additionally, we identified significant differences in iron and zinc losses among dehullers, although there were no interactions between dehuller used and variety. This underscores the complexity of factors determining losses during dehulling, suggesting the potential for breeding for high dehulling yields and adopting specific dehullers, both of which may not be easily practicable.

Given Malawi's precarious food and nutrition insecurity situation, adopting whole maize meal is imperative. To drive adoption, emphasis should be placed on highlighting its health benefits and leveraging existing dietary norms observed in places like boarding schools. Additionally, conducting comprehensive studies to assess the rationale of dehulling, consumer preferences, attitudes, and behaviours towards whole maize meal could inform targeted promotion and education efforts. However, recognizing that not all consumers may prefer whole maize meal, optimizing the dehulling and degerming processes is also essential to minimize excessive losses during milling.

**Supplementary Materials:** Available online at Preprints.org.

**Author Contributions:** Conceptualization, TNN, VT, and LM; methodology, TNN, VT, and LM; validation, TNN, VT, and LM; formal analysis, TNN, VT, APG and LM; investigation, TNN, VT, and LM; resources, VT and LM.; data curation, TNN, VT, APG and LM; writing—original draft preparation, TNN, VT, BMM, APG, NPR and LM; writing—review and editing, TNN, VT, BMM, APG, NPR and LM.; visualization, TNN and APG.; supervision, BMM and LM.; project administration, VT and LM.; funding acquisition, VT and LM. All authors have read and agreed to the published version of the manuscript.

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**Data Availability Statement:** The raw data supporting the conclusions of this article will be made available by the authors on request.

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