

## Research Article

# A Comparative Study of Physicochemical Attributes of Pigmented Landrace Maize Varieties

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Maize has been cultivated and continues to be cultivated for its usability in calorie supply to humans and livestock. There has been great interest in pigmented landrace maize varieties (PLMVs) due to their importance in the pharmaceutical industry. Landraces are to a large extent a repository of the gene pool that enriches biodiversity and maintains but also stabilizes the ecosystem in a sustainable way. PLMVs are still being cultivated by smallholder farmers in smaller portions of their fields and home surroundings despite the high adoption of white hybrid maize. This study examined the ash, moisture, mineral, crude protein, fat, and carbohydrate content of three different PLMVs from central (Ntcheu and Dedza districts) and northern (Mzimba district) Malawi. The mineral content of soils from fields where PLMVs were grown was also analyzed. The study areas experience a warm temperate climate and higher rainfall in summer than in winter but they differ in that Ntcheu has the highest average annual temperature of 20.3°C while Dedza receives the highest annual precipitation of about 1010 mm. Mzimba's average annual temperature and precipitation are 20.1°C and 915 mm, respectively. The study showed that orange maize from Dedza had a significantly higher content of calcium ( $71.00 \pm 0.58 \text{ mg}\cdot\text{kg}^{-1}$ ), magnesium ( $819.00 \pm 0.58 \text{ mg}\cdot\text{kg}^{-1}$ ), and phosphorus ( $2720.35 \pm 0.03 \text{ mg}\cdot\text{kg}^{-1}$ ). Significantly higher contents of zinc ( $54.61 \pm 0.43 \text{ mg}\cdot\text{kg}^{-1}$ ) and potassium ( $808.58 \pm 0.27 \text{ mg}\cdot\text{kg}^{-1}$ ) were observed in purple maize from Dedza and Ntcheu, respectively. Red maize from Dedza had a significantly higher content of iron ( $59.80 \pm 0.26 \text{ mg}\cdot\text{kg}^{-1}$ ). Purple maize from Dedza has significantly higher carbohydrate content ( $65.52 \pm 0.07\%$ ). The findings also revealed that red maize from Dedza provenance had a high content of crude protein ( $12.57 \pm 0.07\%$ ) and fat ( $10.73 \pm 0.14\%$ ). Moisture ( $17.30 \pm 0.21\%$ ) and ash ( $2.28 \pm 0.02\%$ ) were significantly higher in orange maize from Dedza. Dedza's provenance revealed a high content of the analyzed attributes in PLMVs. Mineral analysis showed different levels of mineral bioavailability in different PLMVs and in the soils where maize was grown. It can, therefore, be concluded that production location and maize variety have an influence on the attributes of PLMVs. Understanding the physicochemical attributes of PLMVs and its maximum utilization have the potential of improving food and nutrition security in Sub-Saharan African countries and globally.

## 1. Introduction

Biodiversity conservation in food crops is a backbone of food and nutrition security and maize is one of the food crops that has the largest diversity worldwide [1, 2]. Constant production and utilization of different maize varieties have helped to improve the well-being of the people by supplying

them with the required ingredients in their diet [2]. Production and utilization of PLMVs have to a large extent helped to boost small-scale businesses in different communities globally [3]. Maize is utilized as a staple food crop by many Sub-Saharan African countries, and it also serves as a source of livelihood for smallholder farmers in different niches of the globe [4, 5]. There is an estimate of about 6,400

indigenous plant species that are useful in Africa and more have been discovered worldwide [1]. PLMVs contribute to a wide diversity of maize and their disuse would contribute to their extinction [1, 6]. Over the past years, there has been high adoption of white hybrid maize which has reduced the production of PLMVs [6]. Not much information is available on PLMVs [7] and the effect of the production location on the physicochemical attributes of PLMVs grown in Malawi. This study was therefore conducted to compare the physicochemical attributes of PLMVs from different production locations.

Biased production of selected varieties promotes biodiversity loss in useful crop species which increases the danger of encountering food and nutritional insecurity [8, 9]. Absolute promotion of one crop variety contributes to decreased production and access to another and it is unsustainable in today's world of pandemics [10, 11]. Therefore, there is a need to intensify production systems that promote crop biodiversity conservation [12]. Understanding of the social, cultural, nutritive, culinary value, consumer acceptability, and the impact of production location on proximate compositions of PLMVs grown by smallholder farmers can help its increased production and utilization. The physicochemical properties of different maize varieties give information on maize kernel quality and would help in making choices of which variety to cultivate [13]. Such information would also be very useful in determining which PLMVs to be included in the diet.

PLMVs grown by smallholder farmers globally greatly contribute to the health and well-being of the people in their respective locations [14–17]. A study in Malawi revealed that the orange maize crop plays a vital role in providing essential natural ingredients for micronutrient production [6]. It has sadly been observed that over 2 billion people worldwide are affected by micronutrient deficiency which results in a high rate of morbidity and mortality [17]. This is due to a lack of knowledge and failure to harness the diversity of available food crops.

Micronutrient deficiency which is also described as hidden hunger is highly prevalent among vulnerable populations such as children in Sub-Saharan Africa [18]. This is due to the lack of access and utilization of different kinds of nutritive foodstuffs. The potential increases in food production are far from being realized under field conditions although there are many available technologies provided by science and diversification avenues [6]. One of the main problems, encountered by farmers and all stakeholders involved in maize production, is postharvest losses. Dent corn maize varieties are easily attacked by pests when compared to flint corn of PLMVs [6]. Climate change has aggravated the conditions of both biodiversity loss and food insecurity by increasing the risks of crop failure. There has been crop population extinction because of the higher frequency of extreme events and progressive change in key climate variables [12]. Worldwide food and nutrition insecurity are major and growing problems [19, 20]. About 48% of under-five children in Malawi are said to be chronically malnourished and 5% have acute malnutrition while 22% are categorized as underweight [21]. This has been attributed to

the displacement of a diversity of macronutrient and micronutrient-rich indigenous crops but also the choice and selection of food crops contributing to the diet of many modernized individuals [22].

Indigenous crops usually adapt and grow well in their production provenances [12]. This is mainly because they develop resistance to diseases as a result of developing together with their pests and disease-causing pathogens [6, 23]. This offers a diversity of food crops from which individuals can choose and achieve food and nutrition security [23]. Smallholder farmers continue to cultivate PLMVs due to their yield stability [24]. The process of buffering in PLMVs enables the crop to possess diversity within and between crops [12, 24], and this also contributes to yield stability under low input systems of crop production [12, 14]. Due to these characteristics, PLMVs are therefore the best option for resource-poor smallholder farmers who cannot afford seed and other costly inputs annually. Less cost of maize production would give chance to resource-poor farmers to use their income to access other nutritious food crops which would enable them to deal with problems of food and nutrition insecurity [24, 25].

Production locations experience different climatic factors and are associated with different parameters that contribute to food crop growth and development [26]. Mineral bioavailability is influenced by different abiotic factors such as soil mineral content, nutrient solubility, and the capacity of the different crop varieties to absorb the available nutrients in their vicinity [26]. Soil quality needs to be monitored for quality food production [27]. This study was carried out in three districts having warm temperate climates and higher rainfall in summer compared to winter. For instance, Ntcheu (central region) has an average annual temperature of 20.3°C and receives about 986 mm of precipitation annually, it is located between latitude and longitude coordinates of 14°49'12.97"S, 34°39'9.1"E while Dedza (central region) has an average annual temperature and precipitation of 18.2°C and 1010 mm, respectively, and is located between latitude and longitude coordinates of 14°22'40.44"S, 34°19'59.59"E. Mzimba (northern region) on the other hand has an average annual temperature of 20.1°C and receives about 915 mm of precipitation annually and is located between latitude and longitude coordinates of 11°54'0''S, 33°36'0''E. The observed differences in climatic conditions in the study locations may have an impact on the nutritional and physicochemical attributes of PLMVs grown in Malawi. Looking at the value of PLMVs, it is advisable that individuals should continue to cultivate and utilize PLMVs in order to benefit from its attributes. This study was therefore conducted to compare PLMVs attributes such as ash, moisture, crude protein, fat, carbohydrate, and mineral content of orange, red, and purple maize varieties grown by smallholder farmers in Malawi.

## 2. Materials and Methods

*2.1. Pigmented Landrace Maize Samples.* Fifty-four different farmers were involved in this study. Three different pigmented landrace maize varieties (orange, red, and purple)

were collected from them. Samples were collected and carried in ziplock plastic bags from specific study locations, thus Mzimba (northern region), Ntcheu, and Dedza districts (central region). Orange, red, and purple maize samples were collected from six different farmers in each district. Samples were ground using a wooden mortar and pestle to uniform size (0.5 mm). Thereafter, extraction was conducted. Soils were also taken from the fields where the PLMVs were grown. The samples were kept in ziplock plastic bags until mineral analysis time.

**2.2. Moisture Determination.** Moisture determination was undertaken as described by Shaista et al. [2] with some modifications. Triplicates of each sample (500 mg) were oven-dried at 60°C for 24 hours in pre-weighed aluminum dishes thereafter cooled in a desiccator for 30 min and weighed. Moisture was determined as follows: moisture ( $\mu\text{gg}^{-1}$ ) =  $(W_2 - W_3)/(W_2 - W_1) \times 100$ , where  $W_1$  is the weight of the empty dish,  $W_2$  is the weight of dish + sample before drying, and  $W_3$  is the weight of dish + sample after drying.

**2.3. Ash Determination.** Ash determination was undertaken as described by Shaista et al. [2] with some modifications. Clean crucibles were incinerated in a furnace at 525°C for 1 hour and cooled in a desiccator at room temperature, for 30 min, and weighed on an analytical balance. Then, 200 mg of each sample (in triplicates) was weighed in the crucibles, incinerated in the furnace at 525°C for 30 min, then cooled in a desiccator for 30 min, and reweighed. Ash was determined as follows:  $\text{aAsh} (\mu\text{gg}^{-1}) = (W_3 - W_1)/(W_2 - W_1) \times 100$ ,  $W_1$  is the weight of crucible,  $W_2$  is the weight of crucible + sample before incineration, and  $W_3$  is the weight of crucible + sample after incineration.

**2.4. Crude Protein Determination.** Crude protein determination was undertaken as described by Shaista et al. [2] with some modifications. Digestion, steam distillation, and titration processes were followed, where: 100 mg powdered sample was weighed on filter paper and placed in Kjeldahl flask and mixed with 1.7 g of mixed catalysts (160 g of potassium sulfate, 10 g copper sulfate, and 3 g selenium powder). Thereafter, 2 mL of water and 20 mL of concentrated sulfuric acid were added. The mixture was rested for 20 min and then heated on a hot plate in a fume hood while rotating the flask occasionally until the mixture cleared. A blank was prepared by mixing 1.7 g of mixed catalysts, 2 mL of water, and 20 mL of concentrated sulfuric acid in a Kjeldahl flask without the sample, and all the necessary treatments as done to the samples were also carried out on the blank.

The cooled digest of the sample was quantitatively transferred into a 250 mL volumetric flask and diluted to the mark with distilled water. An aliquot (5 mL) of the diluted digest was placed in a reaction tube in the distillation unit and was mixed with NaOH (46%, 5 mL) and steam distilled to liberate ammonia. The distilled sample was collected in a 250 mL Erlenmeyer flask containing boric

acid (4% w/v, 10 mL) and the indicator (0.1% methyl red in 95% ethanol with 200 mL (0.25 M) bromocresol green in 95% ethanol) was added drop by drop until color changed from red to green. The distillate was then titrated with standard acid HCl (1.0 M) solution and volumes were recorded.

Crude protein calculation equation:  $C_p (\mu\text{gg}^{-1}) = (\text{molarity of HCl} \times 14.007 \times (S - B) \text{ mL HCl} \times 6.25 \times VF) / (\text{mass of the sample (g)} \times 1000) \times 100$ , where  $S$  is the sample titrant volume (of HCl 1.0 M),  $B$  is the Blank titrant volume (of HCl 1.0 M), and  $VF$  is the volume factor (250/5).

**2.5. Crude Fats Determination.** Crude fat determination was undertaken as described by Hwang et al. [28] with some modifications. All the glassware were rinsed with distilled water and dried in an oven at 105°C for 30 min and cooled in a desiccator. Accurately, 100 mg of the milled sample was measured on a filter paper and put into the thimble that had a plug of cotton on its bottom; the sample was covered with another plug of cotton, on top of the extraction thimble. Then, the thimble was placed in the Soxhlet liquid extractor. A clean dry 150 mL round bottom flask was weighed accurately and in it, 90 mL of petroleum ether was added, and the extraction unit was assembled on an electric heating mantle and heated until the solvent in the flask boiled. Then, the heat source was adjusted so that the solvent dripped from the condenser into the sample chamber drop by drop until all the solvent was collected. The extraction unit was then removed from the heat source and the extractor was detached from the condenser.

The round bottled flask was then placed in a desiccator to cool down. Thereafter, the flask was weighed and the % crude fats were calculated as follows: % crude fat =  $((W_2 - W_1) \times 100/S)$ ,  $W_1$  is the weight of the empty flask (g),  $W_2$  is the weight of flask + extracted fats, and  $S$  is the weight of the sample.

**2.6. Carbohydrates Determination.** Carbohydrates were determined by difference, in which the mass of moisture, ash, crude protein, and crude fats as percentages were subtracted from 100% as follows:  $\text{carbohydrates\%} = 100\% - ((\text{moisture\%} + \text{ash\%} + \text{crude fats\%} + \text{crude protein\%}))$  [2].

**2.7. Mineral Determination in Pigmented Maize Grains and Soil Samples.** Mineral determination was done using Carpenter and Hendricks [29] method with modifications. Here, 100 mg of the sample was weighed using an analytical balance and placed in a 150 mL conical flask, and then 5 mL of  $\text{HNO}_3$  was added to the sample. This mixture was rested for 8 hours. Thereafter, 6.9 mL of  $\text{HNO}_3$  and 3.1 mL of perchloric acid were added. This mixture was heated on a hot plate to about 180°C until the white fumes evolved and transparent white content was left in the flask. Then, the transparent content was cooled down in a desiccator. After cooling, 25 mL of distilled water was added and the mixture was filtered into a 100 mL volumetric flask with 3-4 washing

of the conical flask, and then the mixture was made to 100 mL mark with distilled water. The filtrate was used to determine the concentrations of the following minerals: calcium, magnesium, potassium, zinc, iron, and phosphorus.

**2.7.1. Calcium (Ca) and Magnesium (Mg).** Aliquot samples of 5 mL in separate 100 mL volumetric flasks were mixed with lanthanum solution (5 mL) and the solutions were made to the mark with distilled water. Then, intermediate standard stock solutions of 10 ppm for each of the minerals were prepared by diluting their standard stock solution of 1000 ppm, 10 mL to 1000 mL with distilled water. Then, aliquots ranging from 0 to 16 mL of the intermediates standard solution were put in separate 100 mL volumetric flasks mixed with lanthanum solution (5 mL) and diluted to the mark with distilled water yielding a range of 0 to 0.16 ppm calcium and magnesium working standard solutions. Both the samples and the working standard solutions of each of the minerals were aspirated on an Atomic Absorbance Spectrophotometry (AAS) (Agilent tech.200 series, Mumbai, India) to obtain absorbance for each working standard solution. Sample concentration was calculated from the calibrated curve obtained from the concentrations and absorbance of the working standard solutions [29].

**2.7.2. Zinc (Zn) and Iron (Fe).** The working standard solutions were made by diluting the standard stock solutions of each of the minerals (1000 ppm, 10 mL) to 1000 mL with distilled water. The resulting solutions ranging from 0 to 15 mL were further diluted to 100 mL mark with HCl (0.1 M) in a separate volumetric flask to obtain the working standard solutions ranging from 0 to 0.05 ppm of zinc and 0 to 0.15 ppm of iron. Then absorbance was obtained by aspirating the working standard solution on AAS. The calibration curve was plotted from the absorbance and concentrations of the working standard solutions. Samples were then aspirated on an AAS to obtain their absorbance, and concentrations were calculated from the calibration curve [29].

**2.7.3. Potassium (K) and Phosphorus (P).** The working standard solutions ranging from 0 to 2 ppm of potassium were prepared from the standard stock solution of (1000 ppm, 10 mL) which was diluted to 1000 mL with distilled water to obtain a range of 0 to 20 ppm. Then, aliquots of resulting solutions were diluted further to 100 mL with HCl (0.1 M) in separate volumetric flasks to obtain the working standard solutions ranging from 0 to 2 ppm of potassium. Absorbance was obtained by aspirating the working standard solutions on the AAS. The calibration curve was plotted from the absorbance and the concentrations of the working standard solutions of potassium. Then, an aliquot sample (2 mL) was diluted with distilled water to the mark in a 100 mL volumetric flask and was aspirated on the AAS to obtain absorbance. The concentrations of the samples were calculated against the calibration curve. Phosphorus was determined by taking

aliquots of phosphorus standard stock solution (2.00 mg P/mL, 50 mL) which was diluted to 1000 mL to produce an intermediate standard stock solution of (0.1 mg P/mL). Then, a range of 0 to 10 mL aliquots of the intermediate stock solutions were put in separate 100 mL volumetric flasks. And aliquots of the samples (5 mL) were put in freshly rinsed 100 mL volumetric flasks. To each of the flasks containing working standard solutions and samples, molybdo vanadate solution (20 mL) was added. Then, the mixture was diluted to the mark with distilled water, mixed thoroughly, and allowed to stand for about 10 min for 8 full-color development, and the absorbance was determined on the atomic absorbance spectrophotometer (AAS). A curve of absorbance against concentration for the working standard solutions was plotted and was used to determine the concentrations of the samples [29].

$P \text{ (mg g}^{-1}\text{)} = (\text{conc.} \times \text{DF} / \text{V}) / \text{mass} \times 100$ , where Conc. is the concentration reading of samples read off from the standard curve, DF is the dilution factor, V is the volume, 100 is the 100 g of the dried sample (100 mL of mother liquor), and mass is the mass (g) of the sample incinerated (mL, mother liquor incinerated).

**2.8. Statistical Analysis.** Results are presented as mean  $\pm$  standard deviation (SD) of triplicate analysis. On analysis of variance (ANOVA) by Turkey's Honestly Significant Differences (HSD), the method was used to compare the means of composition attributes in the three production locations. All analyses were performed at a 95% confidence level ( $p < 0.05$ ) using IBM SPSS version 26.

### 3. Results and Discussion

Moisture content refers to the number of water molecules that become incorporated into a food product. Moisture content is an important attribute of food crops that affects not only storability but also the enzyme activities within the maize grains [30]. The humidity in the storage environment should be low because when dried foods pick up moisture from the storage area, molds and bacteria can grow. Moisture can also lead to the breakdown of some packaging materials (paper degradation and metal rusting). Product quality and shelf life decrease if dry foods are exposed to moisture. The resulting mold and bacterial growth can lead to spoilage and food-borne illnesses. Moisture content highly contributes to postharvest losses of maize by promoting the rotting of the grains either in the field or in the storage facilities [31, 32]. A moisture reading of 0–15% is quite normal and gives no cause for concern. However, moisture readings over 15% indicate the need for further inspection. Levels between 25% and 30% indicate that there may be water ingress; hence, remedial work is required. Research has shown that 90% of the human population world over is food insecure not because of lack of food production but because three-quarters of the realized food is lost through rotting due to moisture mismanagement [31, 32]. Food preservation methods such as drying, freezing, and adding salt or sugar work by lowering the available moisture

TABLE 1: Proximate content (percentage on a dry weight basis) of whole grain PLMVs.

Maize type	District	Moisture	Ash	Protein	Fat	Carbohydrate
Orange	Ntcheu	15.09 ± 0.37 <sup>b</sup>	1.64 ± 0.04 <sup>b</sup>	11.76 ± 0.03 <sup>a</sup>	6.00 ± 0.28 <sup>b</sup>	65.36 ± 0.05 <sup>a</sup>
	Dedza	17.30 ± 0.21 <sup>a</sup>	2.28 ± 0.02 <sup>a</sup>	12.26 ± 0.01 <sup>a</sup>	8.35 ± 0.36 <sup>a</sup>	59.83 ± 0.10 <sup>b</sup>
	Mzimba	16.70 ± 0.26 <sup>ab</sup>	1.60 ± 0.05 <sup>b</sup>	10.16 ± 0.07 <sup>b</sup>	5.30 ± 0.20 <sup>b</sup>	64.12 ± 0.06 <sup>a</sup>
Red	Ntcheu	17.09 ± 0.06 <sup>a</sup>	1.17 ± 0.11 <sup>b</sup>	12.26 ± 0.08 <sup>a</sup>	5.80 ± 0.12 <sup>c</sup>	62.67 ± 0.60 <sup>ab</sup>
	Dedza	16.80 ± 0.07 <sup>a</sup>	1.26 ± 0.09 <sup>b</sup>	12.57 ± 0.07 <sup>a</sup>	10.73 ± 0.14 <sup>a</sup>	58.73 ± 0.26 <sup>b</sup>
	Mzimba	15.05 ± 0.12 <sup>b</sup>	1.81 ± 0.06 <sup>a</sup>	11.82 ± 0.09 <sup>b</sup>	7.96 ± 0.13 <sup>b</sup>	64.12 ± 0.74 <sup>a</sup>
Purple	Ntcheu	16.83 ± 0.09 <sup>a</sup>	1.69 ± 0.07 <sup>a</sup>	12.04 ± 0.06 <sup>a</sup>	9.14 ± 0.04 <sup>a</sup>	60.43 ± 0.04 <sup>b</sup>
	Dedza	14.03 ± 0.08 <sup>b</sup>	1.40 ± 0.05 <sup>a</sup>	12.13 ± 0.07 <sup>a</sup>	6.37 ± 0.06 <sup>b</sup>	65.52 ± 0.07 <sup>a</sup>
	Mzimba	13.05 ± 0.05 <sup>c</sup>	1.10 ± 0.02 <sup>b</sup>	10.55 ± 0.02 <sup>b</sup>	3.30 ± 0.09 <sup>c</sup>	59.30 ± 0.02 <sup>c</sup>

Values with different subscript letters are significantly different ( $p < 0.05$ ). Values are means of three replicates.

in foods. Moisture in foods occurs in two forms: (1) water bound to ingredients in the food (proteins, salt, and sugars) and (2) free or unbound water that is available for microbial growth. Knowledge and management of moisture content in maize grains may help in saving food crops from damage and improve the food security of the people and the nation at large [33].

Determination of the physicochemical characteristics of maize such as moisture helps to understand important information about the maize grains' quality and nutritional composition [13]. The physicochemical and proximate content of the sampled PLMVs grown by smallholder farmers in three districts of Malawi are not the same (Table 1). Most of these characteristics appeared to differ significantly ( $p < 0.05$ ). The moisture range of the orange, red, and purple maize was between 13.05 and 17.30%. The minimum value was slightly lower and the maximum value was slightly higher than the range of the International Life Sciences Institute (ILSI) Crop database with an expected mean value of 14.5% moisture content in field maize [16]. At harvest, maize usually has a moisture content ranging from 18 to 24% but desirable moisture which is safe for storage is 14% [16]. In the present study, purple maize from Mzimba (13.05%) had the lowest mean value of moisture content while orange maize from Dedza (17.30%) had the highest value. Farmers sun dry maize after harvesting to lower the moisture content for easy storage [16]. It is recommended that moisture content should be regulated because it affects the yield quantity and quality of food crops. Damage to the kernel (usually during the shelling operation) is related to moisture content at harvest; the lower the moisture content, the less the damage [30]. Results from the present study have revealed that farmers who would wish to produce orange, red, and purple maize would have little problems in managing moisture content due to its manageable levels (Table 1). Less damage after harvest would result in achieving food security for the community and the nation as a whole.

Ashing is the first step in preparing a food sample for specific elemental analysis. Ash content measures the total mineral content of the food crops under study [34]. Minerals are generally important in the maintenance of the health of plants and animals [19]. Ash is a source of the macronutrients such as Ca, C, K, Mg, P, S, and N. Higher ash content for maize varieties indicates that the flour contains more of

the germ, bran, and outer endosperm. Lower ash content means that the flour is more highly refined. Ash content observed in our study was within the levels reported in the local and composite maize but slightly higher in some cases [34]. Orange maize from Dedza (2.28%) displayed the highest ash content and the lowest was discovered in purple maize from Mzimba (1.10%). This is similar to what Murayama et al. [35] reported. Differences in ash content in PLMVs were attributed to differences in maize varieties and genetic make up but also environmental differences in mineral composition. The varieties in this study were different and were also grown in different production locations. This would have contributed to the differences in their ash content (Table 1).

In terms of proteins, results in this study mirror the findings of Villa et al. [12], who reported the presence of proteins and fats in pigmented maize varieties but his findings were lower as compared to the findings of the present study. Our findings revealed that red maize from Dedza (12.57%) had the highest protein content than what Shaista et al. [2] reported (12.45%) and Mzimba (10.16%) orange maize reported the lowest. The findings are in line with what Murayama et al. [35] reported in a study that was also done in Malawi on orange maize. The differences in protein content observed in this study would be a result of the interaction between environmental factors and the genetic makeup of the varieties which influences protein metabolic processes within the plants [26]. Maize is probably the major source of protein in the diet of many Malawians because maize is considered a staple food [4]. Nevertheless, the insufficient quantity of lysine and tryptophan, which are among the eight essential amino acids, makes maize's nutritional quality poor [19, 34, 36, 37]. The fat content of corn ranges from 5% to 6%, making it a low-fat food but higher and lower levels have been reported [38, 39]. However, corn germ, an abundant side-product of corn milling, is rich in fat and used to make corn oil, which is a common cooking product. This study revealed high average fat content in Dedza (10.73%) red maize and purple maize from Mzimba (3.30%) had the lowest. The high content of specific attributes has been reported in some corn grains [2, 40]. This study, therefore, revealed that red maize from Dedza is one of the best suppliers of proteins and fats, as reported in other pigmented maize varieties [2, 40]. Utilization of red maize from Dedza would solve the problem of lack of fats in the diet of Malawian people.

About 50% of the Caloric intake of Malawians comes from different varieties of maize [16]. Maize has a characteristic quality of about 85.3% digestibility and is one of the major sources of carbohydrates [4]. In this study, the average carbohydrate content of orange, red, and purple pigmented-landrace maize varieties ranged from 58.73% to 65.52%. The highest value in this study was within the range as reported by Shaista et al. [2] in white maize (65.38% to 78.74%) but was higher than in yellow maize (60.23%) as reported by the same author. Different values of carbohydrates have been reported by different authors, and the highest content range is between 76% and 84% [2, 41]. In this study, the highest value was reported in purple maize from Dedza (65.52%) and is within the published ranges [2, 39, 42]. It has been reported that traditional maize varieties have strong photosensitivity which is linked to their ability to convert energy from the sun into carbohydrates stored in grains which is the consumable part of the crop [16]. The differences in carbohydrate content might be attributed to differences in the light absorption capacities at the filling stage of grain formation by different maize varieties in different environmental conditions [26]. Purple maize inclusion in the diet would ensure an energetic population which would contribute to the development of Malawi.

Phenotypic variations for grain color have been used by farmers to distinguish and maintain diversity within landraces that are underutilized but preferred for specific traditional uses [3, 43, 44]. *Ambuye angafe* and *Mthikinya* are orange pigmented maize varieties cultivated by smallholder farmers in Ntcheu district. Local farmers continue to cultivate *Ambuye angafe* mainly because it matures earlier than *Mthikinya* and it saves communities of people from hunger; hence, it is named “*Ambuye angafe*,” meaning it matures faster so that elders should not die.

Physicochemical analysis of these two phenotypically different maize varieties revealed that *Ambuye angafe* had higher protein (12.26%) and fat (8.35%) content than *Mthikinya* which had 10.99% protein and 5.58% fat, respectively. In terms of carbohydrates, *Mthikinya* had a significantly higher content (68.76%) than *Ambuye angafe* (63.76%) (Figure 1). This study has therefore revealed that Ntcheu provenance influenced the increased protein and fat content in “*Ambuye angafe*” orange maize than *Mthikinya* orange maize. Ntcheu farmers would be advised to produce *Ambuye angafe* if they were to benefit from its high protein and fat content. Diversification of these maize varieties would help to attain the benefits of both varieties. The noted variations in physicochemical attributes in pigmented-landrace maize cultivars may be due to differences in the variety’s genetic makeup and not the environment. This is because they were grown in the same location and the environmental effects; they received were the same. Nevertheless, the interaction between the environmental factors and the crop’s genetic makeup may have contributed to the observed differences [4, 26, 41].

The study revealed significantly high availability of calcium ( $71.00 \pm 0.58 \text{ mg}\cdot\text{kg}^{-1}$ ), magnesium ( $819.00 \pm 0.58 \text{ mg}\cdot\text{kg}^{-1}$ ), and phosphorus ( $2720.35 \pm 0.03 \text{ mg}\cdot\text{kg}^{-1}$ ) in Dedza orange maize than the rest of PLMVs in their different provenances.

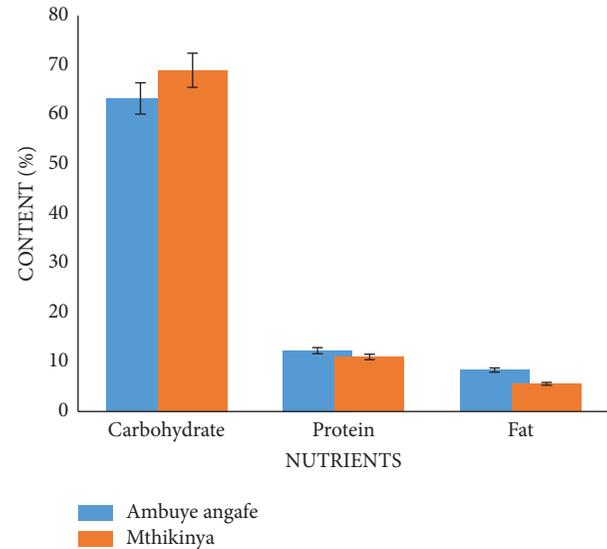


FIGURE 1: Nutrient content of orange PLMVs from Ntcheu by their local names.

Cereal grains, such as wheat (*Triticum aestivum*), finger millet (*Eleusine coracana*), and teff (*Eragrostis tef*), are relatively high in calcium but not as high as dairy sources [26, 45]. The best sources of calcium are dairy products, including milk, yogurt, cheese, and calcium-fortified beverages such as almond and soy milk. Calcium is also found in dark-green leafy vegetables, dried peas and beans, fish with bones, and calcium-fortified juices and cereals. Most whole grains are a good source of magnesium [2]. Phosphorus is an essential nutrient required for bone health and many other bodily functions. Although it can be found in many food grains, maize whole grains provide a substantial amount of phosphorus compared to high levels supplied by animal proteins, dairy products, nuts and seeds, and legumes [38, 39]. Murayama et al. [35] reported concentration ranges of calcium, magnesium, and phosphorus which were higher in orange maize than in hybrid maize. The high levels of minerals revealed in the present study in PLMVs can be an option for those vying for natural sources and would augment the diversity of readily available sources of these minerals to smallholder farmers and rural communities as a whole.

Red maize from Dedza provenance showed a significantly high content of iron ( $59.80 \pm 0.26 \text{ mg}\cdot\text{kg}^{-1}$ ) while purple maize from Dedza and Ntcheu revealed a significantly high content of zinc ( $54.61 \pm 0.43 \text{ mg}\cdot\text{kg}^{-1}$ ) and potassium ( $808.58 \pm 0.27 \text{ mg}\cdot\text{kg}^{-1}$ ), respectively (Table 2). Iron is a major component of hemoglobin, a type of protein in red blood cells that carries oxygen from our lungs to all parts of the body. Without enough iron, there cannot be enough red blood cells to transport oxygen in the body. Iron is an essential micronutrient for plant growth and development. It plays a key role as it is involved in the synthesis of chlorophyll and other enzymatic and metabolic processes [41]. Gopalan et al. [46] reported high iron content in pigmented maize than in white hybrid maize cereal grains which is in line with what was found in the current study. Malawi would, therefore, benefit from these maize varieties as it is

TABLE 2: Mineral content (mg·kg<sup>-1</sup> dry weight basis) of whole grain PLMVs.

Maize type	District	Calcium (Ca)	Iron (Fe)	Magnesium (Mg)	Zinc (Zn)	Phosphorus (P)	Potassium (K)
Orange	Ntcheu	51.31 ± 0.24 <sup>b</sup>	50.09 ± 0.23 <sup>b</sup>	502.59 ± 0.25 <sup>b</sup>	42.79 ± 0.29 <sup>a</sup>	2240.36 ± 0.08 <sup>b</sup>	539.98 ± 0.16 <sup>b</sup>
	Dedza	71.00 ± 0.58 <sup>a</sup>	48.88 ± 0.49 <sup>b</sup>	819.00 ± 0.58 <sup>a</sup>	42.67 ± 0.26 <sup>a</sup>	2720.35 ± 0.03 <sup>a</sup>	521.55 ± 0.13 <sup>b</sup>
	Mzimba	52.56 ± 0.28 <sup>b</sup>	58.81 ± 0.10 <sup>a</sup>	510.91 ± 0.26 <sup>b</sup>	42.65 ± 0.24 <sup>a</sup>	1920.28 ± 0.11 <sup>c</sup>	657.05 ± 0.26 <sup>a</sup>
Red	Ntcheu	52.14 ± 0.23 <sup>a</sup>	58.37 ± 0.55 <sup>a</sup>	656.15 ± 0.26 <sup>b</sup>	43.29 ± 0.15 <sup>a</sup>	2420.35 ± 0.09 <sup>a</sup>	776.45 ± 0.15 <sup>a</sup>
	Dedza	52.50 ± 0.17 <sup>a</sup>	59.80 ± 0.26 <sup>a</sup>	709.05 ± 0.19 <sup>b</sup>	38.85 ± 0.17 <sup>b</sup>	2020.34 ± 0.07 <sup>b</sup>	753.17 ± 0.13 <sup>a</sup>
	Mzimba	41.50 ± 0.58 <sup>b</sup>	45.93 ± 0.63 <sup>b</sup>	807.37 ± 0.12 <sup>a</sup>	38.93 ± 0.19 <sup>b</sup>	1870.27 ± 0.06 <sup>c</sup>	475.12 ± 0.04 <sup>c</sup>
Purple	Ntcheu	45.07 ± 0.33 <sup>a</sup>	56.42 ± 0.20 <sup>a</sup>	441.74 ± 0.26 <sup>a</sup>	49.21 ± 0.37 <sup>a</sup>	1445.28 ± 0.19 <sup>a</sup>	808.58 ± 0.27 <sup>a</sup>
	Dedza	51.19 ± 0.14 <sup>a</sup>	46.64 ± 0.09 <sup>b</sup>	476.43 ± 0.30 <sup>a</sup>	54.61 ± 0.43 <sup>a</sup>	1120.32 ± 0.18 <sup>b</sup>	724.37 ± 0.25 <sup>b</sup>
	Mzimba	35.17 ± 0.43 <sup>b</sup>	36.54 ± 0.06 <sup>c</sup>	365.44 ± 0.13 <sup>b</sup>	40.32 ± 0.16 <sup>b</sup>	1020.15 ± 0.13 <sup>c</sup>	605.23 ± 0.19 <sup>c</sup>

Values with different subscript letters are significantly different ( $p < 0.05$ ). Values are means of three replicates.

reported that iron deficiency is prevalent in 22% of preschool children, 5% of school-aged children, 15% of nonpregnant women of reproductive age, and in 1% of men [47].

Whole grains are zinc-rich foods for vegetarians. Zinc is one of the important components of various enzymes responsible for running different metabolic processes in crops [41]. Growth and development would not continue if specific enzymes were not present in plants. Carbohydrate, protein and chlorophyll formation is significantly reduced in zinc-deficient plants [48]. Zinc is an important mineral in the context of malnutrition, and this mineral also has significant variability in maize. Zinc is necessary for the activity of over 300 enzymes that aid in metabolism, digestion, nerve function, and many other processes [41, 48]. In addition, it is critical for the development and function of immune cells. This mineral is also fundamental to skin health, DNA synthesis, and protein production [41]. The average zinc content of maize kernels is 20 mg·kg<sup>-1</sup>, and 30% of these are located in the endosperm. The lowest value of zinc content revealed in this study was higher and lower in some cases than the reported average maize kernel content [19, 41]. Dedza purple maize would therefore be utilized in the diet of all requiring high supplements of zinc (Table 2).

Potassium is one of the major nutrients in maize which has significance because an average human diet lacks it [34]. Potassium is found naturally in many foods and as a supplement. Its main role in the body is to help maintain normal levels of fluid inside our cells. Sodium, its counterpart, maintains normal fluid levels outside of cells. Potassium is associated with the movement of water, nutrients, and carbohydrates in plant tissue. It is involved with enzyme activation within the plant, which affects protein, starch, and adenosine triphosphate (ATP) production. The production of ATP can regulate the rate of photosynthesis in plants [19]. Potassium also helps muscles to contract and supports normal blood pressure. The present study's mineral content in PLMVs was higher in some cases than what was reported by Murayama et al. [35] and Rouf-Shah et al. [42] (Table 2). This might be due to variety and environmental interactions which influences different attributes of PLMVs [6]. The revealed significantly high content of iron, zinc, and potassium in red maize from Dedza, purple maize from Dedza, and Ntcheu, respectively, would contribute to solving some of the deficiencies of national concern.

Plant growth and development highly depend on the combination but also concentration of mineral nutrients present in the soil where the plants are grown [6]. Plants often face significant challenges in obtaining adequate nutrients to meet the demands of different cellular processes due to their immobility [48]. Soils from Ntcheu and Mzimba grown with orange maize had a significantly higher content of magnesium (925.32 ± 0.24 mg·kg<sup>-1</sup>) and phosphorus (3225.40 ± 0.12 mg·kg<sup>-1</sup>), respectively. This resulted in more than 50% bioavailability of these minerals in orange maize grains; thus, (502.59 ± 0.25 mg·kg<sup>-1</sup>~54.32%) for magnesium and (1920.28 ± 0.11 mg·kg<sup>-1</sup>~59.54%) for phosphorus. The mineral bioavailability trend was not uniform in all production areas (Tables 2 and 3). Some provenances had high mineral availability which resulted in high bioavailability while in other provenances though high mineral availability was observed, PLMVs revealed low content. For instance, soils from Dedza and Mzimba grown with red maize had a significantly higher content of iron (67.42 ± 0.23 mg·kg<sup>-1</sup>) and zinc (78.56 ± 0.15 mg·kg<sup>-1</sup>) but only the maize grains from Dedza had high percentage bioavailability of iron (59.80 ± 0.26 mg·kg<sup>-1</sup>~88.70%) than zinc (38.93 ± 0.19 mg·kg<sup>-1</sup>~50%). Purple maize soils from Ntcheu and Dedza had significantly high content of calcium (87.43 ± 0.31 mg·kg<sup>-1</sup>) and potassium (988.98 ± 0.24 mg·kg<sup>-1</sup>), respectively, but comparing the bioavailability of these two minerals, it was revealed that only (45.07 ± 0.33 mg·kg<sup>-1</sup>~51.55%) of calcium was available in purple maize grains from Ntcheu while (724.37 ± 0.25 mg·kg<sup>-1</sup>~73.24%) potassium was available in purple maize grains from Dedza (Tables 2 and 3). Mineral availability in the soil affects its presence both in the food crops and in individual human beings who utilize a particular food crop [25].

Mineral intake differs in individuals due to differences in dietary preferences and levels of mineral content in the soils on which plants grow [49]. The solubility of the minerals determines their presence in the soil and their potential availability to crops grown on such soils [50]. Environmental factors like pH and parent rock from where soils originate have an influence on mineral availability in the soil [25]. Mineral availability in the crops is therefore influenced by the interactions that exist between the different crop varieties and the environmental factors found in different locations of crop production [26].

TABLE 3: Mineral content (mg·kg<sup>-1</sup>) of soil samples grown with PLMVs.

Soil type	District	Calcium (Ca)	Iron (Fe)	Magnesium (Mg)	Zinc (Zn)	Phosphorus (P)	Potassium (K)
Orange	Ntcheu	70.65 ± 0.21 <sup>b</sup>	63.46 ± 0.24 <sup>a</sup>	925.32 ± 0.24 <sup>a</sup>	64.50 ± 0.13 <sup>b</sup>	3220.21 ± 0.05 <sup>a</sup>	630.87 ± 0.18 <sup>b</sup>
Maize soil	Dedza	80.63 ± 0.06 <sup>a</sup>	64.47 ± 0.43 <sup>a</sup>	920.23 ± 0.59 <sup>a</sup>	65.60 ± 0.21 <sup>b</sup>	2980.22 ± 0.06 <sup>b</sup>	625.44 ± 0.15 <sup>b</sup>
	Mzimba	75.2 ± 440.02 <sup>b</sup>	65.12 ± 0.01 <sup>a</sup>	650.73 ± 0.25 <sup>b</sup>	68.70 ± 0.22 <sup>a</sup>	3225.40 ± 0.12 <sup>a</sup>	743.27 ± 0.23 <sup>a</sup>
Red	Ntcheu	74.92 ± 0.22 <sup>a</sup>	67.36 ± 0.24 <sup>a</sup>	704.33 ± 0.24 <sup>c</sup>	60.43 ± 0.13 <sup>b</sup>	3070.30 ± 0.08 <sup>a</sup>	985.35 ± 0.18 <sup>a</sup>
Maize soil	Dedza	76.97 ± 0.15 <sup>a</sup>	67.42 ± 0.23 <sup>a</sup>	786.44 ± 0.07 <sup>b</sup>	78.32 ± 0.16 <sup>a</sup>	3160.40 ± 0.09 <sup>a</sup>	986.23 ± 0.05 <sup>a</sup>
	Mzimba	75.89 ± 0.43 <sup>a</sup>	62.02 ± 0.31 <sup>b</sup>	978.03 ± 0.03 <sup>a</sup>	78.56 ± 0.15 <sup>a</sup>	2870.00 ± 0.24 <sup>b</sup>	840.70 ± 0.03 <sup>b</sup>
Purple	Ntcheu	87.43 ± 0.31 <sup>a</sup>	64.13 ± 0.23 <sup>a</sup>	675.17 ± 0.22 <sup>b</sup>	72.22 ± 0.31 <sup>a</sup>	2600.60 ± 0.18 <sup>a</sup>	979.70 ± 0.17 <sup>a</sup>
Maize soil	Dedza	86.57 ± 0.14 <sup>a</sup>	65.20 ± 0.06 <sup>a</sup>	780.62 ± 0.31 <sup>a</sup>	70.71 ± 0.21 <sup>a</sup>	2675.40 ± 0.21 <sup>a</sup>	988.98 ± 0.24 <sup>a</sup>
	Mzimba	70.30 ± 0.09 <sup>a</sup>	55.18 ± 0.13 <sup>a</sup>	586.46 ± 0.20 <sup>b</sup>	58.71 ± 0.18 <sup>a</sup>	1098.35 ± 0.17 <sup>a</sup>	786.72 ± 0.15 <sup>a</sup>

Values with different subscript letters are significantly different ( $p < 0.05$ ). Values are means of three replicates.

Many other factors affect the availability of soil nutrients including leaching, soil erosion, soil de-nitrification, volatilization, nitrogen immobilization, and crop nutrient uptake [27]. Soil pH affects nutrient availability for plant growth in that in highly acidic soils, minerals such as manganese can become more available to plants while calcium, magnesium, and phosphorus are less available; hence, environmental factors have a bearing on mineral presence in the soil [6, 48]. In highly alkaline soils, most micronutrients and other macronutrients such as phosphorus become less available. Varietal differences have a great impact on mineral absorption from soils but the temperature is a key factor affecting the rate of nutrient uptake [41]. Low temperature reduces nutrient uptake by decreasing plant growth rate [48]. PLMVs in this study were grown in different locations with different temperature ranges which may have affected cation exchange capacity (CEC) in the soils. As CEC increases, more nutrients are attached to soil particles, while fewer remain in the soil solution. Few nutrients in soil solutions result in few being available to crops. Parent rock has a direct influence on the mineral contents of the soil which has a bearing on the bioavailability of the minerals in the crops [6]. It can therefore be concluded that nutrient availability in both soil and plants is influenced by many interrelated factors hence the differences encountered in the present study. It is very important to know which crop does better in which production area so that its quality attributes such as mineral bioavailability are highly utilized in the diet.

#### 4. Conclusion

This study has revealed that there are significant differences in the physicochemical attributes of pigmented landrace maize varieties in their areas of production. The study has also demonstrated that pigmented landrace maize varieties are a good source of minerals such as Mg, K, P, Fe, Zn, and Ca. These substances are very important in the promotion of healthy living of the people. For instance, minerals such as zinc and iron present in pigmented landrace maize play a great role in solving the problem of micronutrient deficiencies of national concern in many communities in Malawi. Utilization of PLMVs having significantly high content of the revealed minerals in their areas of production would help solve different deficiency diseases.

The significant differences in the proximate composition of PLMVs are attributed to the genetic makeup and the interaction that exist with the environmental factors in their respective areas of production. Enhancing the production and consumption of grains that best suit a particular area of production has a big potential in improving the health status of smallholder farmers and those who directly and indirectly access and utilize the products of these grains. Looking at physicochemical attributes and the value of PLMVs, it can be concluded that biodiversity conservation ensures access to nutritious food crops. Therefore, Farmers are encouraged to produce and utilize PLMVs that have a high content of the different attributes in their localities to benefit from these attributes.

#### Data Availability

All data are included in the manuscript.

#### Conflicts of Interest

The authors declare that there are no conflicts of interest as the research was not conducted for commercial or financial purposes.

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