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Superiority of Malawian orange local maize variety in nutrients, cookability and storability

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The objectives of this study were to evaluate the potential of an orange Malawian local maize variety MW5021 by comparing with a hybrid variety DKC-9089 for nutritional quality and processing properties such as proximate and mineral composition as well as pasting and thermal properties of the flour, and resistance against *Prostephanus truncatus* infestation during storage of the grain. Maize plants sampled for the experiments were cultivated under three different fertilizer applications, namely 0, 92 and 184 kg-N/ha, considering the chemical fertilizer input among Malawian smallholder farmers. Even without fertilizer input, significantly higher contents of crude protein, Mg, P, Ca, Fe and Zn were observed in MW5021, as compared with DKC-9089. Among pasting properties, setback of the flour slurry from MW5021 was significantly lower than DKC-9089 for all fertilizer treatments. Two-way ANOVA indicated that MW5021 had significantly lower number of grains damaged by *P. truncatus* than DKC-9089, throughout 12 weeks of storage experiment at 28±2°C. Thus, this study revealed that the Malawian orange local variety MW5021 retained by the smallholder farmers has considerably higher nutritional quality and *P. truncatus* resistance as well as lower retrogradation hardening after cooking the flour, than the hybrid maize DKC-9089.

Key words: Maize, Mineral composition, pasting properties, postharvest losses, *Prostephanus truncatus*, Malawi.

INTRODUCTION

Maize (*Zea mays* L.) is the most important staple food among cereals, providing food and income to millions of resource-poor smallholder farmers in the eastern and southern Africa (Tefera, 2012). In Malawi, maize-based diets are the major source of energy accounting for more than 70% of daily calorie intake as well as nutrients (Ecker and Qaim, 2011). Thus, the Malawi government has been implementing the agricultural subsidy programs to improve maize productivity since 2005, and, as a result, the maize yield has increased by 2.9 times in 2014 (Dorward and Chirwa, 2011; FAOSTAT, 2016). Although, the smallholder farmers produce 95% of total maize production in Malawi, their maize yield is still significantly lower than the estate farmer (Mutegi et al., 2015). In addition, a large number of the smallholder farmers cannot afford to use chemical fertilizer without the subsidy (Darko and Ricker-Gilbert, 2013).

The Malawian smallholder farmers generally classify maize into local and hybrid varieties. “Local variety” is defined as the farmers' varieties that are not the direct products of the research system (Heisey and Small, 1995), while the term “hybrid variety” refers to any improved seeds including hybrid and open-pollinated varieties (Ricker-Gilbert and Jones, 2015). The local varieties are preferred by the smallholder farmers, owing to a number of favorable characteristics such as storability, poundability, flour-to-grain ratio and taste (Lunduka et al., 2012). Furthermore, Hwang et al. (2016) reported that Malawian orange local variety (MW5021) has the potential to be a remarkable natural source of carotenoids including provitamin A.

In Malawi, maize is milled into several types of dry flour for cooking staple food of *Nsima*, namely stiff maize flour porridge (Smale, 1995). Chinsinga (2011) and Lunduka et al. (2012) reported that the local varieties are preferred by the smallholder farmers in Malawi because of their taste, as compared with the hybrid maize. Texture of the maize flour porridge is known as one of important traits determining consumer preference (Bolade, 2009), and Osungbaro (2009) stated that pasting properties of maize flour can be used to predict gelling characteristics of the porridge.

After harvest, the smallholder farmers mainly store their maize in plastic sacks until its consumption (Kamanula et al., 2010). *Prostephanus truncatus* is known as the most destructive storage pest causing post-harvest losses on stored maize in the eastern and southern Africa including Malawi (Farrell et al., 1996; Denning et al., 2009). Without chemical insecticides, post-harvest losses of stored maize caused by storage pests at the household-level are reported to be in the range of 40 to 100% in Malawi (Denning et al., 2009). The farmers in Malawi believe that local varieties have higher resistance to storage pests than that of hybrid varieties (Smale, 1995; Chinsinga, 2011; Lunduka et al., 2012). Differences in poundability and flour-to-grain ratio between the local and hybrid varieties implies existence of varietal differences in grain hardness (Blandino et al., 2010; Lunduka et al., 2012), which has long been suspected to play a role in resistance against the storage pests among others (Meikle et al., 1998).

Limited information of the local varieties is, however, available on the nutritional quality, and the processing properties of its flour as well as storability of the grains against storage pest. Therefore, we chose popular orange local variety of MW5021, and commercial hybrid maize of DKC-9089 to identify the possible varietal differences in:

(1) Proximate and mineral composition as well as pasting and thermal properties of maize flours and
(2) Resistance against *P. truncatus* during storage of the grains.

Maize samples subjected to the experiments were cultivated under three different fertilizer applications, namely 0, 92 and 184 kg-N/ha, in consideration with the chemical fertilizer input among Malawian smallholder farmers.

MATERIALS AND METHODS

Maize varieties

Two maize varieties were used in the present study, namely an orange local variety (MW5021, locally known as *Mthikinya*) obtained from Malawi Plant Genetic Resources Center in Chitedze Agricultural Research Station (CARS) and a hybrid maize (DKC-9089, DeKalb Genetics Corp., USA).

Field experiment

To obtain maize samples, six plots were prepared as a bi-factorial experiment where the A factor was three fertilization rates, and the factor B was two maize varieties without randomization. A trial was conducted at the experimental field of CARS from December 2012 to May 2013. Each plot size was 10 m × 10 m consisted of 14 rows with 0.75 m inter-row spacing. Forty seeds were planted in each row with 0.25 m in-row spacing. Two types of chemical fertilizers, which include a compound fertilizer (N: P: K= 23: 21: 0% and 4% of S) and urea (46% of N), were applied in a ratio of 2:3 to give 0, 92 and 184 kg-N/ha, and coded as treatments A, B and C, respectively. Of these, the treatment B is the standard fertilization application recommended by the Ministry of Agriculture and Food Security in Malawi (Mutegi et al., 2015). Three plots, where the hybrid variety of DKC-9089 was planted, were coded as plots AH, BH and CH, while the rest three plots cultivated with the local variety of MW5021 were coded as plots AL, BL and CL, respectively. Maize cobs were shelled after harvesting and drying, grains were weighed for calculation of yield and stored in plastic bags. Grain yields of AH, BH, CH, AL, BL and CL were 7.7, 10.7, 11.3, 4.2, 6.4 and 6.5 Mg/ha, respectively.

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Analytical methods of chemical properties

Maize grains were kept in a deep freezer at -30°C for disinfection of storage pests until use, and thawed at 4°C for 1 week to determine the chemical composition. Thawed maize grains were placed at room temperature for 1 h, and milled by a blender (New Power Mill PM-2005, OSAKA Chemical Co. Ltd., Japan) to obtain maize flour with less than 350 μm of particle size. The maize flour samples were stored at 4°C until use. Moisture, crude protein, crude fat and ash contents were determined using the standard methods by the Association of Official Analytical Chemists (AOAC) with triplicate determinations (AOAC International, 2005). Mineral contents of magnesium (Mg), phosphorus (P), potassium (K), calcium (Ca), iron (Fe) and zinc (Zn) were determined by an inductively coupled plasma mass spectrometry (ICP; ICPS-8100, Shimadzu Co. Ltd., Japan) with triplicate determinations based on the method reported by George et al. (2004) with slight modification. Maize flour in a porcelain crucible was preliminary ashed using a Bunsen burner until smoking had ceased, and then it was dry-ashed using a muffle furnace (FM-35, Yamato Scientific Co., Ltd., Japan) at 550°C for 8 h. The resultant ash was dissolved in 100 mL of 2N-HCl, and then diluted 10-fold using deionized water. The solution obtained was subjected to mineral analysis by ICP.

Analytical methods of physical properties

Pasting and thermal properties of maize flours from three treatments were determined for the two varieties. Pasting properties were measured based on the method reported by Uarrota et al. (2013). Twenty-eight grams of maize flour slurry (8% dry wt.) were subjected to analysis using a Rapid Visco Analyzer (RVA-4, Newport Scientific, Inc., USA) with a paddle rotating at 960 rpm for the first 10 s, and then at a fixed speed of 160 rpm. The slurry was heated from 50 to 95°C at a rate of 12°C /min, held at 95°C for 2.5 min, cooled to 50°C at a rate of 12°C/min, and then kept at 50°C for 2 min. Breakdown is defined as the difference between peak and trough viscosities, and setback is the difference between trough and final viscosities.

Thermal properties were determined using a differential scanning calorimeter (DSC) (DSC7000X, Hitachi High-Tech Science Corp., Japan). A sample of 18 mg dry wt. was weighed in a DSC pan, and deionized water was added to give a suspension of 30% dry wt. The scanning temperature range was set at 30 to 95°C. and the heating rate was 1.5°C/min. Forty-two milligrams of water was used as a reference. Thermal transitions of maize flour samples were defined as T_o, T_p and T_c for initial, peak and conclusion temperatures.

Maize grains kept in a deep freezer at -30°C were used to determine hardness of maize grains after thawing at 4°C for 1 week. Thawed maize grains were dried in a hot air oven (WFO-700, TOKYO RIKAKIKI Co. Ltd., Japan) at 40°C until they achieve 13.0±1.0% of moisture content, and resultant dried maize grains were stored at 20°C for 1 week to obtain an equilibrium moisture content. After adjustment of moisture content of maize grains, grain hardness was determined using the method reported by Blandino et al. (2010). Puncture test was carried out on upper lateral surface of 25 maize grains each from 6 experimental plots using a texture analyzer (TA-XT2, Stable Micro Systems, UK) equipped with a flat probe (diameter 2 mm, P/2) and 25 kg load cell. The tests were performed at 1 mm/s of puncture speed, and grain was punctured to a depth of 2 mm. Grain hardness was expressed as break force calculated in Newton (N).

Evaluation methods of *Prostephanus truncatus* resistance

P. truncatus resistance was evaluated according to the methods reported by Abebe et al. (2009) and Tefera et al. (2011) with slight modification. Each evaluation was conducted with triplicate determinations using 6 different samples of maize grains after adjustment of moisture content with 13.0±1.0%. 100 g of maize grains were placed in a glass jar covered with stainless screen lid (60 mesh). *P. truncatus* used in this study was obtained from CARS, and successively generated in the laboratory. Thirty adult *P. truncatus* (1-14 days old) were released to each jar containing maize grains, and these jars were kept in an incubator (MIR-254, Panasonic Healthcare Co., Ltd., Japan) at 28±2°C. Number of adult *P. truncatus* and damaged grains were measured on 1st, 2nd, 3rd, 4th, 8th and 12th weeks after release. All *P. truncatus* were removed from maize grains using sieves with 1.0 and 4.0 mm openings, and then live *P. truncatus* were counted for determining number of adult present. For measuring number of damaged grains, 100 maize grains were randomly taken from each jar, and then damaged grains namely grains holed by *P. truncatus* were counted with triplicate. Grains and live *P. truncatus* were returned to each jar for further measurement.

Statistical analysis

Statistical analyses were conducted using statistical package for social sciences (SPSS) for Windows (ver. 17.0). Two-way analysis of variance (ANOVA) was performed to evaluate the main effects of maize variety, and fertilization treatment as well as the interaction at 5% significance level. When significant interaction was detected between the variety and the fertilization treatment, *t*-test and Tukey's multiple-range test were used for comparison of means to assess the variety difference with the same fertilization and the amount of fertilizer application among each variety, respectively, at 5% significance level. Pearson's correlation analysis was conducted to evaluate the effects of grain hardness on resistance against *P. truncatus.*

RESULTS

Nutritional quality of maize flours

Nutritional quality, namely proximate and mineral compositions of MW5021 and DKC-9089 applied with the different amounts of fertilizer are shown in Table 1. Ash, crude protein and crude fat contents of the two varieties ranged between 1.11 to 1.34, 9.23 to 11.80 and 5.17 to 5.58% dry wt., respectively. Most dominant mineral for both varieties was P followed by K, Mg, Ca, Fe and Zn with 212.20-287.83, 116.36-139.79, 86.31-108.07, 4.87-5.73, 2.93-5.43 and 1.09-1.85 mg/100g on dry wt., respectively. Table 2 represents the corresponding results of two-way ANOVA. Significant effects of the variety were observed in all components, and significant main effects of the fertilization treatment were detected in all components, except for K and Zn ($p < 0.05$). Significant interactions were also found in all components, excluding ash and Ca. Thus, nutritional quality components, except for ash and Ca, were compared by *t*-test for assessing the effect of variety with the same fertilization, while Tukey's test for the fertilizer application was used to compare among each variety.

Among proximate composition, MW5021 showed significantly higher contents of ash regardless the

Table 1. Nutritional quality of Malawian orange local maize variety of MW5021 and hybrid maize of DKC-9089 grown in Malawi.

Variable	MW5021			DKC-9089		
	Fertilizer treatments					
	A	B	C	A	B	C
Proximate composition (%, dry wt.)						
Ash	1.27±0.01b*	1.28±0.04ab*	1.34±0.02a*	1.12±0.02b	1.11±0.01b	1.18±0.02a
Crude protein	10.20±0.05c*	11.16±0.04b*	11.80±0.09 a*	9.23±0.07c	9.77±0.03b	10.81±0.02a
Crude fat	5.32±0.03b	5.49±0.07a*	5.34±0.06b	5.24±0.06b	5.17±0.01b	5.58±0.01a*
Mineral composition (mg/100g, dry wt.)						
Mg	102.08±0.69b*	108.07±0.96a*	95.33±1.6c	86.31±1.55 c	92.94±0.29b	97.39±1.45a
P	276.41±2.08b*	287.83±4.35a*	261.60±3.45c	212.20±4.66 c	227.67±0.42b	244.50±5.62a
K	132.46±2.58a	132.95±2.51a	116.36±3.62b	127.92±1.94 b	129.94±1.06b	139.79±1.09a*
Ca	5.73±0.09a*	5.09±0.35a	5.32±0.06a	5.08±0.22 a	4.87±0.11a	5.31±0.38a
Fe	5.43±0.06a*	3.33±0.01b	2.93±0.15c	4.34±0.02 a	3.29±0.07c	3.76±0.08b*
Zn	1.83±0.16a*	1.85±0.12a*	1.62±0.03a*	1.09±0.05 b	1.18±0.02a	1.29±0.01a

Mean values in the same column with different letters are significantly different among each variety ($p < 0.05$); Mean values in the same column with * are significantly higher than that of the corresponding maize variety with the same fertilizer treatments ($p < 0.05$); n=3; Fertilizer treatments; A, 0 kg N/ha; B, 92 kg N/ha; C, 184 kg N/ha.

Table 2. Two-way ANOVA for the effect of maize variety and fertilizer treatment on nutritional quality of MW5021 and DKC-9089 grown in Malawi.

Variable	Variety	Fertilizer treatment	Variety × Fertilizer
	***p* value**		
Proximate composition			
Ash	<0.001	<0.001	0.745
Crude protein	<0.001	<0.001	<0.001
Crude fat	0.029	<0.001	<0.001
Mineral composition			
Mg	<0.001	<0.001	<0.001
P	<0.001	<0.001	<0.001
K	0.001	0.114	<0.001
Ca	0.030	0.023	0.128
Fe	0.012	<0.001	<0.001
Zn	<0.001	0.541	0.014

Values of p in bold are significant ($p < 0.05$).

fertilizer level than that of DKC-9089, based on the two-way ANOVA ($p < 0.001$). For the same fertilizer treatment, MW5021 had significantly higher contents of crude protein than that of DKC-9089 counterparts ($p < 0.05$). Main effect of the fertilizer level was observed in ash content by the two-way ANOVA, that is, the highest input of fertilizer led to significant increase in ash contents as compared with the treatments of A and B ($p < 0.05$). It was observed that increase in amounts of fertilizer led to significant increase in crude protein contents of both MW5021 and DKC-9089 ($p < 0.05$), while significant increase in crude fat contents were observed only in DKC-9089 with the treatment C as compared to the treatments A and B ($p < 0.05$).

For mineral composition, Ca contents were significantly higher in MW5021 than those of DKC-9089 ($p < 0.05$), based on the two-way ANOVA. When compared between the two varieties for the same fertilizer treatments of A and B, Mg and P contents were consistently and significantly higher in MW5021 than that of DKC-9089 ($p < 0.05$). Similarly, Zn contents were also higher in MW5021 when compared with DKC-9089 for all fertilizer

Table 3. Physical properties of maize grains and flours of Malawian orange local maize variety of MW5021 and hybrid maize of DKC-9089 grown in Malawi.

Variable	MW5021			DKC-9089		
	Fertilizer treatments					
	A	B	C	A	B	C
Pasting properties						
Peak viscosity (cP)	375.0±4.0a	304.3±7.8b	313.7±3.1b	544.7±4.0a*	444.0±1.7b*	428.0±4.4c*
Breakdown (cP)	7.0±1.0b	13.3±1.5a	10.0±1.7ab	83.0±4.4a*	61.3±0.6c*	75.0±3.0b*
Setback (cP)	909.3±15.9a	783.3±23.2b	802.7±6.7b	1017.3±20.0a*	913.0±7.8b*	889.7±18.0c*
Final viscosity (cP)	1277.3±19.2a	1074.3±31.6b	1106.3±10.3b	1479.0±16.5a*	1295.7±6.8b*	1242.7±20.0b*
Pasting temperature (°C)	90.2±0.1b*	90.3±0.1 b*	92.0±0.1a*	87.2±0.1b	88.5±0.4a	88.0±0.1 a
Thermal properties						
T_o (°C)	69.90±0.32a	69.98±0.18a	69.92±0.07a	69.73±0.08a	69.79±0.43a	69.99±0.23 a
T_p (°C)	75.87±0.11a*	75.69±0.06a*	75.93±0.14a*	75.36±0.15a	75.34±0.15a	75.49±0.13 a
T_c (°C)	82.06±0.54a*	82.28±0.17a*	82.54±0.3a*	80.45±0.11a	80.43±0.61a	80.45±0.16 a
ΔH (J/g, dry wt.)	6.78±0.22a	6.29±0.07b	6.80±0.18a	7.73±0.21a*	7.06±0.05b*	6.88±0.15 b
Grain property						
Hardness (N)	246.73±53.3a*	232.56±41.9a*	239.19±54.1a*	152.58±25ab	145.74±23.8b	172.33±50.0 a

Mean values in the same column with different letters are significantly different among each variety ($p < 0.05$); Mean values in the same column with * are significantly higher than that of the corresponding maize variety with the same fertilizer treatments ($p < 0.05$); Hardness, n=25; pasting and thermal properties, n=3; Fertilizer treatments: A, 0 kg N/ha; B, 92 kg N/ha; C, 184 kg N/ha.

treatments ($p < 0.05$). The two-way ANOVA showed significant differences in Ca contents with fertilizer levels, where higher Ca content with the treatment A than that with C was observed. There were no consistent patterns for other minerals for the differences among varieties or fertilizer treatments. However, at no fertilizer treatment of A, MW5021 had consistently higher Mg, P, Ca, Fe and Zn contents as compared to DKC-9089.

Pasting and thermal properties of maize flours

Table 3 indicates physical properties of maize grains and flours of MW5021 and DKC-9089 with the different fertilizer applications. Results of the two-way ANOVA in Table 4 showed significant effects of the variety and/or the fertilization treatments in setback, T_p and T_c without significant interactions ($p < 0.001$).

Among pasting properties, significant effect of the variety in setback by the two-way ANOVA indicated that the values of MW5021 were consistently lower than those of DKC-9089, regardless the fertilization levels ($p < 0.001$). In comparison between the two varieties, peak viscosity, breakdown, and final viscosity of DKC-9089 were significantly higher than those of MW5021 at the same fertilizer treatments ($p < 0.05$). Contrary, MW5021 showed significantly higher pasting temperatures than that of DKC-9089 in all fertilizer applications ($p < 0.05$). The two-way ANOVA showed significant effect of the fertilization on setback with the highest value with the treatment A as compared with B and C ($p < 0.05$). Significant decrease in peak viscosities was observed in both MW5021 and DKC-9089 with increase in the amount of fertilizer applied ($p < 0.05$). Similarly, in final viscosity, significant decrease with increase in the fertilizer application was found in both varieties ($p < 0.05$).

For thermal properties, T_p and T_c were significantly higher in MW5021 of all fertilizer treatments as compared with those of DKC-9089, with significant effects of the variety from two-way ANOVA as shown in Table 4 ($p < 0.001$). Significant differences resulting from the fertilizer treatments were not observed in T_o, T_p or T_c among MW5021 and DKC-9089 ($p < 0.05$), while DKC-9089 showed significantly higher ΔH than MW5021 in the fertilizer treatments of A and B.

Hardness and storability of maize grains

Grain hardness of two varieties for the different fertilizer treatments were also shown in Table 3. Significant effect of the variety was observed by two-way ANOVA as shown in Table 4 without significant effect of the fertilization or the interaction ($p < 0.001$). This means that grain hardness of MW5021 was significantly higher than that of DKC-9089 counterparts in each fertilizer treatment.

Three-way ANOVA carried out with the sources of the variety, fertilization treatment and storage period for numbers of adult *P. truncatus* and damaged grains

Table 4. Two-way ANOVA for the effect of maize variety and fertilizer treatment on physical properties of MW5021 and DKC-9089 grown in Malawi.

Variable	Variety	Fertilizer treatment	Variety × Fertilizer
	***p* value**		
Pasting properties			
Peak viscosity	<0.001	<0.001	<0.001
Breakdown	<0.001	<0.001	<0.001
Setback	<0.001	<0.001	0.122
Final viscosity	<0.001	<0.001	0.006
Pasting temperature	<0.001	<0.001	<0.001
Thermal properties			
T_o	0.436	0.639	0.625
T_p	<0.001	0.065	0.585
T_c	<0.001	0.549	0.543
ΔH	<0.001	<0.001	0.001
Grain property			
Hardness	<0.001	0.155	0.267

Values of *p* in bold are significant ($p < 0.05$).

Table 5. Two-way ANOVA for the effect of maize variety and fertilizer treatment on *P. truncatus* resistance of MW5021 and DKC-9089 grown in Malawi.

Variable	Storage period (week)	Variety	Fertilizer treatment	Variety × Fertilizer
		***p* value**		
P. truncatus resistance				
Number of adult *P. truncatus*	1st	0.092	0.574	0.302
	2nd	0.001	0.805	0.124
	3rd	0.024	0.978	0.448
	4th	0.079	0.672	0.239
	8th	0.070	0.500	0.425
	12th	0.092	0.545	0.590
Number of damaged grains	1st	0.005	0.720	0.495
	2nd	0.001	0.461	0.676
	3rd	0.001	0.242	0.667
	4th	<0.001	0.161	0.327
	8th	0.007	0.167	0.524
	12th	0.003	0.466	0.680

Values of *p* in bold are significant ($p < 0.05$).

showed a significant interaction for the variety with storage period ($p < 0.001$). Thus, two-way ANOVA for numbers of adult *P. truncatus* and damaged grains were performed at each storage period with the variety and the fertilization treatment as sources (Table 5).

Numbers of adult *P. truncatus* counted on 1st, 2nd, 3rd, 4th, 8th and 12th week of storage are illustrated in Figure 1. Numbers of adult *P. truncatus* slightly decreased in the first 4 weeks of storage in all samples, and then increased steadily from 4 to 12th weeks. The highest number of adult *P. truncatus* was observed in DKC-9089 with the fertilization treatment of B as 292.7 on 12th week of storage, while in MW5021 with the treatment of A showed the lowest number of adults as 121.0. After 8 weeks of storage, DKC-9089 fertilized with the treatments A and B showed clearly higher numbers of adult *P. truncatus* among all samples. Results of two-way ANOVA are shown in Table 5, and significant effects of

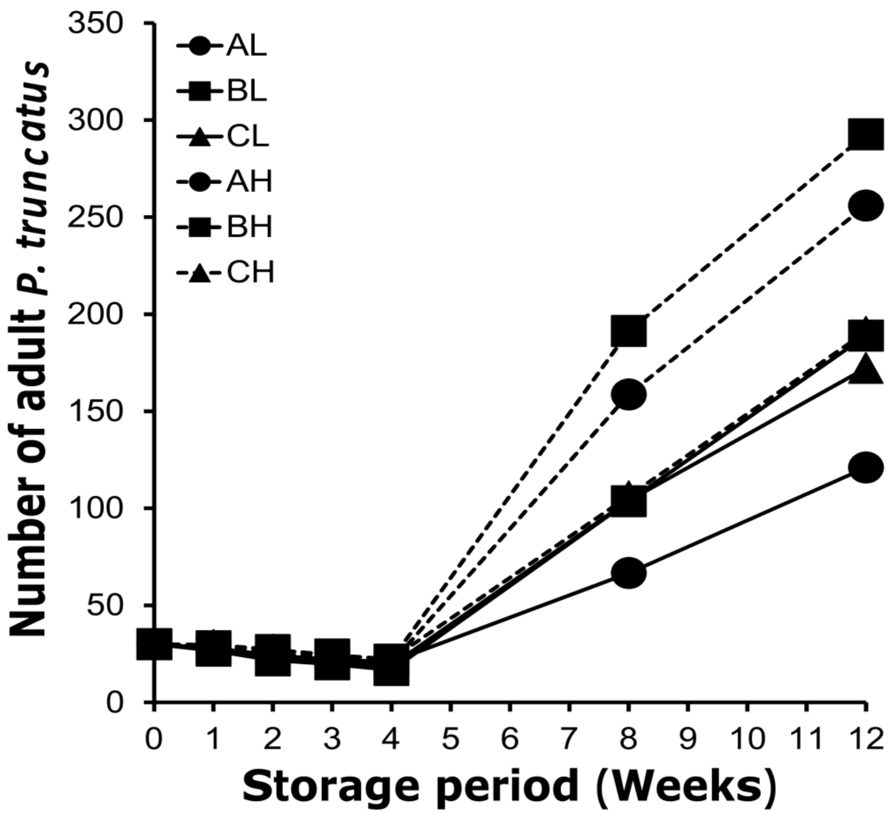

Figure 1. Number of adult *P. truncatus* present during 12 weeks of incubation of maize grains of Malawian orange local variety of MW5021 (AL, BL, CL) and hybrid maize of DKC-9089 (AH, BH, CH). At time zero, 30 adults were released into jars containing 100 g maize grains. A, B and C refers to fertilizer treatments.

the variety were observed in numbers of adult *P. truncatus* on 2^{nd} and 3^{rd} weeks with lower numbers in MW5021 ($p < 0.05$). On the other hand, significant effects of either the fertilization or the interactions were not observed at any storage periods.

Number of damaged grains of MW5021 and DKC-9089 during 12 weeks of infestation by *P. truncatus* is shown in Figure 2. On 12^{th} week of storage, the highest number of damaged grains was observed in DKC-9089 with the fertilization treatment of B as 84.3 grains/100 grains, and in MW5021 with the treatment of A showed the lowest number.

During 12 weeks of storage experiment, MW5021 consistently showed lower numbers of damaged grains as compared with DKC-9089. From two-way ANOVA, significant effects of the variety were found throughout 12 weeks of storage periods ($p < 0.001$ to $p = 0.007$) with lower values for MW5021, while the significant effects of either the fertilization or the interactions were not found at any measuring date ($p > 0.05$).

Correlation analysis

Table 6 summarizes correlations between hardness and *P. truncatus* resistance of maize grain measured throughout 12 weeks of storage experiment. There were significantly negative correlations between the number of adult *P. truncatus* and grain hardness on 3rd, 8th and 12th weeks ($p < 0.05$). The number of damaged grains was negatively, and significantly correlated with grain hardness throughout the storage periods ($p < 0.05$).

DISCUSSION AND CONLUSION

Widespread deficiencies of Fe and, particularly, Zn have been known in Malawi (Dickinson et al., 2014). Furthermore, high risk of mineral deficiencies such as Ca and Zn was reported by Joy et al. (2015). In the present study, without fertilizer input, Ca and Fe contents of MW5021 were significantly higher than those of DKC-9089 (Table 1). In addition, in all fertilizer treatments, Zn contents of MW5021 were significantly higher than those of DKC-9089 (Table 1), and this was also statistically confirmed by two-way ANOVA analysis (Table 3). Bioavailability of Zn contained in maize is thought to be restricted, due to the presence of phytic acid which inhibits Zn absorption by binding Zn to form an unabsorbable complex called phytate in the gut (Krebs,

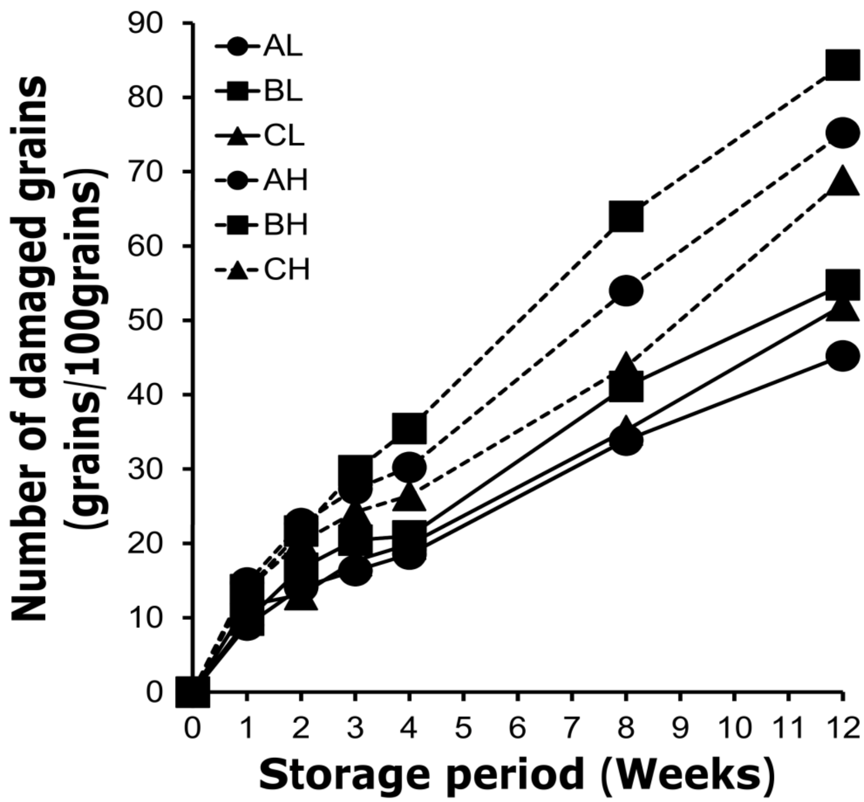

Figure 2. Number of damaged grains present during 12 weeks of incubation of maize grains of Malawian orange local variety of MW5021 (AL, BL, CL) and hybrid maize of DKC-9089 (AH, BH, CH). At time zero, 30 adults were released into jars containing 100 g maize grains. A, B and C refers to fertilizer treatments.

Table 6. Correlations between grain hardness and *P. truncatus* resistances on throughout 12 weeks of incubation.

Variable	Storage period (week)	Grain hardness
Number of adult *P. truncatus*	1st	-0.566
	2nd	-0.800
	3rd	-0.829*
	4th	-0.587
	8th	-0.860*
	12th	-0.881*
Number of damaged grains	1st	-0.913*
	2nd	-0.964**
	3rd	-0.975**
	4th	-0.962**
	8th	-0.909*
	12th	-0.979**

Correlation coefficients with * and ** are significant at $p < 0.05$ and 0.01, respectively.

2000). However, Miller et al. (2013) reported that dietary Ca and protein modestly enhanced Zn absorption by possible inhibition by forming complex form phytate with Zn. Thus, not only quantity but also bioavailability of Zn contained in MW5021 might be superior to the DKC-9089, owing to significantly higher Ca and crude protein contents of MW5021 (Table 1). It was, therefore, found, that an intake of maize-based diets prepared from

MW5021 may be desirable in effectivity supplying insufficient minerals such as Ca, Fe and Zn as compared with the DKC-9089, especially for the smallholder farmers who cannot always afford fertilizer for maize cultivation (Darko and Ricker-Gilbert, 2013).

In this study, whole maize flours were used to evaluate pasting and thermal properties, since whole maize grain flour called Mgaiwa is commonly used to cook Nsima in Malawi. Significant differences in pasting properties suggested that varietal differences exist between the flour prepared from MW5021 and DKC-9089 on texture of Nsima. Maize flour prepared from DKC-9089 showed significantly higher peak viscosity, breakdown, setback and final viscosity than those of the MW5021 (Table 2), and this is may be due to relatively and significantly lower crude protein and ash contents, which indicate higher starch content (Table 1). Indeed, it is reported that starch content is prime factor determining viscosity of maize flour (Zilic et al., 2011). Further, Almeida-Dominguez et al. (1997) reported that maize flour prepared from softer grain shows higher viscosity than that of harder one, due to loosely packed starch with reduced protein-to-starch bounds in softer maize grain, and such loosely packed starch hydrates and swells more rapidly in the presence of heat and water.

During cooking of *Nsima*, continuous heating and stirring is applied to achieve uniform gelatinization of starch without formation of clumps. Thus, significantly lower breakdowns of the flours prepared from MW5021 indicate a relatively high ability to withstand heating and shear stress than those of DKC-9089, that is, higher stability of the gel during the cooking (Table 2; Newport Scientific, 1998). From the results of setback, it is clear that there are changes incurred in texture of *Nsima* after cooking, between MW5021 and DKC-9089. Setback indicates short-time retrogradation hardening of starch dominantly determined by amylose aggregation and re-association (Karim et al., 2000). In this study, setbacks of maize flours prepared from MW5021 were significantly lower than those of the MW5021for all fertilization treatments (Table 2). Sandhu and Singh (2007) reported that the gel firming is mainly caused by retrogradation of maize starch gels during cooling. Thus, *Nsima* cooked from the flour prepared from MW5021 may be more tolerant against starch retrogradation, that is, hardening tendency of the *Nsima* made from the MW5021 flour may be being slower than that prepared from the DKC-9089 flour. Physical properties such as viscosity and retrogradation tendency may influence the differences in consumer preferences between maize flours prepared from the MW5021 and DKC-9089.

In Malawi, post-harvest losses of stored maize grain caused by storage pests have been reported to be 40 to 100%, and *P. truncatus* is known to be the major cause of such losses (Denning et al., 2009). Thus, higher storage ability, arising from lower post-harvest losses caused by *P. truncatus*, must be considered for choosing maize varieties for cultivation not only in Malawi but also in African countries invaded by this pest. In the present study, two-way ANOVA analysis suggests that MW5021 has the higher potential of reducing post-harvest losses (Table 3) by lowering numbers of adult *P. truncatus* and damaged grains, as compared with DKC-9089 (Figure 1 and 2). Under the experimental conditions, superior storability of the orange local variety of MW5021 was observed in this study, and it enables us to further discuss the post-harvest losses of maize grains during storage. MW5021 cultivated under three different fertilizer applications showed 24.5 to 40.0 % lower number of damaged grains as compared with the corresponding DKC-9089 after 12 weeks of storage period incubation, while yields were 40.2 to 45.5 % lower in the local variety. On the other hand, the estimated amounts of wholesome maize grains after 12 weeks of storage, based on the yields and percentages of damaged grains, were 1.9, 1.7, 3.5, 2.3, 2.9 and 3.1 Mg/ha for AH, BH, CH, AL, BL and CL, respectively. Therefore, under *P. truncatus* infestation, MW5021 may have higher amount of maize grains remaining after prolonged storage as comparinged to DKC-9089, particularly for the smallholder farmers who cannot afford to use chemical fertilizer.

Puncture test was conducted on maize grain, and break force was defined as grain hardness in this study. It is assumed that hardness of maize grain is mainly influenced by the chemical composition of endosperm (Dombrink-Kurtzman and Knutson, 1997; Chandrashekar and Mazhar, 1999), indicating that grain hardness is compression resistance of endosperm but not hull. Santiago et al. (2013) reported that grain defenses against storage pests occur in both pre-ingestion and post-ingestion phase. In the pre-ingestion phase, host plants can limit food supplies to insects by physical barriers such as the cell wall. Therefore, grain hardness may be regarded as strength of physical barrier, and harder grain could limit food supply to *P. truncatus* in the pre-ingestion phase. This limit of food supply may result in suppressing propagation of *P. truncatus*. The observed significantly negative correlations between grain hardness and, the number of adults and damaged grains (Table 4) support this assumption. In addition, Li (1988) stated that, since *P. truncatus* lay eggs in blind-ending tunnel in maize grain, higher energy cost for tunneling through harder maize grain, leads to reduction of its fecundity and population size. Several local varieties native to Africa have been reported to have higher resistance against *Sitophilus zeamais* than hybrid varieties (Gudrupsa et al., 2001; Siwale et al., 2009), while the present study provides evidence for the superiority of the Malawian local orange variety of MW5021 over the commercial hybrid maize of DKC-9089 for losses caused by *P. truncatus* infestation during post-harvest storage.

In the present study, one genotype was chosen from each of local and hybrid varieties to obtain fundamental information on the varietal differences. MW5021 showed superiority in:

(1) Significantly higher contents of crude protein, Mg, P, Ca, Fe and Zn even without fertilizer application
(2) Cookability with significantly lower setback value for all fertilizer treatments and
(3) Storability with significantly lower number of damaged grains throughout 12 weeks of storage experiment, as compared with DKC-9089.

It appears therefore that the orange local variety of MW5021 is beneficial for low-input sustainable agriculture among the smallholder farmers with higher nutritional value, better porridge retrogradation tendency and lower post-harvest losses.
Thus, further search of local varieties with desired characteristics should be carried out to achieve food security and provide genetic sources on breeding for variety development in the eastern and southern Africa region.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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