AGRICULTURAL SCIENCE AND TECHNOLOGY, VOL. 12, No 2, pp 171-177, 2020
Published by Faculty of Agriculture, Trakia University, Bulgaria
ISSN 1313-8820 (print)
ISSN 1314-412X (online)
http://www.agriscitech.eu
DOI: 10.15547/ast.2020.02.029

Product Quality and Safety

Influence of variety endosperm type and seed moisture content on threshability and mechanical damage of sorghum seeds

W.M. Muiru[1], P.L. Fabiola[1], D. Mbuge[2], L. M'Ragwa[3], S.L. Kimaru[1]*

[1]Department of Plant Science and Crop Protection, University of Nairobi, P.O Box 30197, Nairobi, Kenya
[2]Department of Environmental and Biosystems Engineering, University of Nairobi, P.O Box 30197, Nairobi, Kenya
[3]Kenya Agricultural and Livestock Research Organization (KALRO), Kenya

(Manuscript received 13 April 2020; accepted for publication 3 June 2020)

Abstract. *Sorghum is an important cereal crop and it is native in African tropical areas. It is a globally cultivated crop and the fifth most important cereal after maize, rice, wheat and barley. The objective of this study was to determine the effects of endosperm type, seed moisture content and threshing methods on percentage threshability and mechanical damage of sorghum seeds. Two varieties of sorghum (Kari-mtama 1 and Seredo) were grown in two diverse locations, Kiboko and Katumani. Variety Kari-mtama1 has hard (vitreous) endosperm while the other variety Seredo has soft (non-vitreous) endosperm. After harvesting, sorghum panicles were dried in the sun and oven. The panicles were threshed separately for each drying method at two moisture levels, namely 18-20% and 13-14%. The three threshing methods used included beating with wooden stick in tied sack, using wooden mortar and pestle as well as using threshing machine. The results showed that the vitreous endosperm variety had significantly high percentage threshability and significantly low mechanical damage than non-vitreous endosperm variety under both drying methods. There was a significant ($p \leq 0.05$) increase in threshability and decrease in mechanical damage when the seeds were threshed at 13-14% moisture content compared to 18-20%. For better seed quality, threshing machine is the best method to be used to avoid mechanical damage and seed quality deterioration. Drying methods used to dry seed panicles before threshing had no effects on threshability and mechanical damage. This implies that sorghum panicles can be dried either in the sun or oven without affecting threshability and mechanical damage at the two moisture levels and by using the three threshing methods.*

Keywords: sorghum panicles, vitreous and non-vitreous endosperm, seed moisture content, drying methods, seed quality

Introduction

Threshing process involves application of mechanical force using hand or by machine to separate the seed grains from panicles. Threshability is one of the important considerations in sorghum production due to its impact on total grain yield, grain quality and hence market value. The ease with which seed are detached from the panicles and glume is important especially to smallholder farmers where threshing is practised manually (Adeyanju et al., 2015). It has been reported that some sorghum varieties are free threshing where seeds are detached easily from the panicles and glumes. Also, other varieties have sticky glumes where seed get off from the panicles easily but the glumes remain attached to the seed (Adeyanju et al., 2015). Free threshing varieties produce clean and quality seeds. This saves time and energy during processing. However, the vitreosity or hardness of seed grains and environmental conditions during crop growth play an important role in seed threshing and seed quality (Loerger et al., 2007; Adeyanju et al., 2015). Damaged seeds have minimum storage life and poor germination because they have damaged embryo and are less resistant against pests and diseases. Furthermore, damaged seeds weaken germination capacity (Spokas et al., 2008). The mechanical damage of the seed can occur when the seed is threshed at unsuitable seed moisture content or using improper threshing method (Kavaki et al., 2012). Seed damage also depends on the vitreosity of the variety. It has been reported that vitreous or hard kernels have better breakage resistance than non-vitreous kernels (Felker and Paulis, 1993). According to Saedirad et al. (2013) and Adeyanju et al. (2015), there is inadequate knowledge about threshing of sorghum and few studies have been conducted on threshability with no focus on the quality aspect of threshed seed grain.

The purpose of the study was to determine the effects of endosperm type, seed moisture content and threshing methods

*e-mail: samuelklinguya@gmail.com.

on percentage threshability and mechanical damage of sorghum seeds. This will form basis of providing the appropriate advice to the growers to avoid losses caused by improper handling.

Material and methods

Study area

The seed crop - two sorghum varieties (Kari-mtama 1 and Seredo) was planted at two locations Kiboko and Katumani which are under Agricultural Mechanization Research Institute (AMRI). Kiboko research sub centre is located in Kiboko, Makindu Division, Makindu Sub-county, Makueni County. It lies within longitudes 37.7235°E and latitudes 2.2172°S. Kiboko is 975 m above sea level and the station receives between 545 and 629 mm of rainfall coming in two seasons. The long rains season is between April and July while the short rains season is between October and January. This is a hot dry location with a mean annual temperature of 22.6°C, mean annual maximum of 28.6°C and mean annual minimum of 16.5°C. Soils are well drained, very deep, dark reddish brown to dark red, friable sandy clay to clay (Acri-Rhodic Ferrassols) developed from undifferentiated basement system rocks, predominantly banded gneisses. Katumani is AMRI headquarter and located in Machakos County, at latitude 1º35'S and longitude 37º14'E, and at an altitude of about 1600 m above sea level. It receives mean annual rainfall of around 655 mm. The average seasonal rainfall for the long rains is 272 mm while that for the short rains is 382 mm. The mean maximum and minimum temperatures at the centre are 24.7ºC and 13.7ºC, respectively. The soils in the area show a strong coherence to the different rock types and landforms and mainly cambisols, ferralsols, luvisols and vertisols are found (CYMMIT, 2013).

Experimental design

Two sorghum varieties were the study object: Kari-mtama1 with vitreous (hard) endosperm as variety 1 and Seredo variety with non-vitreous (soft) endosperm as variety 2. The varieties were established under split-split plot on Randomized Completely Block Design (RCBD) with three factors and these are variety (V) as main factor, moisture level (M) as sub-factor and threshing method (T) as sub-sub-factor with three replications. The seeds obtained by the tested sorghum varieties were threshed at two moisture levels which are between 18-20% moisture content (M1) and 13-14% moisture content (M2) using three threshing methods:

- threshing by beating with wooden stick (T1);
- threshing by wooden mortar and pestle (T2) and
- threshing by using machine (T3).

There were 12 treatments in each location which are variety 1, moisture level 1, threshing method 1 (V1M1T1), variety 1, moisture level 1, threshing method 2 (V1M1T2), variety 1, moisture level 1, threshing method 3 (V1M1T3), variety 1, moisture level 2, threshing method 1 (V1M2T1), variety 1, moisture level 2, threshing method 2 (V1M2T2), variety 1, moisture level 2, threshing method 3 (V1M2T3), variety 2, moisture level 1, threshing method 1 (V2M1T1), variety 2, moisture level 1, threshing method 2 (V2M1T2), variety 2, moisture level 1, threshing method 3 (V2M1T3), variety 2, moisture level 2, threshing method 1 (V2M2T1), variety 2, moisture level 2, threshing method 2 (V2M2T2) and variety 2, moisture level 2, threshing method 3 (V2M2T3).

Set up of the experiment

The size of each experimental plot was 5.0 m x 3.0 m, giving rise to 15 m^2 area plots separated by one meter path. There were 12 plots in each replication/block. Therefore, the total number of plots in all three replications was 36. The path between one block/ replication to another was 1.5 m. In each plot, sorghum seeds were drill sown at a spacing of 60 cm x 25 cm and there were 6 rows which were thinned to 20 plants per row. Thinning was done three weeks after germination. The total number of plants in each plot was 120. The inner four rows were used as net plot for taking data.

Seed harvesting, panicle drying and threshing

The seed crop was harvested by hand and the panicles were cut using a knife after seed grain had reached the physiological maturity. The panicles from plots that were threshed at higher moisture level (18-20%) were harvested when the seed was about 25% while the panicles from the plots that were threshed at lower moisture level (13-14%) were left in the field. These were harvested when moisture content was at about 20%. From each plot, only 60 plants were harvested from the inner rows (net plots). The harvesting was done in two batches, each containing 30 randomly selected plants. After harvesting, sorghum heads/panicles were dried to the required moisture content. Two drying methods - sun and oven were used for drying of the plant materials. Therefore, from 60 plants harvested in each plot, 30 heads/panicles were dried in the sun before threshing and the other 30 were dried in the oven at 36ºC before threshing. Extra five heads/panicles were included in each drying method. These were used to regularly monitor the moisture content until the seeds attained the required moisture for threshing. The moisture content of seeds was determined using agraTronix MT-16 grain moisture tester before threshing. Machine threshing was done by one specific bulk machine thresher in both locations which contained rotating rasp bar cylinder. The machine used was from Allan Machine Company (ALMACO 99, M AVE NEVADA 10WA 50201 USA) (Annex 1). The mortar hole depth was 22 cm and the weight of the pestle and wooden stick was 1.5 kg (Annex 2). After threshing, the seeds were separated from dirt and chaffs by manual winnowing, and then the seeds from each sample were divided into two groups; completely threshed seeds and the seeds that remained in glumes. Percentage threshability was calculated as weight of completely threshed seed (seeds without glumes) out of total seed weight threshed from 30 panicles in each sample as described by Nalam et al. (2007) and Adeyanju et al. (2015), i.e.:

$Th (\%) = \{(CThS / (CTh + SG)\}100$,

Where: Th is percentage threshability, %;

CThS is completely threshed seed (seeds without glumes);

CTh is completely threshed;

SG is seeds in glumes.

Mechanical damage test

After threshing, the seed samples were taken to the University of Nairobi laboratory for mechanical damage test. The mechanical damage was carried out using 200 seeds for each sample. The seeds were preconditioned in moistening paper towel for 18 hours at room temperature. After preconditioning, the seeds were cut longitudinally with a sharp surgical blade through the centre of the embryo. The seeds were completely bisected and one half of each seed was used to represent one seed in the evaluation. After cutting, the seeds were immersed in 1% aqueous solution of 2,3,5 triphenyltetrazolium chloride for about 3 hours for staining at room temperature. The procedures were done according to ISTA (2015). Each seed was evaluated based on staining pattern, intensity, location of stain and unstained embryonic tissue and the seeds were divided into three groups namely; undamaged seeds, mechanically damaged seeds and dead seeds. The undamaged seeds were uniformly stained with dark pink at the embryonic axis. Damaged seeds had very darker stained embryonic tissue or the embryo had very weak stain which was not uniform with some darkish parts at the embryonic axis. The dead category included seeds which had not stained or parts of the embryonic axis were completely unstained. The number of seeds with mechanical damaged plus dead seeds category was considered as damaged seed in calculation of the percentage of mechanically damaged seeds. The results were presented in percentage of mechanically damaged seed as number of mechanically damaged seed out of total number of seed tested per each sample. Data collection included percentage of threshability and percentage of mechanical damage of the seeds. All data were subjected to analysis of variance using General Statistical package (GENSTAT) edition 13 for Windows. The means were separated using least significant different (LSD) test at 5% and 1% levels of significance.

Results

The results obtained for the effects of location on threshability and mechanical damage of sorghum seeds from panicles dried in the sun and oven are presented in Table 1. From the means separation, the results showed that, means for panicle threshability were significantly high in Katumani at 86.86% and 86.30% when panicles were dried in sun and oven, respectively. The means for panicle threshability were significantly low in Kiboko at 82.72% and 81.5% when panicles were dried in the sun and oven, respectively. The mean seed mechanical damage was not significantly different between locations where at Katumani, they were 15.84% and 16.31% when panicles were dried in the sun and oven, respectively and at Kiboko - 16.26% and 15.9% when panicles were dried in the sun and oven, respectively. The means for seed mechanical damage percentage were not significantly different in both locations when panicles were dried in the sun and oven. The coefficients of variations were low (0.9-2.7%) indicating that variability between and among treatments were low.

Table 1. Effects of location on threshability and mechanical damage of sorghum seeds from panicles dried in the sun and oven

Site	Mean threshability (%)		Mean mechanical damage (%)	
	Sun dried panicles	Oven dried panicles	Sun dried panicles	Oven dried panicles
Katumani	86.86[a]	86.3[a]	15.84[a]	16.31[a]
Kiboko	82.72[b]	81.59[b]	16.26[a]	15.9[a]
LSD ($p\leq0.05$)	1.717	4.332	0.665	1.054
CV	0.9	2.3	1.8	2.7

*Numbers followed by the same letters within columns do not differ significantly according to LSD test at $p\leq0.05$

Means for panicle threshability of vitreous variety Kari-mtama1 were significantly high at 89.41% and 89.65% when panicles were dried in the sun and oven, respectively (Table 2). The means for panicle threshability of non-vitreous variety Seredo were significantly lower at 80.21% and 78.24% when panicles were dried in the sun and oven, respectively. The mean seed mechanical damage was 12.74% and 13.88% for vitreous variety Kari-mtama1 when panicles were dried in the sun and oven, respectively. Mean seed mechanical damage of non-vitreous variety Seredo was significantly high at 19.37% and 18.33% when panicles were dried in the sun and oven, respectively. The results showed that the variety with vitreous endosperm (Kari-mtama1) had significantly high percentage threshability and significantly low mechanical damage as compared to non-vitreous variety (Seredo) which had low threshability and high mechanical damage for both drying methods. Coefficients of variations were low (3.8-7.7%) indicating that, variability between and among treatments was low.

Table 2. Effects of variety on threshability and mechanical damage of sorghum seeds from panicles dried in sun and oven

Variety	Mean threshability (%)		Mean mechanical damage (%)	
	Sun dried panicles	Oven dried panicles	Sun dried panicles	Oven dried panicles
Kari-mtama1	89.41[a]	89.65[a]	12.74[a]	13.88[a]
Seredo	80.21[b]	78.24[b]	19.37[b]	18.33[b]
LSD ($p\leq0.05$)	8.244	5.049	1.979	1.993
CV	6.1	3.8	7.7	7.7

*Numbers followed by the same letters within columns do not differ significantly according to LSD test at $p\leq0.05$

Similarly, sorghum panicles that were threshed at lower moisture level (13-14%) had significantly high percentage threshability and significantly low seed mechanical damage ($p \leq 0.05$) compared to panicles that were threshed at higher moisture level for both drying methods (Table 3). The mean threshability of panicles that were threshed at low moisture content was significantly high at 86.94 % and 85.93% when panicles were dried in the sun and oven, respectively. The mean threshability of panicles that were threshed at high moisture content was significantly low at 82.67% and 82.09% when panicles were dried in the sun and oven, respectively. The mean seed mechanical damage was 13.97% and 14.70% for panicles that were threshed at low moisture content and were dried in the sun and oven, respectively. Mean seed mechanical damage of panicles that were threshed at high moisture content was significantly high at 18.14% and 17.51% when panicles were dried in the sun and oven, respectively.

Table 3. Influence of seed moisture content (SMC) on panicle threshability and seed mechanical damage of sorghum seeds from panicles dried in the sun and oven

Seed moisture content (%)	Mean threshability (%)		Mean mechanical damage (%)	
	Sun dried panicles	Oven dried panicles	Sun dried panicles	Oven dried panicles
18-20	82.67[a]	82.09[a]	18.14[a]	17.51[a]
13-14	86.94[b]	85.93[b]	13.97[b]	14.7[b]
LSD (p≤0.05)	3.742	3.818	2.253	1.969
CV	4.7	3.8	14.9	13

*Numbers followed by the same letters within columns do not differ significantly according to LSD test at p≤0.05

Means for panicle threshability and seed mechanical damage percentages for the threshing methods for panicles dried in the sun and oven are presented in (Table 4). There was no significant difference in panicle threshability between panicles threshed by using mortar and pestle and beating with wooden stick at both methods of drying – sun and oven, 87.55-87.65% and 87.67-87.32%, respectively. The means for panicle threshability percentages of panicles threshed using machine were significantly lower (79.21 % and 76.87%, respectively) than the other two methods of threshing. However, the means for seed mechanical damage percentage for panicles dried in sun and oven and threshed using the three threshing methods were all significantly different. The means for seed mechanical damage of panicles dried in the sun and threshed by mortar and pestle was 26.06%, threshed by beating in bags with stick was 12.98% and threshed by machine was the lowest at 10.12%. The means for seed mechanical damage of panicles dried in the oven and threshed using mortar and pestle was 25.98%, threshed by beating in bags with stick was 13.99% and the lowest was threshing by machine at 8.35%. Finally, there was highly significant difference in panicle threshability and seed mechanical damage among threshing methods at $p \leq 0.001$ in both drying methods.

Table 4. Influence of threshing method on threshability and mechanical damage of sorghum seeds from panicles dried in the sun and oven

Threshing methods	Mean threshability (%)		Mean mechanical damage (%)	
	Sun dried panicles	Oven dried panicles	Sun dried panicles	Oven dried panicles
Mortar and pestle	87.55[a]	87.65[a]	26.06[a]	25.98[a]
Beating with stick	87.67[a]	87.32[a]	12.98[b]	13.99[b]
Threshing machine	79.21[b]	76.87[b]	10.12[c]	8.35[c]
LSD (p≤0.05)	4.124	2.893	2.244	2.027
CV	8.3	7.6	23.8	21.4

*Numbers followed by the same letters within columns do not differ significantly according to LSD test at p≤0.001

In oven dried panicles, the results showed significant interaction for threshability between variety and threshing method. The percentage of threshability of vitreous (hard) endosperm variety Kari-mtama1 when threshed by machine was not significantly different from the percentage of threshability of non-vitreous (soft) endosperm variety Seredo when threshed using wooden stick or mortar and pestle (Figure 1). There was significant increase in threshability when the seeds were threshed at 13-14% SMC especially using mortar and pestle or wooden stick. Threshability of the seeds threshed with machine had no significant difference between the two seed moisture levels for both drying methods. Higher percentage of threshability for both varieties was recorded in the panicles that were threshed at seed moisture content of 13-14% using mortar and pestle or wooden stick (Figures 1 and 2).

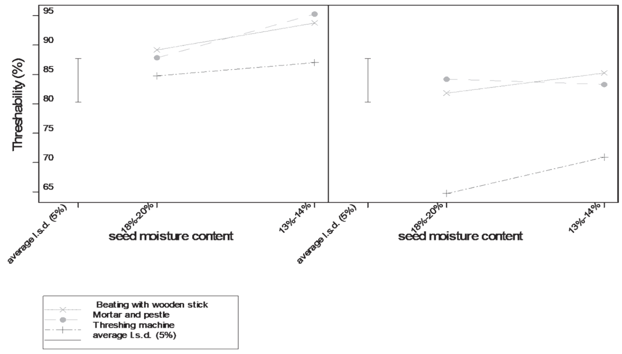

Figure 1. Mean percentage of threshability for sorghum panicles threshed at two moisture content levels using three threshing methods (oven dried panicles)

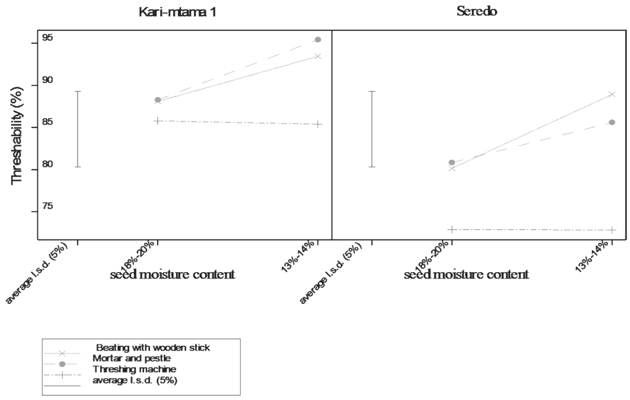

Figure 2. Mean percentage of threshability for sorghum panicles threshed at two moisture content levels using three threshing methods (sun dried panicles)

Similarly, for both varieties, there was significant decrease in mechanical damage when the seeds were threshed at 13-14% seed moisture content (SMC). However, the difference in mechanical damage between the SMC was not significant especially from the seeds that were threshed using machine and wooden stick. There was highly significant difference in mechanical damage between moisture levels when the seeds were threshed using mortar and pestle. The lowest mechanical damage was found from the seeds threshed by machine at SMC 13-14% while the highest damage was found in mortar and pestle at SMC 18-20% in both drying methods (Figures 3 and 4).

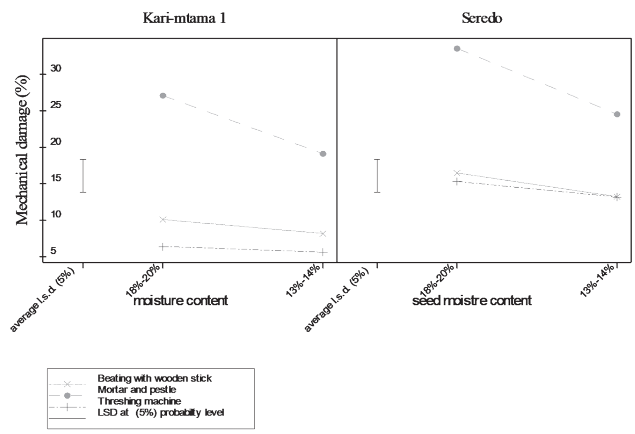

Figure 3. Mean percentage of mechanical damage for two sorghum varieties seeds threshed at two moisture content levels using three threshing methods (sun dried panicles)

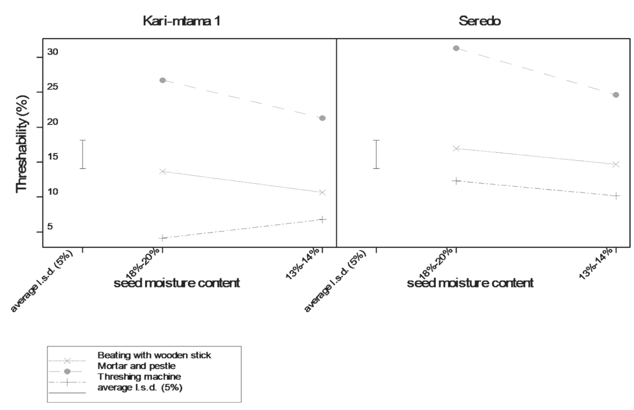

Figure 4. Mean percentage of mechanical damage for two sorghum varieties seeds threshed at two moisture content levels using three threshing methods (oven dried panicles)

There was no significant difference between the drying methods (sun and oven) in threshability and mechanical damage (Table 5). Mean threshability for panicles dried in the sun was 84.81% and similar to panicles dried in the oven which was 84.01%. Mean seed mechanical damage for panicles dried in the sun was 16.05% and for the seeds from panicles dried in the oven it was 16.11%.

Table 5. Influence of panicle drying method on threshability and mechanical damage of sorghum seeds

Drying method	Mean threshability (%)	Mean mechanical damage (%)
Sun	84.81[a]	16.05[a]
Oven	84.01[a]	16.11[a]
LSD ($p \le 0.05$)	2.514	0.541
CV	1.3	1.5

*Numbers followed by the same letters within columns do not differ significantly according to LSD test at $p \le 0.05$

Discussion

Influence of location on sorghum threshability

Threshability of sorghum panicles from Katumani was significantly higher than Kiboko ($p \le 0.05$) (Table 1). This could be attributed to the difference in growing conditions such as environmental temperature and relative humidity which influenced drought stress at Kiboko. Adeyanju et al. (2015) reported that certain environmental growing conditions such as late season and drought stress lead to premature termination of grain filling which may cause poor threshability. Robertson et al. (2004) also pointed out that the threshability of the seed could be affected by the environmental conditions of the day and time during harvesting. The poor threshability of sorghum grown at Kiboko could be due to drought stress which the crop experienced. The crop at Kiboko was grown late in the season and the area had water stress conditions compared to Katumani where the crop was grown on season and received enough rainfall. At Kiboko, when the crop was at critical stage of grain filling, there was water stress resulting in small grains and the temperatures were too high to the extent that the seeds dried within short period which could have resulted into premature termination of grain filling and hence poor threshability. It is therefore important to grow seed crop under optimum conditions in order to produce high quality seeds.

Influence of endosperm type on sorghum threshability and seed mechanical damage

Panicles of vitreous (hard endosperm) variety (Kari-mtama1) had significantly higher threshability than the panicles of non-vitreous variety (Seredo) (Table 2). During threshing, most of the seeds from the non-vitreous variety appeared tightly attached to the glumes. This could be due to the inherent genetic trait of the Seredo. It has been reported that genotypes with tight sticky glumes are difficult to thresh and when the seeds are threshed, they tend to remain in the glumes (Adeyanju et al., 2015). Also, another reason could be the non-vitreous nature of endosperm of Seredo variety which caused the seed grain not to be detached easily from the glumes especially when threshed at higher seed moisture content (18-20%). Ioerger et al. (2007) found that grain hardness plays a significant role on threshability and seed quality during seed processing. This could be the reason for easy threshability of vitreous endosperm variety (Kari-mtama1) especially at low moisture content level (13-14%). Also, there was significant difference in seed mechanical damage caused by threshing methods between the two varieties. Seredo variety which has non-vitreous endosperm type had significantly higher mechanical damage than vitreous endosperm variety Kari-matma1 ($p \leq 0.05$). The mechanical damage was due to the impact the grains received during threshing. The possible reason for the significant difference between the two varieties is that soft endosperm was easier to get damaged than vitreous variety. Felker and Paulis (1993) established that vitreous kernels are resistant to breakage during seed processing.

Influence of seed moisture content and threshing methods on sorghum threshability and seed mechanical damage

Threshing methods showed significant difference in panicle threshability. For both drying methods used to dry panicles, machine showed significantly lower threshability than the other two methods (Table 4). There was no significant difference between wooden stick and mortar and pestle. The significantly higher percentage of threshability in beating with wooden stick; and using mortar and pestle could be due to the high impacts of wooden stick, mortar and pestle and forces that were used to beat panicles. Machine had rotating rasp bar cylinder which had soft surface and may have induced little force to the panicles. The increase in threshability at low SMC (13-14%) could be due to the fact that at low moisture the seeds become harder and were easily detached from the panicles and glumes (Vara Prasad and Sterggenborg, 2010). Also, the seeds at high moisture content were soft and may have resulted in poor threshability and cracked grains (Sumner, 2012). Although threshability was significantly higher for the seed threshed using mortar and pestle and beating with wooden sticks, the percentage of mechanical damage was also higher compared to the machine threshing method. This could be due to the impact of wooden materials on the seeds during beating and pounding. Wooden mortar and pestle had higher mechanical damage followed by wooden stick while threshing by machine had the lowest percentage of mechanical damage. Similarly, Dharmaputra et al. (2012) found that the method of threshing of sorghum seeds had significant effects on damage of grain in terms of cracked and broken grains. According to the reported results, the percentage of damaged grain of sorghum threshed using a wooden stick was higher and significantly different from those that were threshed with a paddy thresher. This could be related to the results of mechanical damage in this experiment because the mechanical damage of the seeds may be due to the physical impacts which the seeds receive during threshing by wooden mortar and pestle, and beating with stick. The mechanical damage of seeds from panicles threshed with machine was significantly lower. This contributed to high seed quality although threshability was lower than the other two methods. For both varieties, there was significant decrease in mechanical damage when seeds were from panicles threshed at 13-14% SMC (Table 3). This could be due to the hardness of the seed grains at this moisture level. The seeds with high moisture content are soft which may have resulted into more cracked grains than seeds with low moisture content (Sumner, 2012). Another research has also shown that too low moisture content below 13% can be as damaging to seed quality as too much moisture. When seeds are over dried to below 13% seed moisture content, seeds become more brittle and can be cracked and break easily and much damage can occur when the seeds are too wet above 22% moisture content (Conley et al., 2003). Saeidirad and Javadi (2011) and Ajav and Adejumo (2005) evaluated the effect of thresher variables including seed moisture content in cumin and okra, respectively, and they found that moisture contents significantly affects seed mechanical damage and germination. In cumin seeds, the results showed that as moisture content increased from 7% to 13%, separated seed and damaged seed decreased from 92.8% to 90.4% and from 10.1% to 7.6%, respectively. In this study mechanical damage was significantly higher at 18-20% seed moisture content compared to low moisture content (13-14%). There was no significant interaction between location, variety and threshing methods (L x V x T) and location, variety and moisture content (L x V x M). This indicates that location had no effects on the mechanical damage. There were no differences observed in the mean threshability values and the mean mechanical damage values of the tested sorghum varieties at both drying methods used (Table 5). So, the sun and oven can be successfully used as methods for sorghum panicles drying before threshability.

Conclusion

In this study it was found that: the type of sorghum endosperm affects threshing efficiency, the sorghum variety with vitreous endosperm (Kari-mtama1) has better threshing efficiency with minimum seed mechanical damage than non-vitreous endosperm sorghum variety (Seredo); non-vitreous sorghum type (Seredo) has considerably higher mechanical damage and threshing methods such as use of mortar and pestle are not suitable for such varieties; the seed mechanical damage results in poor germination and seedling vigour; that way the method should only be used where sorghum is produced for consumption and not for seed purposes; the threshing machine is the best method for threshing sorghum panicles to obtain high quality seeds.

Acknowledgements

The Kenya Agricultural and Livestock Research Organization (KALRO) and the University of Nairobi are acknowledged. We also extend our gratitude to AGRA for funding this research.

Competing interests

The author declares no competing interests.

References

Adeyanju D, Perumal R and Tesso T, 2015. Genetic analysis of threshability in grain Sorghum (*Sorghum bicolor* (L) Moench). Plant breeding, 134,148-155.

Ajav EA and Adejumo BA, 2005. Performance evaluation of an okra thresher. Agricultural Engineering International, 7, 1-8.

Conley S, Bailey W, Casady W, Fishel F, Johnson B, Massey R, Scharf P, Smeda R, Sweets L and Wrather A, 2003. Integrated Pest Management - Management of soft red winter wheat. Plant protection programme, College of Agriculture, Food and Natural resources, Published by MU Extension, University of Missouri-Columbia, IPM 1022.

Dharmaputra O, Ambarwati S and Retnowati I, 2012. Postharvest quality improvement of sorghum (*Sorghum bicolour* (L.) Moench) grain. BIOTROPIA, 19, 115-129.

Felker FE and Paulis JW, 1993. Quantitative estimation of corn endosperm vitreosity by video image analysis. Cereal Chemistry, 70, 685-689.

International Maize and Wheat Improvement Center (CIMMYT), 2013. Kiboko Crops Research Station: A brief and visitors' guide: CIMMYT.

International Seed Testing Association (ISTA), 2015. International Rule for Seed Testing. Vol. 2015, International Seed Testing Association, Switzerland, New York, USA: Folnwiley and sons Inc.

Kavaki S, İlbi H, Eser B, Powell AA and Matthews S, 2012. Effects of seed moisture content and threshing methods on bean (*Phaseolus vulgaris* L.) seed quality. Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi, 7, 51-57.

Loerger B, Bean SR, Tuinstra MR, Pedersen JF, Erpelding J, Lee KM and Herrman TJ, 2007. Characterization of polymeric proteins from vitreous and floury sorghum endosperm. Publications from USDA-ARS / UNL Faculty Paper 212.

Nalam VJ, Vales MI, Watson CJW, Johnson EB and Riera-Lizarazu O, 2007. Map based analysis of genetic of loci on chromosome 2D that affects glumes tenacity and threshability, components of free-threshing habit in common wheat (*Triticum aestivum* L.). Theory Applied Genetics, 116, 135-145.

Robertson LD, Guy SO and Brown BD, 2004. Southern Idaho dryland winter wheat production guide. University of Idaho, College of Agriculture and life Sciences. http/www.Idahowheat.org.

Saeidirad MH and Javad A, 2011. Study on machine-crop parameters of cylinderthreshers for cumin threshing. Agricultural Engineering International: CIGR Journal, 13, 1746.

Saeidirad HM, Esaghzade M, Arabhosseini A and Zarifneshat S, 2013. Influence of machine-crop parameters on the threshability of sorghum. Agricultural Engineering International: CIGR Journal, 15, 55-59.

Spokas L, Steponavicius D and Petkevicius S, 2008. Impact of technological parameters of threshing apparatus on grain damage. Agronomy Research, 6, 367-376.

Sumner PE, 2012. Grain sorghum: harvesting, drying and storing. The University of Georgia, Cooperatives extension, College of Agriculture and Environmental Sciences.

Vara Prasad PV and Saggenborg S, 2010. Growth and production of Sorghum and Millet.
http//www.researchgate.net/publication/260392531.