



Tannin and Flavonoid Contents Influence Seed Pigmentation and Seed Quality Aspects during Seed Development of Bambara Nut [*Vigna subterranea* (L.) Verdc.] Landraces

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ABSTRACT

Background: Tannins and flavonoids are seed polyphenolics that largely accumulate in the testa and may influence seed physiological quality and seed coat color. The pattern of accumulation of these compounds and the relationship of their seed contents with seed quality of Bambara nut (BN) is poorly understood. A study was therefore conducted to determine the relationship between seed physiological quality and seed coat color development and tannin and flavonoid contents of BN landraces.

Methods: Dark seeded (LocalBam), intermediate (AbiBam001) and light seeded (TVSU544) BN landraces were harvested from field experiments and tested for final germination percentage, germination velocity index and seedling dry weight. Seeds were also analyzed for total tannin and flavonoid contents in relation to maturity stage.

Result: Tannin and flavonoid contents of AbiBam001 and LocalBam significantly decreased ($P < 0.05$) as the seeds developed and matured, then leveled off after maturation. At maturity, LocalBam and AbiBam001 had higher contents of the polyphenolics than TVSU544, alluding to their influence on seed coat color of BN. Seed quality characteristics of the landraces predominantly showed negative correlations with tannin and flavonoid contents before maturation, indicating that these compounds may negatively affect seed quality of BN at early stages. However, after maturation, the relationships were mostly positive, suggesting that tannins and flavonoids might enhance seed quality at later stages of development. These results provide further insights into the roles of tannins and flavonoids in BN seed quality and the potential for their manipulation for seed quality management.

Key words: Bambara nut, Flavonoid, Phytochemical, Seed coat color, Seed development, Tannin.

INTRODUCTION

Bambara nut (BN) [*Vigna subterranea* (L.) Verdc.] possesses a number of seed coat color patterns that constitute a diversity useful to farmers in a number of ways (Gao *et al.*, 2020; Uba *et al.*, 2022). Bambara nut seed coat color is a basis for consumer preference, for instance, in Southern Africa and parts of West Africa, the light colored are preferred to dark colored types (Massawe *et al.*, 2005; Ibrahim *et al.*, 2018). In Southern Ghana however, dark/brown types are preferred (Asante *et al.*, 2021). This mostly relates to the end use of the seeds, for example, light colored seeds are preferred for milling into flour (Mubaiwa *et al.*, 2018), while dark colored types are reportedly better for medicinal purposes (Klompang and Benjakul, 2015). Seed coat color is also an important trait for variety identification, selection in breeding and germplasm characterization (Tiryaki *et al.*, 2016; Nadeem *et al.*, 2020). Moreover, seed coat color has a relation to polyphenolic content, which may have an influence on: seed physiological quality (Ochuodho and Modi, 2013; Mandizvo and Odindo, 2019; Gowda *et al.*, 2025; Sujatha *et al.*, 2025); seed longevity (Sano *et al.*, 2016; Tetteh *et al.*, 2023; Gowda *et al.*, 2025) and tolerance to biotic and abiotic stresses (Mabhaudhi and Modi, 2013; Shomali *et al.*, 2022). The report by Sano *et al.* (2016) indicated that polyphenols, complex polysaccharides, suberin and cutin contribute to the physical and chemical

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resistance of the seed coat, which is important for seed survival. This however, may have negative effects on seed germinability (Smykal *et al.*, 2014; Tiryaki and Topu, 2014). Condensed tannins in the seed coat of *Lupinus albus* and *Trifolium pratense* are suggested to contribute to coat-imposed dormancy (Tiryaki and Topu, 2014), thus poor germination. However, de Almeida *et al.* (2014) found no relationship between the tannin contents and dormancy of

sorghum seeds. On the other hand, Chibarabada *et al.* (2014) showed that dark colored landraces of BN had better germination than light colored types. This was attributed to higher polyphenolic (tannins) content in dark seeded compared to light seeded landraces (Mabhaudhi and Modi, 2013). Likewise, Kantar *et al.* (1996) demonstrated that faba bean seeds with higher tannin content had higher vigour, better laboratory germination and better field emergence. Other studies have similarly indicated that dark colored BN seeds and other legumes had higher tannins and flavonoids than light colored seeds (Ren *et al.*, 2012; Harris *et al.*, 2018). With respect to physiological seed quality of BN, attainment of full seed coat color is often used by farmers and scientists as an indication of crop maturity and to estimate the time of harvest (Obura *et al.*, 2021). A related report by Oballim *et al.* (2022) indicated that BN farmers in Uganda harvest seeds at the end of a three-week harvest period, a few weeks after full color attainment. The seed coat color of a BN landrace therefore has implications for agronomic and seed physical and physiological characteristics of that landrace, hence, its significance to BN farmers as a reliable and easily identifiable trait for selection, maintenance and use. However, the relationship between the polyphenolic content, seed quality and seed coat color has not been described before for Ugandan BN landraces. This study therefore aimed at describing the relationship of physiological seed quality to seed coat color development and tannin and flavonoid contents of Ugandan BN landraces during seed development and maturation. This would elucidate the roles of these polyphenolics in determining BN seed quality which will in turn help improve aspects of seed quality management for better yields.

MATERIALS AND METHODS

The materials and methods of the field experiments and seed germination tests summarized in this report have been described in details in Oballim *et al.* (2023).

Field experiments

The experimental sites

Two field experiments were set up at on-farm sites in Ocettoke, Kitgum district (03°22'33.071" N/032°51'55.69"E, 1020 masl) in 2020 and Koro, Omoro district (02°39'22.92"N/032°18'44.27"E, 1085 masl) in 2021, both in the northern region of Uganda. Both sites lie in the warm sub-humid zone of the northern moist farmlands agro-ecological zone (AEZ) (Wortmann and Eledu, 1999). The AEZ is characterized by a unimodal rainfall (>1200 mm annual average) from March/April to October with an average annual temperature ranging above 20°C. A long dry spell normally occurs from November to March (Nsubuga *et al.*, 2014; Wortmann and Eledu, 1999). The soils are mostly sandy and sandy clay, with low organic matter and low nutrient availability (Wortmann and Eledu, 1999).

Plant material

Bambara nut seeds of three landraces namely, AbiBam001, LocalBam and TVSU544 were obtained from the market in Arua, north western region of Uganda and planted in randomized complete blocks with three replicates. AbiBam001 is small, round and cream with black stripes (intermediate color), LocalBam has large oblong mottled seeds with brown or purplish specs and of dark color. TVSU544 has medium sized cream seeds with black eyes and is of light color (Fig 2-4) (Oballim *et al.*, 2023).

Field operations and seed sampling

Standard crop management practices were applied at all stages of the crop growth. Pods were harvested from randomly selected rows in each plot in a block, constituting the three replicates for each genotype. This was done following predetermined days after sowing (DAS) of 93, 103, 113, 123 (Ocettoke); and 123, 130, 138 (Koro). Pods were sun dried and temporarily kept at room temperature then later transferred to a -20°C freezer until use. Pods were hand threshed and used for the seed quality and polyphenolic analyses.

Germination tests

The germination experiments and assessment of seed pigmentation were done in the seed laboratory at the Department of Seed, Crop and Horticultural Sciences at the University of Eldoret, Kenya, from 2021 to 2022. A germination test was performed on seeds sterilized with 1% sodium hypochlorite solution on sterilized moistened sand media in a growth chamber at alternating conditions of 30°C 8-hour light and 20°C 16-hour darkness. The number of seeds germinated were recorded on a daily basis for 16 days. A seed was considered germinated when the plumule had emerged from the sand surface. On the last day of the germination counts (16th day), final germination percentage (FGP) was calculated using the formula;

$$FGP = \frac{N_g}{N_T} \times 100$$

Where;

N_g = Number of germinated seeds.

N_T = Total number of seeds sown (Damalas *et al.*, 2019) after modification.

Germination velocity index (GVI) was calculated as proposed by Maguire (1962) as:

$$GVI = G_1/N_1 + G_2/N_2 + \dots \dots + G_n/N_n$$

Where

$G_1, G_2 \dots \dots G_n$ = Number of seeds germinated on first, second and last count.

$N_1, N_2 \dots \dots N_n$ = Number of days at first, second and last count from the day of sowing.

Five normal seedlings from each tray (each replication) were air oven dried at 95°C for 24 hours and weighed to determine seedling dry weight (SDW). A combined ranking of FGP, GVI, SDW for sampling days was used to estimate stages of highest seed quality. Mass maturity stages were estimated as the point of diminished increase in seed dry weight (Oballim *et al.*, 2023).

Assessment of seed pigmentation during seed development

Seeds of the three BN landraces (Fig 2-4) were harvested from a field experiment as described above (Oballim *et al.*, 2023). Fresh pods and seeds of each landrace were visually assessed for color variation at every harvest (developmental) stage. Pods were then sun dried, shelled and dried seeds also visually assessed for color variation at each developmental stage of a landrace. Seed coloration at important stages of seed maturation *i.e.* stage of highest seed quality and mass maturity for each landrace were compared with other stages of seed development.

Determination of phytochemical contents of Bambara nut seeds

The phytochemical analyses for flavonoids and tannins were conducted at the International Livestock Research Institute, Nairobi, Kenya, from 2021 to 2022. Dried whole seeds with intact seed coats were ground into a fine powder using the Cyclotec™ 1093 mill (FOSS Analytics, Hillerød, Denmark). The resulting powder was used for both flavonoids and tannins determination.

Determination of flavonoids

Sample extraction

Approximately 0.1 g of powdered sample was weighed into clean propylene tubes and 10 ml of 80% methanol added to each sample. The samples were shaken on a mechanical shaker at room temperature for 24 hours and the mixture centrifuged at 3500 rpm for 10 minutes. Aliquots of the supernatant were recovered for determination of total flavonoids.

Determination of total flavonoids

Total flavonoid content (TFC) was determined using the Aluminum chloride colorimetric procedure (Shraim *et al.*, 2021). A micro-titer plate was used in the preparation of final reaction solutions. The following steps were followed: 20 µl catechin standards (0, 20, 40, 60, 80 and 100 µg/ml), 20 µl aliquots of sample extracts and 20 µl of 80% methanol (reagent blank) were pipetted into known respective wells, followed by 80 µl deionized distilled water; 10 µl of 5% NaNO₂, orbital shaking, five minutes equilibration time; 10 µl of 10% AlCl₃, orbital shaking, five minutes equilibration; and 80 µl of 2 M NaOH, orbital shaking. The combined mixtures were then covered with aluminum foil and left to stand at room temperature for 30 minutes. The absorbance of samples and standard solutions were read against the blank using the BioTek Synergy HTX Multimode reader (Agilent Technologies, California, USA) at 510 nm. A standard calibration curve of catechin (µg/ml) in 80% methanol was generated (Fig 1) and used to determine the total flavonoids concentration in each sample. Total flavonoids content was expressed as mg catechin equivalents (mg CE) per 100 g of dry sample using the formula:

$$\text{Total flavonoids (mg CE/100 g dry sample)} = \frac{C \times DF \times 100}{W \times 1000}$$

Where,

C = Concentration obtained from the calibration in µg/ml.

DF = Total dilution factor.

W = Weight of the sample in grams.

100 = Conversion factor to report results in mg/100 g.

1000 = Conversion factor from µg/ml to mg/ml.

Determination of tannins

Sample extraction

Approximately 0.25 g of the powdered sample was weighed into a clean conical flask and 37.5 ml of deionized distilled water was added. The flask was gently heated for 30 minutes and brought to the boil. The mixture was cooled

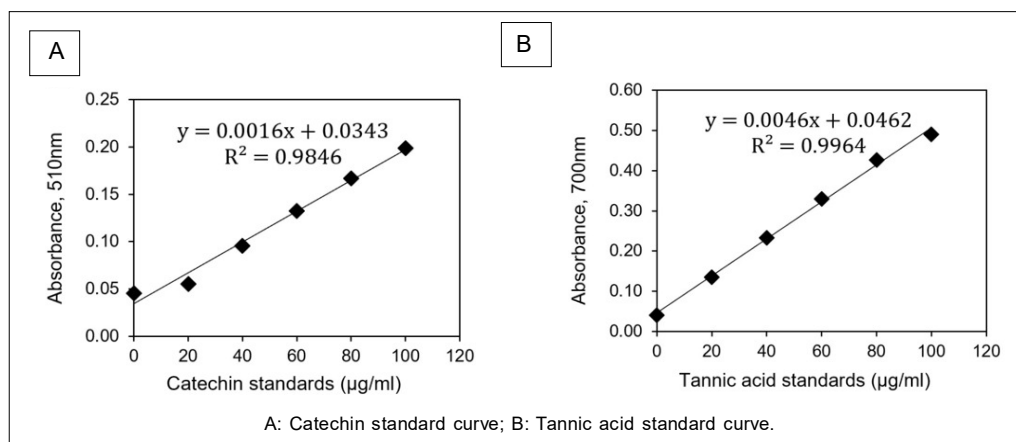


Fig 1: Standard curves used in the determination of flavonoids and tannins contents of seeds.

and transferred to a clean 50 ml falcon tube, made up to 50 ml with deionized distilled water and centrifuged at 3.500 rpm for 15 minutes. The supernatant was taken out for the determination of tannin contents.

Determination of tannin contents

The tannin content was determined using a modified Folin-Denis procedure (Saxena *et al.*, 2013). The following steps were taken: 50 µl tannic acid standards (0, 20, 40, 60, 80, 100 µg/ml), 50 µl aliquots sample extracts and 50 µl deionized distilled water (reagent blank) were pipetted into micro-titer wells of known positions; 50 µl of Folin-Denis reagent, orbital shaking, five minutes equilibration; 100 µl of 7% Na₂CO₃ and orbital shaking. The microtiter plate was then covered with aluminum foil and left to stand at room temperature for 30 minutes. The absorbances of the samples and standards were read against the blank in the BioTek Synergy HTX Multimode reader (Agilent Technologies, California, USA) at 700 nm. A standard calibration curve of tannic acid (µg/ml) was generated and used to determine the tannins concentration in each sample (Fig 1). Tannins content in each sample was expressed as mg tannic acid equivalents (mg TAE) per 100 g of dry sample using the formula:

$$\text{Total content (mg TAE/100g dry sample)} = \frac{C \times DF \times 100}{W \times 1000}$$

Where;

C = Concentration obtained from the calibration in µg/ml.

DF = Total dilution factor.

W = Weight of the sample in grams.

100 = Conversion factor to report results in mg/100 g.

1000 = Conversion factor from µg/ml to mg/ml.

Data processing and analysis

Data was entered in Excel and analysis of variance (ANOVA) performed on tannin and flavonoid contents of seeds in GenStat® 14th Edition (VSN International Ltd, Hemel Hempstead, UK). ANOVA was performed to compare different developmental stages for tannin and flavonoid contents of landraces and to compare landraces at their respective mass maturity stages. Means were separated using Tukey's procedure at the 5% level. To describe relationships between the tannin and flavonoid contents of seeds and different germination variables (Oballim *et al.*, 2023), Kendall's rank correlation coefficient (τ) (Kendall's tau-b) was calculated in IBM® SPSS® Statistics (Version 20) statistical software (IBM Corporation, Armonk, New York, USA). Paired variables were subjected to significance tests at both the 5% and 1% levels.

RESULTS AND DISCUSSION

Seed pigmentation during development and maturation

Both fresh and dry seeds of all landraces showed distinctive characteristic patterns of coloration that gradually developed and intensified during the latter phases of

development (Fig 2-4). At 83 DAS, there was hardly any coloration in fresh seeds of landraces from the first (*Ocettoke*) experiment, although for TVSU544, some coloration had begun to appear (Fig 2-4). Clearly visible color patterns began to appear by 93 DAS for all landraces, and by 103 DAS, complete characteristic color patterns had developed for the majority of seeds of both LocalBam and TVSU544. Beyond this stage, there was hardly any visible color change for both landraces (Fig 2 and 4). For AbiBam001 however, full coloration developed only after 113 DAS, with no further distinguishable color change beyond this stage (Fig 3). Table 1 shows the stages at which the seeds of the landraces reach full color development. For both AbiBam001 and TVSU544, full color development and highest seed quality are aligned at the same stage of development and precede mass maturity. For LocalBam however, highest seed quality is aligned with mass maturity and are both preceded by full color development.

Seed coat color is largely genetically controlled, with certain environment conditions exerting an effect (Marles *et al.*, 2003; Herniter *et al.*, 2019). The first appearance of color on fresh developing seeds signals the beginning of expression of the color regulating gene(s) which are upregulated throughout seed development until full color development when they are maximally expressed (Marles *et al.*, 2003; Herniter *et al.*, 2019). They are then down regulated following the attainment of full/characteristic color (Marles *et al.*, 2003; Herniter *et al.*, 2019). In the present study, this is shown to occur after 103 DAS for both TVSU544 and LocalBam and after 123 DAS for AbiBam001. Post maturation and post-harvest color intensification was not visually detectable in the landraces. Nevertheless, in this study, full color attainment seemed to be suitably aligned with important stages of seed maturity and it was observed that full color development in landraces precedes both mass maturity and harvest maturity (Oballim *et al.*, 2023). It is quite common for farmers to use seed color as an indicator of maturity and harvest (Obura *et al.*, 2021), and they tend to harvest seeds nearly one month later at harvest maturity (Obura *et al.*, 2021; Oballim *et al.*, 2022). According to the findings in the present study, earlier harvest (just after physiological maturity) than what farmers do, is likely to produce better quality seeds. Farmers can therefore use the appearance of distinctive color patterns in combination with other indicators such as days after sowing, yellowing and browning of leaves and drying of stems for better timing of harvest.

Tannin and flavonoid contents of seeds during seed development and maturation

AbiBam001 and LocalBam had significantly different contents of both tannins and flavonoids during seed development ($p < 0.01$) while for TVSU544, they were both not significant at the *Ocettoke* site ($p > 0.05$) (Table 2). There was no difference in tannin and flavonoid contents of all landraces at *Koro* (Table 2). The tannin and flavonoid

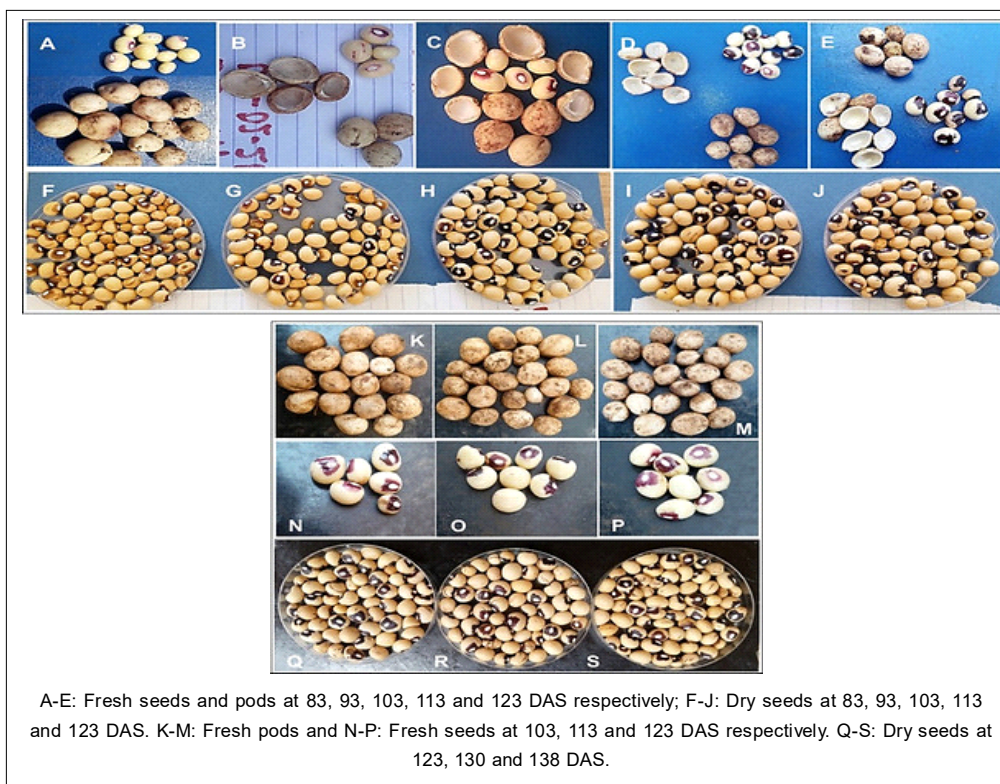


Fig 2: Stages of seed pigmentation of TVSU544 during seed development and maturation.



Fig 3: Stages of seed pigmentation of AbiBam001 during seed development and maturation.

contents at *Ocettoke* followed an overall declining trend, but no clear trend was observed at *Koro*. At mass maturity, significant differences were observed in the tannin ($P < 0.01$) and flavonoid ($P = 0.019$) contents of the landraces (bold text) (Table 2). At this stage, LocalBam had the highest tannins and flavonoids contents, followed by Abibam001, with TVSU544 (cream and black eyed) having significantly lower content of especially tannins (Table 2). There were no differences in the tannins and flavonoids contents of landraces at full color development, highest seed quality and mass maturity, except for the flavonoid content of AbiBam001 (Table 2).

According to Elsadr *et al.* (2015), darker colored bean varieties accumulated more condensed tannins during seed development which steadied slowly towards maturity compared to lighter colored types. The varieties with darker colored seeds also had semi-indeterminate to indeterminate growth habits with extended flowering time compared to those with lighter colored seeds. These growth patterns determined the pattern of tannin and other polyphenolic accumulation. The pattern of growth of bean varieties reported by Elsadr *et al.* (2015) is analogous to that of BN landraces. It is therefore plausible that the pattern of accumulation of condensed tannins for the bean varieties

is similar to that of polyphenolics in BN landraces in the present study. The same study by Elsadr *et al.* (2015) observed that condensed tannins was detectable in seeds as early as 6 days after flowering and rapidly increased afterwards before peaking and declining or steadying. It can thus be inferred that the stages of maturity in the *Ocettoke* experiment fall within the declining phase while at *Koro*, they are within the steadying phase of polyphenolic accumulation. This also suggests that rapid increase and peak phases of polyphenolic accumulation both occur earlier than 93 DAS. Further report by Xu *et al.* (2015) showed that tannin content of edamame (green soybean) seeds steadily increased throughout the development period of six weeks starting at the seed initiation stage (R5). In the present study, landraces differed in their tannin and flavonoid contents at the point of maturity, with dark seeded LocalBam and intermediate colored AbiBam001 having higher contents of these polyphenolics compared to the light colored TVSU544. This is in agreement with Puozaa *et al.* (2021) who observed that dark (black and red) colored BN seeds had higher flavonoid content than light (cream) colored seeds. Similarly, Harris *et al.* (2018) demonstrated that brown and red BN seeds had higher concentrations of flavonoids and tannins in their hulls

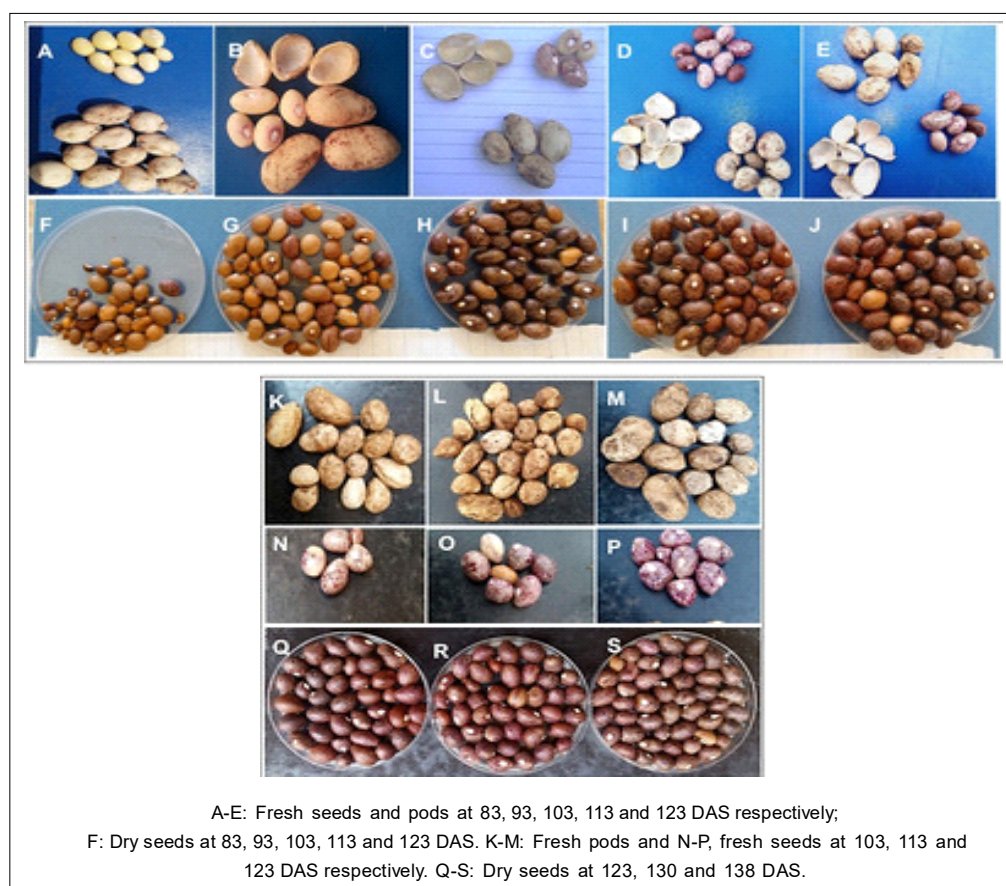


Fig 4: Stages of seed pigmentation of LocalBam during seed development and maturation.

compared to light seeds. Furthermore, a study on similar dry legumes revealed that the total flavonoid contents of the dark colored broad bean, kidney bean, rice bean and black soybean was higher than for light colored legumes such as chickpea and pea (Ren *et al.*, 2012). Conversely however, Wang *et al.* (2008) observed no consistent relationship between seed coat color and flavonoid content of soybean, groundnut, cowpea, lablab and mungbean, which was attributed to differences in their genetic backgrounds. Nevertheless, beyond maturity, there was no difference in the tannin and flavonoid content of seeds of all landraces. This is expected as most metabolic and synthetic activities slow down to a halt at mass maturity and seeds enter a state of metabolic inactivity and maturation drying (Bewley *et al.*, 2013; Elsadr *et al.*, 2015). Besides their role in seed coloration (Marles *et al.*, 2003; Harris *et al.*, 2018), the tannins and flavonoids (polyphenolics) of seeds have been suggested to influence other seed physico-chemical characteristics that are mostly under the control of the seed coat (Ochuodho and Modi, 2013; Mandizvo and Odindo, 2019). The polyphenolics are also known to possess nutraceutical and anti-nutritional

properties (Mohan *et al.*, 2016; Thi and Nguyen, 2021). Seed coat color is therefore an important seed quality parameter for variety identification, selection in breeding, germplasm characterization, and as a basis for market and consumption preferences (Tiryaki *et al.*, 2016; Nadeem *et al.*, 2020). The tannin and flavonoid content of the landraces in the present study are somehow a confirmation of the basis for their seed coat coloration and a reference for their polyphenolic categorization.

Relationship between seed quality characteristics and polyphenolic composition of seeds

Seed quality characteristics (FGP, GVI, SDW) of the landraces showed mostly negative or no relationships with flavonoid and tannin contents at *Ocettoke*, except for TVSU544 which were positive (Table 3). Nearly the reverse trend was observed at *Koro* where there were mostly positive or no relationships between seed quality parameters and tannin and flavonoid contents (Table 4). Tannin and flavonoid contents had positive relationships for all landraces except for TVSU544 at *Koro* which was negative (Tables 3 and 4).

Polyphenols (flavonoids, tannins) complex polysaccharides (cellulose, pectin, and callose), suberin and cutin are known to contribute to the physical and chemical resistance of the seed coat, which are important for seed longevity (Sano *et al.*, 2016). However, this may negatively affect seed germinability (Smykal *et al.*, 2014; Tiryaki and Topu, 2014). Condensed tannins in the seed coat of *Lupinus albus* and *Trifolium pratense* are suggested to contribute to coat-imposed dormancy (Tiryaki and Topu, 2014), thus inducing poor germination. This concurs with

Table 1: Stages (DAS) at which seeds of the different landraces attain key indicators of maturity.

	Full color development	Highest seed quality	Mass maturity (approx.)
AbiBam001	113	113	130
Localbam	103	113	113
TVSU544	103	103	113

Source: Oballim *et al.* 2023 (Highest seed quality and mass maturity).

Table 2: Flavonoid and tannin contents of seeds of landraces at different developmental stages from the *Ocettoke* and *Koro* sites.

Location	Seed developmental stage (DAS)	Landrace					
		AbiBam001		LocalBam		TVSU544	
		Flavonoids ^a	Tannins ^b	Flavonoids	Tannins	Flavonoids	Tannins
<i>Ocettoke</i>	93	211.49c	916.36b	133.21c	981.02b	41.31a	405.98a
	103	179.36c	905.41b	68.64a	766.29a	51.07a	449.43a
	113	80.66a	675.08a	64.03a	739.24a	45.21a	412.11a
	123	135.88b	612.54a	101.93b	730.50a	44.80a	392.04a
	p-value	<.001	0.001	<.001	0.005	0.798	0.238
	s.e.d.	10.60	45.94	6.59	45.82	9.83	25.46
	l.s.d.	25.93	112.40	16.11	112.13	24.04	62.30
<i>Koro</i>	123	46.01a	693.75a	94.08a	963.14a	32.81a	441.22a
	130	49.05a	653.88a	142.92a	993.20a	28.31a	476.36a
	138	40.50a	595.51a	100.12a	955.49a	29.85a	441.46a
	p-value	0.156	0.089	0.392	0.868	0.935	0.875
	s.e.d.	2.64	21.84	30.22	72.29	12.22	75.60
	l.s.d.	11.36	93.99	130.05	311.04	52.55	325.27

^aTotal flavonoids measured as mg CE/100g dry sample; ^btotal tannins measured as mg TAE/100g dry sample. The texts in bold show tannin and flavonoid contents at mass maturity. Means followed by the same letters are not significantly different (p<0.05).

observations in the present study where seed quality characteristics negatively correlated with tannin and flavonoid contents. Nevertheless, de Almeida *et al.* (2014), reported no relationship between the tannin content and dormancy of sorghum seeds. A similar trend was observed in this study where no apparent relationship existed between tannin contents and seed germination characteristics of especially LocalBam (at *Ocettoke*) and TVSU544 (at *Koro*). On the other hand, darker seeded landraces of BN were shown to have better germination than lighter seeded types (Chibabada *et al.*, 2014). A similar work by Kantar *et al.* (1996) indicated that faba bean seeds with higher tannin content had higher vigor, better laboratory germination and better field emergence. These reports

may explain the positive trends observed (mostly at *Koro* for all landraces and at *Ocettoke* for TVSU544) for the seed quality parameters and polyphenolic contents of landraces. It was also reported that dark-colored BN seeds had higher tannin and flavonoid contents than light-colored seeds (Harris *et al.*, 2018). This was similarly demonstrated in an earlier study by Ren *et al.* (2012), who determined the total flavonoid contents of the dark colored legume varieties to be higher than for light colored types. Together, these observations suggest that the darker the seeds, the higher the polyphenolic content and the better the germination of the seeds. However, there seems to be no consistent pattern of the relationship between tannin and flavonoid contents of landraces and their seed quality in the present

Table 3: Values of Kendall's rank correlation coefficient (τ) among the various seed quality and polyphenolic parameters of the landraces at *Ocettoke*.

Landrace	Parameter	FGP	GVI	SDW	Flavonoids	Tannins
AbiBam001	FGP (%)	1.0				
	GVI	0.3	1.0			
	SDW	0.0	0.0	1.0		
	Flavonoids	-0.7	-0.7	-0.3	1.0	
	Tannins	-1.0**	-0.3	0.0	0.7	1.0
LocalBam	FGP (%)	1.0				
	GVI	1.0**	1.0			
	SDW	-0.3	-0.3	1.0		
	Flavonoids	-0.7	-0.7	0.7	1.0	
	Tannins	0.0	0.0	0.0	0.3	1.0
TVSU544	FGP (%)	1.0				
	GVI	0.9	1.0			
	SDW	0.2	0.0	1.0		
	Flavonoids	0.9	0.7	0.3	1.0	
	Tannins	0.9	1.0**	0.0	0.7	1.0

**Correlation is significant at the 1% level.

Table 4: Values of Kendall's rank correlation coefficient (τ) among the various seed quality and polyphenolic parameters for the landraces at *Koro*.

Landrace	Parameter	FGP	GVI	SDW	Flavonoids	Tannins
AbiBam001	FGP (%)	1.0				
	GVI	1.0**	1.0			
	SDW	1.0**	-1.0**	1.0		
	Flavonoids	0.3	0.3	-0.3	1.0	
	Tannins	1.0**	1.0**	-1.0**	0.3	1.0
LocalBam	FGP (%)	1.0				
	GVI	0.8	1.0			
	SDW	-0.8	-0.3	1.0		
	Flavonoids	0.0	0.3	0.3	1.0	
	Tannins	0.8	1.0**	-0.3	0.3	1.0
TVSU544	FGP (%)	1.0				
	GVI	1.0**	1.0			
	SDW	1.0**	1.0**	1.0		
	Flavonoids	0.3	0.3	0.3	1.0	
	Tannins	0.0	0.0	0.0	-0.8	1.0

*Correlation is significant at the 5 % level; **Correlation is significant at the 1% level.

study. A study on seed coat color in relation to germinability of wild mustard seeds similarly revealed no consistent pattern (Ochudho and Modi, 2013). Nevertheless, the tannin and flavonoid contents of seeds were positively related for all landraces. Both flavonoids and tannins are polyphenolic compounds that are produced through the same biosynthetic pathways (Smykal *et al.*, 2014; Elsadr *et al.*, 2015). For dry legumes such as BN and common beans, they are predominantly found in the seed coats (Harris *et al.*, 2018).

CONCLUSION

The present study showed that full color development in the landraces precede mass maturity and are aligned with key indicators of maturity such as seed germinability and vigor. Characteristic landrace seed color can thus complement days to maturity and other indicators of harvest maturity, in determining stage of harvest for maximum seed quality. The tannin and flavonoid contents of the BN landraces confirm the basis for their seed coat coloration and provide a reference for their polyphenolic categorization. Higher tannins and flavonoids in landraces appeared to have negative effect on seed quality of BN landraces at earlier stages, but positive effect at later stages of development when polyphenolic contents are lower. These results further highlight the roles of tannins and flavonoids in BN seed quality and the potential for their manipulation for seed quality management.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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