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The quality of vegetable seed in formal and informal seed systems across Africa

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Abstract

Seed quality is a critical determinant of agricultural productivity, yet farmers cannot observe it at the point of sale. Therefore, quality assurance mechanisms such as seed certification and phytosanitary controls are meant to ensure seed quality in the market. However, empirical evidence on the effectiveness of such mechanisms for vegetable seed in Africa is limited. Drawing on 995 samples of tomato, okra, and onion seed collected from 648 seed sellers across nine African countries, this study compares four aspects of seed quality—germination, purity, moisture content, and seed-borne fungal pathogens—across three seed systems: formal imported, formal domestic, and informal. Using hedonic pricing, the study then quantifies price premiums for each seed-quality attribute. The results show that seed quality is generally poor across all systems. Seed from the formal imported system had higher mean seed purity and a slightly lower incidence of seed-borne fungal pathogens. However, formal systems did not perform better in seed germination and seed moisture content. The hedonic pricing model showed that seed purity is most strongly associated with price premiums, whereas high germination is associated with higher prices only for tomato. Overall, prices reliably signal germination, purity and absence of fungal pathogens for tomato seed but are less informative for other crops or other seed quality attributes. These findings suggest a clear need to improve vegetable seed quality in Africa's markets, but indicate that current approaches to seed quality assurance such as certification and phytosanitary controls are ineffective.

Keywords: Agriculture, agrodealer, seed certification, seed quality, hedonic price.

1 Introduction

Seed systems are a cornerstone of agricultural productivity and food security. Farmers need reliable access to high-quality seed of good crop varieties, but they cannot observe seed quality at the point of sale. Therefore, governments have instituted seed laws and regulations to protect farmers by ensuring that seed sold in the market meets certain quality standards (Kuhlmann et al., 2023; Codjo et al., 2026). In Africa, these regulations usually translate into stringent testing requirements for new varieties, mandatory field inspections and certification of commercial seed production, and restrictions preventing farmer-saved seed from entering the market. Private seed companies also make a substantial effort to win farmers' trust in the quality of their products through seed testing, packaging, marketing, and branding (Gharib et al., 2021; Win et al., 2025). These efforts increase the cost of seed, which is reflected in higher prices for certified and branded seed.

Seed quality is a multifaceted concept that represents the overall value and performance of a seed lot. According to the International Seed Testing Association (ISTA), seed quality has four primary components, including physical quality (the seed must be pure, free of contaminants, and free of physical damage), physiological quality (high germination and vigor and low moisture content to ensure longevity), genetic quality (varietal identity and homogeneity), and health or sanitary quality (free of pathogens and pests) (Prasad, 2023). Previous studies have identified low seed quality as a major bottleneck for smallholder farmers in sub-Saharan Africa (Pincus et al., 2018; Ayenan et al., 2021; Wanyama et al., 2023; Breen et al., 2024), but empirical research on seed quality remains limited.

Seed systems in sub-Saharan Africa and elsewhere are often categorized as formal or informal (e.g., Muricho et al., 2023; Ncube et al., 2023). Formal seed systems are characterized by the involvement of public research organizations and private seed companies in plant breeding,

47 variety testing and registration, and certified seed production. The formal seed system is
48 governed by national seed laws and regulations. Informal seed systems, by contrast, refer to
49 farmer- and community-managed seed production involving seed saving of open-pollinated
50 varieties for farmers' own use, exchange through farmers' networks, or informal selling.
51 However, there is often no rigid divide between formal and informal seed systems, as the
52 informal system may multiply seed from varieties developed by the formal system (de Boef et
53 al., 2025).

54 Despite efforts to strengthen formal seed systems through regulation, certification, and private-
55 sector development, informal seed systems continue to dominate seed use among smallholder
56 farmers in Africa, with some studies reporting that they account for 70-90% of farmers' seed
57 use (McGuire and Sperling, 2016; Muricho et al., 2025). However, most previous studies on
58 seed systems in Africa have focused on staple food crops, especially maize, not vegetables
59 (Ayenan et al., 2021).

60 Vegetable production in sub-Saharan Africa (SSA) is increasingly market-oriented, driven by
61 rapidly rising consumer demand, especially from the continent's expanding urban population
62 (OECD and SWAC, 2025). African consumers are increasingly interested in exotic vegetables
63 such as tomatoes, cabbage, carrots, and salad greens, reflecting shifting preferences (Levasseur
64 et al., 2007). Much of the seed demand for these crops is met by imports from Europe and Asia,
65 as domestic seed production capacity is limited (Schreinemachers et al., 2021). Hence, the
66 formal vegetable seed sector comprises two distinct systems: one of imported seed, mostly F1
67 hybrids from large multinational companies, and another of domestically produced seed,
68 mostly of open-pollinated varieties produced by local and regional seed companies (ter Steeg
69 and Louwaars, 2024).

This coexistence of formal (domestic and imported) and informal seed sources raises a central but insufficiently explored question: do seeds supplied through different market channels and origins differ in quality, and how are such differences reflected in market prices? Despite the importance of seed quality in improving agricultural productivity, empirical evidence on quality differentials across seed systems remains limited, particularly for vegetable crops. In one of the few studies on this topic, Croft et al. (2018) compared seed quality of formal and informal sources in Western Kenya for indigenous vegetables, such as amaranth and nightshade. They found that seed from the informal seed system outperformed that from the formal system in terms of germination and local adaptation. They, therefore, recommended strengthening informal seed markets rather than solely focusing on the development of formal seed systems.

Consistent with this, Biemond et al. (2013), studying seed-borne pathogens in maize and cowpea in Nigeria, found no evidence that seed in the informal seed system was of inferior quality to that of the formal system. They noted that repeated seed recycling by farmers did not lead to increased presence of seed-borne pathogens. Furthermore, Barriga and Fiala (2020) examined purity, germination and genetic similarity along the maize seed supply chain from breeder to retailer in Uganda. They found that seed quality was highly variable and quality dropped between breeder and wholesaler. However, the study did not compare seed quality between formal and informal channels.

There is also evidence for large and systematic price differences between seed from the formal and informal systems. For example, Blalogoe et al. (2025) showed that imported okra seed was consistently more expensive than local okra seed in Benin. Similarly, Okry et al. (2011) in their analysis of the rice seed sector in Guinea, found that seed from formal producers was, on average, three times more expensive than that sold by local dealers at open markets. Adigoun

et al. (2022) also reported that certified maize seed producers tend to set prices that are often unaffordable for smallholder farmers, largely because high production and certification costs are passed on to farmers. However, it remains uncertain whether the observed price differentials between formal and informal seed systems reflect measurable differences in seed quality.

This study focuses on vegetable crops because their productivity in SSA is low and stagnant, and access to quality seed remains a key constraint for farmers in the region (Pincus et al., 2018; Ayenan et al., 2021; Honfoga et al., 2026; Codjo et al., 2026). It addresses three key gaps in the existing literature. First, it provides a systematic comparison of seed quality across informal, formal domestic, and formal imported seed systems using objective laboratory-based measures of germination, purity, moisture content, and seed health. By doing so, it contributes to a small but growing body of work that moves beyond perception-based assessments of seed quality (Urrea-Hernandez et al., 2016; Houegban et al., 2024; Blalogoe et al., 2025). Second, the study applies a hedonic pricing framework to estimate the implicit value of both intrinsic and extrinsic attributes of vegetable seed, thereby quantifying how markets prize seed quality attributes and related signals. To the best of our knowledge, this is the first study in Africa to examine vegetable seed markets by analyzing price variation as a function of seed quality attributes and market characteristics. Previous studies relied on stated-preference and experimental approaches to analyze preferences and estimate willingness to pay for seed quality attributes (Timsina et al., 2016; Tapsoba et al., 2022; Voss et al., 2025; Houngbo et al., 2026). Third, by integrating laboratory-based seed quality data with market price data across vegetable crops and African countries, the study analyzes whether price premiums for seeds from formal domestic and imported seed systems reflect genuine quality differences, as they are often perceived as higher quality than those from informal seed systems.

Understanding these dynamics is critical for policy and market development. For example, if higher prices in formal domestic seed systems reflect genuine quality advantages rather than product claims by seed producers, then strengthening formal seed systems could yield productivity and welfare gains (Maredia et al., 2019; Mastenbroek et al., 2021). Conversely, if signaling effects of company marketing largely drive price premiums, then this would point to the need for stronger information systems, more effective quality verification, and enhanced regulatory oversight to support more efficient and equitable seed markets (Wossen et al., 2024). By combining seed quality measurement with hedonic price analysis, this study offers new insights into the functioning of vegetable seed markets in SSA, contributing to the broader debate on seed system transformation and agricultural intensification.

2 Methods

2.1 Data

The study covers nine countries: Benin, Burkina Faso, Ghana, Mali, and Nigeria in West Africa, and Ethiopia, Kenya, Tanzania, and Uganda in East Africa. These countries were selected because they have active vegetable seed sectors with formal and informal supply chains, and because the World Vegetable Center has on-the-ground staff to collect seed samples and interview participants.

Seed samples were collected using a standard protocol from agrodealers between December 2024 and March 2025. Seed producers and farmer associations in each country were contacted to compile a comprehensive, though not exhaustive, list of agrodealers selling vegetable seeds. Approximately 70 agrodealers per country were randomly selected from these lists, with equal representation from sellers operating in formal and informal seed systems. In countries where fewer than 70 agrodealers were identified, all were surveyed. In some cases, additional

141 agrodealers were included when more were available and consented to participate. The final
142 sample included 638 agrodealers (**Table 1**).

143 **Table 1.** Geographic distribution of the seed samples collected

Region	Country	Agrodealers	Seed samples			
			Tomato	Okra	Onion	Total
West Africa	Benin	61	51	35	-	86
	Burkina Faso	70	64	61	-	125
	Ghana	70	56	60	-	116
	Mali	70	66	69	-	135
	Nigeria	72	68	57	-	125
East Africa	Kenya	71	55	-	56	111
	Tanzania	74	43	-	48	91
	Ethiopia	72	37	-	40	77
	Uganda	78	72	-	57	129
Total		638	512	282	201	995

144 Agrodealers are private-sector retailers or wholesalers of agricultural inputs who act as key
145 intermediaries in agricultural input value chains, supplying seed, fertilizers, agrochemicals, and
146 related products. Within African seed systems, Codjo et al. (2026) identified different types of
147 agrodealer businesses, including specialized seed sellers, agroinput shops that sell seed
148 alongside other agricultural inputs such as fertilizers and pesticides, and diversified retailers
149 selling seed alongside food products.

150 The analysis distinguishes among three seed system categories in which agrodealers operate:
151 informal, formal domestic, and formal imported. Seed from the informal system refers to seed
152 sold outside the national seed regulatory system, typically by unlicensed agrodealers selling
153 farmer-saved non-certified seed. Seed from the formal domestic system refers to seed produced
154 by local seed enterprises and certified by national seed authorities. Seed from the formal
155 imported system refers to seed produced by multinational companies outside the study
156 countries and imported into SSA. While multinational companies have strict quality assurance

mechanisms, the seed is not necessarily certified by a national seed authority. Seed from the formal domestic and formal imported systems are generally distributed through licensed agrodealers.

Seed was purchased from the agrodealers sampled for the study. In East Africa, one tomato and one onion seed package were purchased, while in West Africa, one tomato and one okra seed package were purchased. The choice of crops reflects regional priorities and differences in seed markets. Considering the seed size of these crops and the requirements for rigorous laboratory analysis, 5 grams (g) of tomato and onion seed and 20g of okra seed were purchased. When seed packages exceeded these weights, the smallest available package was purchased. The study collected a total of 995 seed samples, including 512 tomato, 282 okra, and 201 onion samples (**Table 1**).

For each purchased seed sample, it was recorded whether the purchased seed was imported or locally produced and whether it was packaged. All samples were stored and shipped to Benin for laboratory analysis in accordance with official seed import and export procedures. Unpackaged (unbranded) seed was put in aluminum envelopes and labeled with the seed purchase information. All samples were stored in a cool, dark environment (0–10 °C; 20–40% relative humidity) and placed in plastic containers for shipment. The protocol for seed sample purchase, storage, transportation, and shipping is described in **Table A1**. Seed purchase prices were recorded. The team also recorded detailed information on agrodealer characteristics, including dealer type, store type, main business type, gender, years of experience in seed sales, and whether the store is part of a chain. All respondents were informed about the purpose of the study and provided their consent to participate.

2.2 Seed quality assessment

Seed samples were analyzed in a seed laboratory to assess key quality attributes, including analytical purity, germination, moisture content, and seed health, in accordance with ISTA guidelines (ISTA, 2016, 2023). These parameters constitute core components of laboratory-based seed quality evaluation and are the principal standardized indicators used internationally for assessing seed lot quality (FAO and ISTA, 2023).

Germination

Germination is defined as the emergence and development of the seedling to a stage where its essential structures indicate whether it can develop further into a satisfactory plant under favorable field conditions (ISTA, 2023). For each sample, 100 seeds were placed on moistened, sterile, distilled water–soaked paper and incubated at room temperature (25°C) with an 8-hour light period for 7 days for okra and 14 days for tomato and onion. Regular observations were conducted to classify seedlings as normal or abnormal. Normal seedlings have well-developed essential structures for producing healthy plants whereas abnormal seedlings have defects or malformations in essential structures that impair normal development. The germination percentage was calculated as the number of normal seedlings (*NS*) divided by the total number of seeds sown (*TN*). Substrate moisture was kept constant, all equipment was disinfected prior to use, and seeds were handled carefully to avoid mechanical damage. Germinated seeds were counted at the end of the incubation period, and the germination rate (*GR*) was calculated as:

$$GR = \left(\frac{NS}{TN}\right) \times 100 \quad (1)$$

Purity

Analytical purity is defined as the percentage by weight of pure seed in a seed sample, determined through separation and analysis of pure seed, inert matter, and seed of other species (ISTA, 2023). Inert matter may include broken, unformed seeds and plant debris. A high level

of analytical purity is a key indicator of seed quality, as contaminants can reduce planting efficiency and increase production risk (Maalouf et al., 2021). We conducted purity tests to determine the proportion of pure seeds of a given species in a seed lot and the proportion of inert matter or seeds of other species it contained. For each sample, a representative subsample of 100 seeds was taken and weighed to determine the total weight (*TW*). The seeds were then manually sorted on a clean surface to separate pure seeds (*PS*), inert matter, and seeds of other species, if present. Each fraction was separately weighed. The analytical purity percentage (*PP*) was calculated as:

$$PP = \left(\frac{PS}{TW}\right) \times 100 \quad (2)$$

Moisture

Seed moisture content is defined as the percentage of water present in the seed, expressed relative to the total fresh (wet) weight of the sample (ISTA, 2023). It strongly affects seed longevity and storage stability, making it one of the most important determinants of seed quality and longevity (FAO and ISTA, 2023). Higher moisture levels increase the rate of deterioration and reduce storability, while also increasing susceptibility to mechanical damage, insect infestation, and fungal attack. To analyze moisture, two replicates of each seed sample were dried in an oven at 103°C for 17 hours for tomato and onion. Okra seed was dried at 130-133°C for one to four hours. The seed moisture content (*MC*) was calculated as:

$$MC = \left(\frac{WB - WA}{WB}\right) \times 100 \quad (3)$$

where *WB* is the weight before drying, and *WA* is the weight after drying.

Seed health

Seed health refers to the presence or absence of infection/infestation with seed-borne pathogens or insect pests (fungi, bacteria, viruses, nematodes, insects, etc.) (Prasad, 2023). The study

focused on pathogenic fungal identification because fungi are the most common seed-borne pathogens. Of each sample, 50 seeds of tomato, okra, and onion were plated on a sterilized Potato Dextrose Agar (PDA) medium. Prior to plating, seeds were disinfected in 1% sodium hypochlorite (2 min) and 70% ethanol (1 min), rinsed three times in sterile distilled water (1 min per rinse), and dried on absorbent paper. The seeds were incubated in the dark at 25°C for 48 hours, or for 72 to 120 hours, until fungal mycelia and fruiting bodies were observed under a stereomicroscope, allowing for identification. The number of seed-borne pathogenic fungal infections was recorded. Seed lots with high levels of pathogenic fungal contamination were re-examined to confirm the results.

FAO seed quality requirements

FAO's Quality Declared Seed (QDS) standards were applied to determine if seed samples met the minimum quality requirements for germination, analytical purity, moisture content, and seed health (FAO, 2010). The minimum germination rate is 80% for tomato, okra, and onion seed; the minimum analytical purity threshold is 98% for tomato and okra and 97% for onion; the maximum moisture content is 8% for all three crops; and seed should be free of diseases or pathogens. Four binary seed-quality variables were constructed, one for each quality attribute: *germination* equals 1 if a seed sample has a germination rate of at least 80% and 0 otherwise; *purity* equals 1 if analytical purity meets or exceeds the crop-specific thresholds (98% for tomato and okra; 97% for onion) and 0 otherwise; *moisture* equals 1 if seed moisture content is 8% or less and 0 otherwise; and *fungi* takes the value 1 if fungal contamination is absent and 0 if present. These variables were used in the hedonic price models.

2.3 Hedonic price analysis

Theoretical model

The hedonic pricing method decomposes prices for purchased goods or services into the aggregate contributions of individual attributes (Rosen, 1974). This method enables researchers to evaluate the relationship between the market value of a composite good and each attribute by producing a set of implicit prices for all attributes (Latinopoulos, 2018). The observed price of a good or service can be decomposed into the implicit prices of its attributes (Schamel, 2012). Hedonic pricing assumes that a product is a basket of attributes, each with an assigned value that contributes to its price. This approach is rooted in Lancaster's theory of demand, which states that a product can be described as a bundle of characteristics or attributes (Lancaster, 1971). Based on this, the hedonic price can be modeled as an implicit price function:

$$p = f(x_1, x_2) + e \tag{4}$$

where p is the observed price of the good, x_1 is a vector of quantitative attributes, x_2 is a vector of qualitative attributes, and e is an error term. The quantitative and qualitative attributes may capture both intrinsic and extrinsic characteristics of the good. Interaction terms may also be included in the model specification. The marginal or implicit price of a quantitative attribute is equal to the partial derivative of the hedonic price function with respect to that attribute, holding all other characteristics constant:

$$\frac{\partial p}{\partial x_1} = \frac{\partial f(x_1)}{\partial x_1} \tag{5}$$

The qualitative attributes (x_2) are included in the model as dummy variables, allowing the effect of their presence or absence on price to be identified. The marginal or implicit price of a qualitative attribute is typically derived from the estimated coefficient of the corresponding dummy variable. Inference may be based on the coefficient's standard error. In log-linear

specifications, a bias correction may be applied following Kennedy (1981) to adjust for retransformation bias using the estimated variance of the coefficient. The implicit price of qualitative attributes can thus be estimated as follows:

$$g = \left[exp\left(\beta_{x2} - \frac{1}{2}V(\beta_{x2})\right) - 1\right] \times 100 \quad (6)$$

where $V(\beta_{x2})$ is the estimated variance of the estimated coefficient β_{x2}.

Empirical estimation

Identifying appropriate functional forms and estimation procedures is an important challenge in hedonic price analysis (Nickerson and Zhang, 2014). The choice of functional form for the relationship between price and product attributes affects estimation outcomes. Borchers et al. (2014) suggested that, among the various functional forms used in hedonic price models, linear and log-linear specifications generally perform best, exhibiting lower mean percentage errors than more complex functional forms. Recent studies have therefore often employed either linear or log-linear specifications (e.g., Ndindeng et al., 2021; Khanal and Dhoubhadel, 2023; Zanou et al., 2024). The log-linear specification, which uses the logarithm of the price as the dependent variable, also helps control for heteroskedasticity (Zanou et al., 2024). Therefore, this study adopted the log-linear functional form.

For each crop, two model specifications were estimated. The first model included only seed quality attributes (germination, purity, moisture content, and fungal absence) to capture the intrinsic value of seed quality. The extended model added market and geographic characteristics, including packaging, seed origin, and region, to account for broader market and geographic influences on seed pricing. Both specifications were estimated using Ordinary Least Squares (OLS). Diagnostic tests were then carried out on each model to validate the basic assumptions of the OLS estimator. The Shapiro-Wilk test was used to determine the normality

of the residuals, with the null hypothesis stating that they follow a normal distribution. The Variance Inflation Factor (VIF) was used to assess multicollinearity among the independent variables. A VIF of 10 or below is required (Chatterjee and Hadi, 2006) since VIFs greater than 10 cause the coefficients to be overestimated. The Ramsey RESET test evaluates model specification, while the Breusch-Pagan (BP) test checks for homogeneity of the residual variance. For regression parameter vectors, the OLS estimator is inefficient when heteroskedasticity is present. Following MacKinnon and White (1985), we used the heteroskedasticity-consistent covariance matrix (HCCM) to obtain heteroskedasticity-consistent standard errors (HC1) where heteroskedasticity was detected.

Before conducting the regression analysis, Welch's one-way ANOVA was used to compare mean seed prices and key quantitative seed quality attributes—germination rate, analytical purity rate, and moisture content—across three seed systems: informal, formal domestic, and formal imported. Welch's ANOVA was chosen for its robustness to unequal variances among groups. When significant differences were found, the Games-Howell post-hoc test identified specific pairwise differences, as it accounts for unequal variances and sample sizes while controlling for multiple comparisons.

The analysis includes eight variables. The dependent variable is the natural logarithm of seed market price, measured in dollars per gram and denoted $log(Price)$, which addresses potential nonlinearity in the price distribution. The main independent variables are seed quality attributes, while additional variables control for market and geographic differences. As explained above, the seed quality attributes used in the hedonic price models are binary variables derived from germination rates, purity rates, moisture content, and seed health analysis results, in line with the FAO QDS standard.

Market and geographic characteristics are included as control variables. *Packaging* takes the value 1 if seed is sold in packaged form, and 0 otherwise. *Seed system* is coded as 2 for the formal imported system (*FormalImp*), 1 for the formal domestic system (*FormalDom*), and 0 for the informal system. *Seed system* was used as a factor variable with the informal system category serving as the reference category. *Region* takes the value 1 for observations from East Africa and 0 for those from West Africa.

To examine how seed quality attributes, market characteristics, and region jointly determine seed prices, the hedonic price models are specified as follows. The model is estimated for all crops; however, regional controls are excluded for okra and onion, as data on okra were collected only in West Africa and data on onion only in East Africa.

$$log(Price) = \beta_0 + \beta_1 Germination + \beta_2 Purity + \beta_3 Moisture + \beta_4 Fungi + \varepsilon \quad (7)$$

$$log(Price) = \beta_0 + \beta_1 Germination + \beta_2 Purity + \beta_3 Moisture + \beta_4 Fungi + \beta_5 Packaging + \beta_6 FormalImp + \beta_7 FormalDom + \beta_8 Region + \varepsilon \quad (8)$$

3 Results

3.1 Characteristics of vegetable seed sellers

Table 2 summarizes the socioeconomic characteristics of seed dealers by seed system. Dealers operating in the formal domestic system had the highest average experience across all regions, with 11.6 years in West Africa, 8.0 years in East Africa, and 9.6 years overall. Dealers in the informal system ranked second overall (9.1 years), slightly ahead of those in the formal imported system (8.4 years). In East Africa, however, dealers in the formal imported system were slightly more experienced (6.5 years) than those operating in the informal system (6.4 years).

330 **Table 2.** Socioeconomic characteristics of agrodealers

Variables	West Africa			East Africa			Overall		
	IF (n=300)	FD (n=56)	FI (n=231)	IF (n=123)	FD (74)	FI (n=211)	IF (n=423)	FD (n=130)	FI (n=442)
Years of selling seed	10.20 (8.32)	11.62 (7.71)	10.12 (8.73)	6.37 (4.71)	8.03 (6.91)	6.54 (6.48)	9.09 (7.65)	9.58 (7.46)	8.41 (7.93)
Gender (1=male)	0.65	0.62	0.77	0.79	0.54	0.41	0.69	0.58	0.60
Part of a chain store (1=yes)	0.24	0.55	0.69	0.06	0.34	0.26	0.19	0.43	0.49
Business type (1=yes):									
- Specialized seed seller	0.10	0.09	0.20	0.00	0.07	0.06	0.07	0.08	0.14
- Agroinput shop	0.59	0.88	0.77	0.37	0.93	0.94	0.52	0.91	0.85
- Food seller selling seed	0.27	0.04	0.01	0.01	0.00	0.00	0.20	0.02	0.01
- Other	0.04	0.00	0.01	0.62	0.00	0.00	0.21	0.00	0.00
Store type (1=yes):									
- Brick-and-mortar store	0.56	0.98	0.99	0.32	0.89	0.97	0.49	0.93	0.98
- Open-air stand/market stall	0.30	0.02	0.00	0.09	0.00	0.02	0.24	0.01	0.01
- Mobile store (cart, truck, bike)	0.09	0.00	0.00	0.57	0.00	0.00	0.23	0.00	0.00
- Other	0.05	0.00	0.00	0.02	0.11	0.01	0.04	0.06	0.01

331 **Note:** IF= Informal, FD= Formal domestic, FI= Formal imported

332 In West Africa, seed sellers were predominantly male across all systems: 65% in the informal
333 system, 62% in the formal domestic system, and 77% in the formal imported seed system. In
334 East Africa, dealers in the informal system were mostly men (79%), whereas sellers in the
335 formal domestic and imported systems were more gender-balanced, 54% and 41% male,
336 respectively. Overall, the informal system (69% male) and the formal imported system (60%
337 male) were male-dominated, while the formal domestic system was the most gender-balanced
338 (58% male).

339 Unsurprisingly, store chains were more common in the formal system. In West Africa, 69% of
340 sellers of imported seed and 55% of sellers of domestically produced seed were part of a chain

store, compared to 24% for sellers operating in the informal seed system. In East Africa, chain-store participation was lower but remained concentrated among the formal seed system (26–34%) compared with the informal system (6%). This pattern held overall, with limited participation among dealers from the informal system (19%) and moderate participation among dealers from the formal system (43–49%).

Across both regions, the agroinput shop model was the dominant business model for the formal seed system. In West Africa, 88% of dealers in the formal domestic system and 77% in the formal imported system operate through agroinput shops, compared with 59% in the informal sector. In East Africa, this model was even more prevalent, with 93% of dealers from the formal domestic system and 94% from the formal imported system operating as agroinput shops, while only 37% of dealers were in the informal system. A notable pattern in West Africa's informal system was the combination of food and seed selling (27%), a practice virtually absent among dealers in the formal seed systems in East Africa. Specialized seed selling was rare in all systems, peaking at 20% of dealers among the formal imported system in West Africa. In East Africa's informal system, a large share of seed sellers (62%) fell under the "Other" business type, suggesting greater diversity or informality in their operations.

Store types further highlight structural differences among seed sellers. Dealers from the formal seed system operate exclusively from brick-and-mortar stores (89–99%). In contrast, those from the informal system used a mix of store types. In West Africa, dealers from the informal system primarily operated from fixed locations (56% brick-and-mortar, 30% open-air), whereas in East Africa, they relied heavily on mobile distribution (57%). Overall, mobile stores were concentrated in the informal system (23%), indicating greater flexibility and spatial mobility in the informal system.

3.2 Seed prices by system

Table 3 shows seed prices (in USD per gram) for tomatoes, okra, and onions across the three seed systems. Statistically significant price differences were found for most crops, with seeds from the formal imported system consistently priced higher than those from the informal and formal domestic systems. For tomato seed, significant price differences existed across categories and regions ($p < 0.01$ in all cases). Tomato seed from the formal imported system was more expensive (USD 1.20/g) than from the informal (USD 0.28/g) and formal domestic (USD 0.25/g) systems, which were similarly priced. This difference was consistent across regions. In West Africa, seed from the formal imported system was significantly more expensive than from the other two systems. In East Africa, the price gap was wider, with seed from the formal imported system averaging USD 1.53/g, compared to USD 0.21/g for the informal system and USD 0.17/g for the formal domestic system. These results indicate that imported tomato seed commands a substantial price premium, likely due to perceived differences in quality, branding, or certification.

Table 3. Average market prices of seed (USD per gram) by seed system and region

Crop	Region	Informal	Formal domestic	Formal imported	F-statistic	p-value	Sign.
Tomato	West Africa (n=305)	0.30[a] (0.03)	0.40[a] (0.07)	0.93[b] (0.09)	23.79	<0.001	***
Tomato	East Africa (n=207)	0.21[a] (0.02)	0.17[a] (0.02)	1.53[b] (0.24)	16.84	<0.001	***
Tomato	Overall (n=512)	0.28[a] (0.02)	0.25[a] (0.03)	1.20[b] (0.12)	30.87	<0.001	***
Okra	West Africa (n=282)	0.08[a] (0.01)	0.07[a] (0.01)	0.14[b] (0.01)	16.77	<0.001	***
Onion	East Africa (n=201)	0.15 (0.01)	0.20 (0.06)	0.14 (0.02)	0.51	0.605	

Notes: Values in parentheses are standard deviations. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level. Different letters (a, b, c) indicate results of the Games-Howell post-hoc test and denote statistically significant pairwise differences among seed systems within each crop when Welch's ANOVA is significant at the 5% level ($p < 0.05$). Values sharing the same letters are not significantly different.

A similar pattern was observed for okra. Okra seed from the formal imported system (USD 0.14/g) was significantly more expensive than from both the informal system (USD 0.08/g) and the formal domestic system (USD 0.07/g). In contrast, the mean price of onion seed did not differ significantly across systems.

Overall, the results show that price differentiation depends on both crop and region. For tomato and okra, seeds from the formal imported system consistently commanded significant premiums. Notably, no price differences were found between seeds from the informal and formal domestic systems, indicating that formality alone, without the "imported" label, does not lead to higher seed prices in these markets.

3.3 Seed quality

Table 4 presents the results of Welch's ANOVA and Games-Howell post-hoc tests comparing analytical purity, moisture content, and germination percentage of tomato, okra, and onion seeds across seed sources. For tomato seed, there were no statistically significant differences in germination across seed systems in the overall sample or within each region. Purity was a more consistent differentiator: imported tomato seed had a higher mean purity in West Africa, though not in East Africa. Tomato seed from the formal domestic system also had a lower moisture content in East Africa, but not in West Africa.

Table 4. Seed quality parameters across seed systems and regions

Crop	Region	Quality aspect	Informal	Formal domestic	Formal imported	F-statistic	*p*-value	Sign.
Tomato	West Africa (n=305)	Germination (%)	80.63 (1.55)	81.11 (5.59)	81.85 (1.82)	0.129	0.879	

Crop	Region	Quality aspect	Informal	Formal domestic	Formal imported	F-statistic	*p*-value	Sign.
		Moisture content (%)	6.37 (0.17)	6.70 (0.47)	6.63 (0.17)	0.659	0.522	
		Purity (%)	94.48[a] (0.90)	88.07[a] (4.49)	98.13[b] (0.6)	7.544	0.002	***
	East Africa (n=207)	Germination (%)	80.17 (2.97)	72.14 (3.14)	81.02 (1.81)	3.057	0.052	*
		Moisture content (%)	7.39[a] (0.50)	5.50[b] (0.28)	6.49[a] (0.21)	6.772	0.002	***
		Purity (%)	89.14 (2.39)	95.47 (2.3)	95.29 (1.12)	2.832	0.065	*
	Overall (n=512)	Germination (%)	80.50 (1.40)	75.30 (2.86)	81.48 (1.29)	1.935	0.148	
		Moisture content (%)	6.67[a] (0.19)	5.92[a] (0.26)	6.57[a] (0.13)	3.105	0.048	**
		Purity (%)	92.91[a] (0.96)	92.87[a] (2.2)	96.85[b] (0.61)	6.815	0.002	***
Okra	West Africa (n=282)	Germination (%)	66.94[a] (2.42)	64.73[a] (5.49)	81.58[b] (1.69)	14.434	<0.001	***
		Moisture content (%)	8.47[a] (0.15)	9.44[b] (0.23)	7.64[c] (0.14)	23.485	<0.001	***
		Purity (%)	97.77[a] (0.58)	97.97[a] (0.34)	99.41[b] (0.18)	9.447	<0.001	***
Onion	East Africa (n=201)	Germination (%)	67.81[a] (3.85)	42.79[b] (5.64)	59.82[a] (3.58)	6.660	0.002	***
		Moisture content (%)	6.97 (0.43)	7.02 (0.31)	7.42 (0.19)	0.881	0.418	
		Purity (%)	97.23 (0.84)	98.37 (0.50)	98.75 (0.44)	1.272	0.285	

Notes: Values without parentheses are means, and values in parentheses are standard deviations. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level. Different letters (a, b, c) indicate results of the Games-Howell post-hoc test and denote statistically significant pairwise differences among seed systems within each crop when Welch's ANOVA is significant at the 5% level ($p < 0.05$). Values sharing the same letters are not significantly different. Detailed seed quality attributes by crop, country, and seed system are presented in Table A2.

For okra, imported seed had significantly higher germination and purity rates than seed from the domestic formal and informal systems, which did not differ significantly from each other. Imported okra seed also had a lower mean moisture content ($p < 0.01$) than locally produced seed. Hence, imported okra seed had better quality in terms of germination, moisture content, and purity than the other two seed sources.

For onion, there was no significant difference in mean germination between imported seed and seed from the informal system, both of which were high; but the germination rate of seed from the domestic formal system was significantly lower than that of the other two sources. There were also no significant differences in purity and moisture content across the three seed sources. Hence, these findings suggest that the quality of onion seed from the informal system is as good as that from the formal system.

The variation in seed quality within each seed system indicates substantial heterogeneity in seed quality, particularly in the formal domestic and informal systems, compared with the formal imported system. For tomato, the standard deviations across all quality parameters were consistently higher in the formal domestic and informal systems than in the formal imported system. In West Africa, the standard deviations of tomato germination and purity rates in the informal system were more than three and seven times, respectively, those observed in the formal imported system, indicating substantial variation in seed quality within the informal system. A similar pattern is observed for okra and onion, although the magnitude of the differences varies across quality parameters and seed systems. Overall, seed quality appears to be more consistent in the formal imported system, whereas the formal domestic and informal systems exhibit greater within-system heterogeneity. While the imported system generally shows lower variation in seed quality, the difference in variability is less pronounced for okra and onion than for tomato.

In summary, no seed source excelled across all quality aspects. Imported seed had higher purity for tomatoes and better germination, purity, and moisture content for okra. Yet, onion seed from the informal system had a higher germination rate, while tomato seed from the formal domestic system had lower moisture content in East Africa.

3.4 Comparison against FAO standards

Figure 1 shows the percentage of seed samples of tomato, okra, and onion meeting FAO quality standards for germination, purity, moisture content, and fungal absence across three seed systems. For all crops, seed from the formal imported sector had a significantly higher proportion of samples meeting the purity standard, reaching nearly 100% for okra. In terms of germination, while the differences were less clear than for purity, seed from the formal imported system recorded the highest proportion of samples meeting this standard. Interestingly, for all three crops, the informal sector outperformed the formal domestic seed sector in meeting the FAO germination standard. Okra seed from the formal imported system was also more likely to meet the low moisture content standard. Within formal domestic systems, tomato and onion seed exhibited better moisture control than okra seed. However, for both tomato and onion, the informal sector had the lowest proportion of samples meeting the moisture-content standard among the three systems.

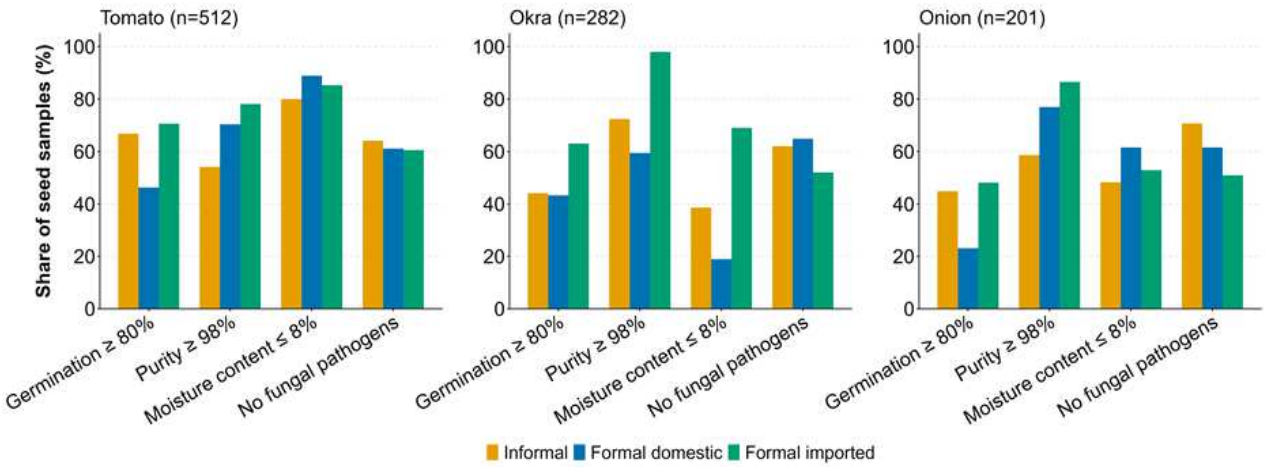


Figure 1. Share of seed samples meeting FAO seed quality standards

Regarding seed health analysis, the pathogenic fungi identified in tomato seeds during laboratory analysis belonged to the genera *Fusarium*, *Rhizoctonia*, *Curvularia*, *Alternaria*, *Botrytis*, *Macrophomina*, and *Phoma*. These pathogens are of particular concern because they can potentially cause seedling damping-off, vascular wilt, and severe necrotic lesions. In onion seeds, the fungi detected were *Fusarium*, *Rhizoctonia*, *Curvularia*, *Cladosporium*, and *Helminthosporium*, which can potentially pose significant threats due to their association with diseases such as basal rot, damping-off, and foliar blight. For okra seeds, the identified fungi were *Fusarium*, *Rhizoctonia*, *Curvularia*, *Macrophomina*, *Phoma*, and *Cladosporium*. These fungi can potentially threaten seed health and impair seedling establishment.

We found that 51% to 71% of the seed samples analyzed were pathogen-free. About 60% of tomato seed samples across seed systems were free of fungal pathogens. For okra and onion, imported seed was significantly less likely to be infected with fungal pathogens, but the differences in mean infection rates were small.

3.5 Hedonic pricing

Model with only intrinsic quality attributes

Table 5 presents the hedonic regression results for the first specification by crop, where the dependent variable is the log of seed price in USD per gram. All three models are statistically significant overall, indicating that the regressors are jointly relevant in explaining price variation. The R-squared values are 0.102 for tomato, 0.059 for okra, and 0.076 for onion, which are low as there is substantial unobserved heterogeneity in cross-sectional seed markets.

Table 5. Hedonic regression of seed prices on intrinsic seed quality attributes (USD/gram)

Predictor	Tomato (East and West Africa)		Okra (West Africa)		Onion (East Africa)	
	Coefficient	Relative change (%)	Coefficient	Relative change (%)	Coefficient	Relative change (%)
Germination (≥80%)	0.391***	46.63	0.103	10.24	-0.220	-20.88
	(0.132)		(0.102)		(0.166)	
Purity (≥98%)	0.830***	127.22	0.376***	44.34	0.582***	75.36
	(0.133)		(0.131)		(0.202)	
Moisture content (≤8%)	-0.141	-14.35	0.112	11.21	-0.275	-25.11
	(0.167)		(0.103)		(0.169)	
Fungal pathogens	-0.264**	-23.81	0.173*	18.22	-0.142	-14.42
(1=absent)	(0.130)		(0.101)		(0.164)	
Region (1=East Africa)	-0.219*	-20.31				
	(0.128)					
Constant	-1.810***		-3.055***		-2.387***	
	(0.211)		(0.125)		(0.238)	
Observations	512		282		201	
R-squared	0.102		0.059		0.076	
F-statistic	11.481***		4.375***		4.027***	

Notes: Values in parentheses are standard errors based on Ordinary Least Squares (OLS). *Significant at 10% level; ** Significant at 5%; *** Significant at 1%.

Tomato seed meeting or exceeding the FAO germination threshold (≥80%) had a 47% price premium over seed not meeting this standard. The regional dummy variables were not significant. Tomato, okra, and onion seed meeting the 98% purity threshold also had a consistently higher price. However, meeting the FAO standard for moisture content (< 8%) was not associated with higher prices for any crop.

The absence of fungal contamination affected seed prices differently across crops. For tomatoes, pathogen-free seed was associated with prices approximately 24% lower, whereas for okra, prices were about 18% higher. No statistically significant effect was observed for onion. These results suggest that market responses to fungal absence are crop-specific, with a price premium for okra seed but a price penalty for tomato seed.

Extended hedonic price estimates

Table 6 shows the results of the extended hedonic model. The inclusion of packaging and seed system significantly improved model fit, with R-squared values increasing to 0.204 for tomato, 0.181 for okra, and 0.099 for onion. The models remained globally significant at the 1% level. Multicollinearity was negligible across all models (VIFs < 2.0). Heteroskedasticity was detected only in the okra model (BP = 14.53, $p = 0.043$), and HC1 robust standard errors were therefore applied to that model. Ramsey RESET tests confirmed no evidence of functional misspecification across all models ($p > 0.10$).

Table 6. Extended hedonic regression results

Predictor	Tomato (East and West Africa)		Okra (West Africa)		Onion (East Africa)	
	Coef.	Relative change (%)	Coef.	Relative change (%)	Coef.	Relative change (%)
Germination (≥80%)	0.341*** (0.127)	39.51	0.017 (0.096) [0.098]	1.27	-0.192 (0.169)	-18.63
Purity (≥98%)	0.553*** (0.131)	72.32	0.145 (0.128) [0.127]	14.68	0.677*** (0.216)	92.25
Moisture content (≤8%)	-0.209 (0.159)	-19.85	-0.048 (0.101) [0.110]	-5.17	-0.231 (0.172)	-21.87
Fungal pathogens (1=absent)	-0.274** (0.123)	-24.57	0.161* (0.097) [0.098]	16.87	-0.087 (0.168)	-9.65
Packaging (1=yes)	0.275* (0.161)	29.98	0.303*** (0.108) [0.106]	34.58	-0.568 (0.371)	-47.10

Formal domestic	0.122	10.33	-0.166	-16.22	0.582	67.48
	(0.219)		(0.147)		(0.364)	
			[0.147]			
Formal imported	0.852***	131.48	0.455***	56.44	0.331	29.35
	(0.157)		(0.123)		(0.384)	
			[0.119]			
Region (1=East Africa)	-0.366***	-31.18				
	(0.125)					
Constant	-2.071***		-3.053***		-2.401***	
	(0.210)		(0.129)		(0.248)	
			[0.125]			
Observations	512		282		201	
R-squared	0.204		0.181		0.099	
F-statistic	16.110***		8.645***		3.020***	

Notes: Values in parentheses are standard errors based on Ordinal Least Square (OLS). Values in brackets are heteroskedasticity-consistent standard errors (HC1). *Significant at 10 % level; ** Significant at 5 % level; *** Significant at 1 % level.

For tomato seed, meeting the FAO germination threshold (≥ 80%) commanded a 40% price premium, which was lower than in the first model specification. No statistically significant premium was observed for the germination rate of okra or onion seed.

Purity remained a significant determinant of seed prices, with strong, statistically significant effects for both tomato and onion. Seed meeting the FAO-recommended purity threshold (≥ 98%) was priced approximately 72% higher for tomato and 92% higher for onion. No statistically significant purity premium was observed for okra seed.

Consistent with the first model specification, moisture content had no significant effect on prices for any crop. Thus, optimal moisture levels (≤ 8%) did not result in a measurable price premium in tomato, okra, or onion markets.

The crop-specific pattern from the first model specification persists in the extended specification for fungal contamination. For tomatoes, the absence of fungal contamination was

associated with an approximate 25% discount, whereas it was associated with a 15% premium for okra seed. No statistically significant effect was observed for onions.

Packaging significantly increased the value of tomato and okra seeds. Packaged tomato seed was priced approximately 30% higher than unpackaged seed, and packaged okra seed commanded a premium of about 35%. The effect for onion seed was not statistically significant.

Seed from formal imported channels had substantial price premiums, 131% for tomato and 56% for okra, over seed from informal channels. In contrast, seed from formal domestic suppliers did not command a statistically significant price premium over seed from informal suppliers. A substantial price gap also existed between East and West Africa. After controlling for packaging and seed systems, tomato seed in East Africa was about 31% cheaper than in West Africa.

4 Discussion

4.1 Key findings

This study explored seed quality parameters and price premiums across informal, formal domestic, and formal imported vegetable seed systems in West and East Africa. One would have expected seed quality from formal imported sources, often produced by multinational companies with strict quality assurance mechanisms and undergoing phytosanitary testing, to be much higher than that of local seed companies. One would also have expected seed quality from (domestic and foreign) formal seed sources, often subjected to seed inspection and certification, to be much higher than from informal seed sources subjected to no or minimal quality control. However, neither of these expectations was confirmed by the data. Differences in seed quality parameters across seed systems were generally small. For instance, the mean germination rate of tomato seed was 81% for imported seed, 75% for locally produced seed by

seed companies, and 80% for farmer-saved seed. Seed purity was the only seed quality aspect in which imported seed tended to outperform the other two systems. Imported seed also tended to have a lower presence of fungal pathogens, but the differences were very small. Imported seed or certified locally produced seed did not clearly outperform the informal seed system in terms of seed germination or moisture content. The findings challenge the perception often held by seed authorities and seed companies that seed quality in the informal system is inferior to that of the formal sector.

These findings are consistent with Ayenan et al. (2021), who, based on a systematic review of the seed systems literature on traditional African vegetables in Eastern Africa, reported that seed quality varies across seed systems and crops, with seed from formal systems not consistently outperforming those from informal systems. For instance, a study in Kenya showed that the germination percentages of amaranth and African nightshade seeds produced in informal seed systems were approximately twice as high as those of seeds sourced from formal systems (Croft et al., 2018). These results suggest that seed from the informal system continues to provide farmers with affordable seed of acceptable quality, particularly where the formal domestic system remains weak.

A key observation of our study is that problems with low seed quality are widespread across all seed sources. For instance, about 40% of all 995 seed samples were infected with fungal pathogens, about 40% had a germination rate below 80%, and 20% of tomato and 50% of onion seed samples had too high moisture content (>8%). Hence, these findings should not be interpreted as meaning that the informal seed system supplies seed of equally good quality as the formal seed system, but rather that all seed systems supply poor-quality seed on average. A rethink is needed of whether commonly used seed quality assurance mechanisms, which currently rely on seed certification and phytosanitary control at national borders, are the right

555 approach to ensuring seed quality in the market. Alternative approaches, such as truthfully
556 labeled seed (as used in India), may be more suitable when certification systems are ineffective.

557 We need to consider, however, that there are many different types of seed imports. Imported
558 seed includes seed from multinational vegetable seed companies like East-West Seed, Rijk
559 Zwaan, and HM Clause, as well as seed from many smaller companies in Turkey, Iran, China,
560 India, and other countries. We were not able to make a more nuanced distinction between seed
561 companies within a particular seed system, and the data confirm substantial variation in seed
562 quality within each seed system. This could be an avenue for future research.

563 The study also identified key quality factors influencing the price of tomato, okra, and onion
564 seed in African markets. The germination rate has a positive, statistically significant effect on
565 tomato seed prices. Tomato seed meeting the FAO germination threshold (≥ 80%) received a
566 significant price premium in both the baseline and extended models. These results are
567 consistent with agronomic expectations and previous research highlighting germination as a
568 primary indicator of seed performance (Nautiyal et al., 2023; Pandita et al., 2023). However,
569 the absence of statistically significant effects for germination in okra and onion suggests that
570 this aspect of seed quality is not uniformly valued across crops. This heterogeneity could be
571 explained by farmers' adaptive behavior. For crops with highly variable germination rates, such
572 as onion, farmers often compensate by over-sowing, adding seed per hole to offset expected
573 losses rather than paying a premium for higher-quality seed (McGuire & Sperling, 2016). This
574 risk management approach, widely observed in informal seed markets, reduces the willingness
575 to pay for germination quality.

576 Purity emerges as the most consistent and economically meaningful determinant of seed prices.
577 The statistically significant purity premiums observed, particularly in tomato and onion in the
578 extended model, underscore its role as a core quality attribute. These results are consistent with

agronomic predictions and previous research highlighting purity as a key predictor of seed success (Pandita et al., 2023). In contrast, purity does not significantly affect okra prices. This may reflect okra's larger seed size and direct-seeding practice, which makes physical or varietal contamination less of a perceived threat to crop establishment compared to the delicate nursery stages of tomato and onion. Additionally, okra seed from the formal imported system reached almost 100% purity compliance. This suggests that purity standards are already uniformly met across systems for this crop, leaving little room for price differentiation based on this attribute.

Optimal moisture levels (≤ 8%) did not result in a measurable price premium in tomato, okra, or onion. Therefore, seed meeting the FAO-recommended moisture content threshold (≤ 8%) does not command a measurable price premium (FAO, 2010). This suggests that moisture content, while important for seed storability, is not independently valued or verifiable by market actors at the point of sale. This finding is consistent with the seed storage literature, which identifies moisture content primarily as a prerequisite for preserving seed viability and vigor during storage rather than as a visible quality attribute that buyers can readily assess during market transactions (Bakhtavar et al., 2019). This lack of significance may also reflect the possibility that acceptable moisture content levels are already standardized across marketed seeds. Therefore, moisture content may serve as a minimum quality threshold rather than a differentiating attribute. This aligns with the broader literature on agrifood value chains, where certain quality attributes are treated as minimum thresholds for market participation but are not, by themselves, sufficient to command price premiums (Barrett et al., 2022).

The crop-specific pattern in fungal price effects observed in the baseline persists and is reinforced in the extended model. For tomato, fungal absence is associated with a price discount of 25%, while for okra, it is associated with a price discount of 17%. No significant effect was found for onion samples. One plausible explanation of the negative association between fungal

603 absence and tomato seed prices is that seed with higher fungal counts may be linked to specific
604 highly valued local varieties or traditional processing techniques that buyers prefer for other
605 reasons, such as taste and resilience, and the model may be capturing that preference rather
606 than a preference for fungus itself. This interpretation is further supported by the fact that low
607 compliance with fungal pathogen standards is consistent across all tomato seed systems, with
608 nearly 60% of samples containing pathogens regardless of the source. This suggests the market
609 has largely normalized fungal presence and does not systematically penalize it in pricing
610 models.

611 Conversely, the negative and significant price effect for okra aligns with theoretical
612 expectations, as pathogenic fungal contamination reduces perceived seed quality and expected
613 yields. The absence of significant effects for onion further reinforces the conclusion that market
614 responses to quality defects are highly crop-specific, potentially reflecting differences in
615 storage sensitivity, disease transmission risks, or farmer awareness.

616 Packaging emerges as a new and significant price determinant in the extended model. Packaged
617 tomato seed commands a premium of approximately 30%, and packaged okra seed commands
618 a premium of approximately 35%. Packaging may reduce information asymmetry by signaling
619 product authenticity, protecting seed quality during storage and handling, and providing
620 information on variety identity and quality standards, thereby increasing buyers' confidence in
621 the product (FAO, 2010; Kuhlmann et al., 2023). The statistically insignificant coefficient for
622 packaged onion seed in East Africa may indicate that packaging norms differ across regional
623 markets, or that the East African onion market operates through channels where packaging
624 conveys less information to buyers.

625 Seed from the formal imported system commands price premiums of approximately 131% for
626 tomato and 56% for okra. This result suggests that imported seed sold through the formal

627 system serves as a quality signal in African seed markets. Farmers in SSA have limited choice
628 of quality seed of vegetable cultivars adapted to local growing conditions, with only a handful
629 of vegetable seed companies investing in local breeding research, while nearly all rely on seed
630 imports (Kuhlmann et al., 2023). In this context, imported seed may be perceived as carrying
631 implicit quality assurances associated with foreign quality standards, stricter phytosanitary
632 controls, or the reputation of international seed companies.

633 Seed from the formal domestic system shows no significant price premium over that from the
634 informal seed sector. This may reflect buyers' skepticism about the quality of locally produced
635 seed. It suggests that domestic formal seed producers struggle with a "credibility gap," where
636 their products are not yet perceived as superior to those from the informal system unless they
637 are packaged or imported. In addition, seeds from the formal domestic system show no
638 premium over those from the informal system because unlicensed agrodealers may source and
639 market imported seed or locally produced, certified seed, increasing the quality of the seed they
640 sell.

641 ## 4.2 Study strengths and limitations

642 Major strengths of this study are its scale, covering nine African countries, and its integration
643 of laboratory-based seed quality assessments with market survey data. By combining objective
644 measurements of seed quality with information on market prices and seed distribution channels,
645 the study provides valuable insights into whether quality differences across seed systems are
646 reflected in market prices. To our knowledge, this is the first regional study to examine the
647 relationship between seed quality and market prices in vegetable seed markets across multiple
648 African countries.

649 Nevertheless, the study has some limitations. Seed quality is inherently multidimensional,
650 encompassing physical, physiological, genetic, and seed health attributes. While this study

assessed several key quality parameters—including germination, physical purity, moisture content, and the absence of pathogenic fungi—it did not evaluate genetic purity or other important aspects of seed health, such as bacterial, viral, or viroid infections. These attributes are recognized as important components of comprehensive seed quality evaluation (FAO & ISTA, 2023). Future research should incorporate these additional quality dimensions to provide a more comprehensive assessment of seed quality across seed systems. Furthermore, while seed quality is an important aspect of crop performance, other aspects are equally important, including genetic quality (e.g., yield potential, disease resistance) and adaptation to agroecological conditions (e.g., the ability to grow under constrained conditions). Future research could compare these aspects between seed systems.

5 Conclusion

There is a problem with low quality vegetable seed in sub-Saharan Africa, and this problem is not restricted to the informal seed sector of farmer-saved seed. Imported vegetable seed had only a slightly better quality in terms of soil moisture content and purity, but was not clearly better than locally produced seed in terms of seed germination and the presence of seed-borne fungal pathogens. Seed prices signal certain seed quality attributes in some crops: higher prices of tomato seed signal higher germination and purity and lower fungal presence, and higher onion seed prices signal higher purity but no other quality attribute. Okra seed prices were not associated with any seed quality attribute.

These findings have important implications for seed system development in sub-Saharan Africa. Governments have paid clear attention to seed quality assurance, as seed certification and phytosanitary controls at international borders are almost universally mandated across the region. Governments have also severely restricted the informal seed system of farmer- and community-based seed producers in an attempt to formalize seed production under government

675 control. Our data, however, show that these efforts have not resulted in quality vegetable seed
676 in the formal seed system, but have raised seed prices for farmers. The current approach to seed
677 quality assurance for vegetables needs to be reconsidered.

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