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# Traditional Seed Systems and Seed-Borne Pest and Pathogen Management of Okra (*Abelmoschus esculentus*) around Mount Cameroon

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## Abstract

Unavailability of high-quality seed constrains okra (*Abelmoschus esculentus* (L.) Moench) production in sub-Saharan Africa, where most farmers depend on informal, farmer-saved seed. A survey of 94 farmers across nine villages around Mount Cameroon characterised traditional seed sourcing, viability-testing, storage and disposal practices, while a parallel bioassay compared seed-health outcomes of farmer-saved versus researcher-produced seed treated with five locally available botanicals (Azadirachta indica, Capsicum annuum, Carica papaya, Lantana camara, Vernonia amygdalina), a synthetic dressing (Calthio C, positive control) and an untreated control. Most farmers (96%) sourced seed by saving part of the previous harvest (48% exclusively), tested viability by water floatation (86.2%), and stored seed in jute bags in barns (85.1%). Own-produced seed had markedly better baseline quality than farmer-saved seed (germination 60.2% vs 15.0%; moisture 11.7% vs 14.7%; 100-seed weight 4.44 g vs 5.65 g). Separate within-source analyses described treatment and storage-time effects; a seed-source-by-treatment interaction was not established. For own-produced seed, reported mean germination was 34.0% for Calthio C, 34.9% for untreated seed, 33.6% for Capsicum annuum and 31.9% for Azadirachta indica, with the lowest value for Vernonia amygdalina (21.4%). Seed-borne bacterial load differed significantly among treatments (Kruskal-Wallis H = 17.94, P = 0.003) and seed sources (H = 8.72, P = 0.003); only Calthio C fully suppressed bacterial and fungal recovery, while Azadirachta indica and Lantana camara supported the highest fungal isolation frequencies, predominantly *Fusarium oxysporum* f. sp. *melongenae*. Mean damaged-seed counts across seven treatment entries were 7.43 for farmer-

saved and 2.57 for own-produced seed (reported t = 2.75, P = 0.019). Capsicum annuum did not outperform untreated seed in the reported germination comparisons, and shared Tukey grouping does not establish equivalence to Calthio C. Seed-source differences cannot be attributed specifically to storage because species composition and production history were not controlled.

## Keywords

Okra Seed Systems, Seed-Borne Pathogens, Botanical Seed Treatment, Farmer Seed-Saving, Mount Cameroon

## 1. Introduction

Seeds are the fundamental input of any crop production system, and vulnerability in seed supply directly undermines farmers' livelihoods [1]. Non-availability of improved seed constitutes a major constraint to the cultivation and productivity of both indigenous and exotic vegetables across Africa [2], and because farmers remain the principal source of seed for vegetable production on the continent, the informal "farmer seed system"—he seed-saving, selection, exchange practices, associated knowledge and social relationships that govern how planting material moves among households—lies at the heart of any strategy for improving seed security [1]. Where farmers grow indigenous or exotic vegetables from unselected varietal stock, seed quality is typically poor, and viability deteriorates further under sub-optimal on-farm storage conditions [3].

Okra (*Abelmoschus esculentus* (L.) Moench) is among the most widely cultivated vegetables in the world, grown in at least 54 countries on nearly three million hectares [4], primarily as a warm-season annual for its immature pods, which are consumed fresh across tropical and sub-tropical regions [3]. Nutritionally, the driest and most concentrated part of the plant is the mature seed [5], yet okra seed available on local markets in producing countries is typically of variable quality, with limited farmer access to reliably high-quality stock [6]. Cameroon remains among the leading okra producers in Africa, drawing on recent FAOSTAT-based production statistics [4], with the South-West, Far North, Adamawa, Western and Centre Regions as the principal production zones; production in Cameroon, as elsewhere on the continent, remains overwhelmingly dependent on farmer-saved seed, with all the quality drawbacks this entails, and okra constitutes an important component of internal trade for smallholder households around Mount Cameroon.

Formal seed systems, structured around breeder, foundation, registered and certified seed classes and subject to regulatory oversight [7], remain poorly developed for vegetable crops such as okra in most of sub-Saharan Africa. The great majority of farmers instead rely on informal channels—farm-saved seed, seed exchange among neighbours, and local grain/seed markets—in which seed lots gradually lose genetic purity and physiological quality over successive cycles of on-

farm saving [8], and most farmers save and use seed from the previous harvest, turning to off-farm sources such as local markets, seed traders, friends or relatives only when own-saved seed is insufficient or a new variety is sought [9]. Compounding this, seed vigour and health cannot be reliably assessed from external appearance alone, leaving farmers with no simple means of distinguishing sound from compromised seed lots before planting [6]; seed-borne pests and pathogens are a major contributor to this quality erosion, with multiple fungal species—including *Fusarium* sp., *Colletotrichum* sp., *Aspergillus flavus*, *A. niger*, *Rhizopus* sp., *Mucor* sp., *Penicillium* sp. and *Curvularia* sp.—documented on farmer-saved okra seed [10], in addition to insect damage incurred during storage.

Addressing this quality erosion is essential to safeguarding smallholder livelihoods and requires interventions compatible with the realities of the existing farmer seed system, rather than measures that presuppose an immediate transition to a formal certified-seed system that few smallholders around Mount Cameroon can access. Chemical seed dressings have demonstrated efficacy against seed-borne fungi of okra, including Fusarium oxysporum and Colletotrichum dematium [11], but their cost, availability and residue concerns limit adoption by resource-poor smallholders and raise ecological and food-safety concerns associated with large-scale synthetic pesticide use [12]. Botanical alternatives—leaf, seed or fruit powders and extracts of locally available plants—offer a biodegradable, pest-specific and comparatively inexpensive route to seed protection: neem (Azadirachta indica) is the most widely documented example, with leaf, seed and oil preparations shown to protect stored grain from insect infestation [13] [14] and to inhibit seed-borne fungi and improve germination in okra at low concentrations [15], while comparable antifungal activity has been reported for aqueous plant extracts against seed-borne and soil-borne pathogenic fungi of cereal and legume crops [16] and for a wider range of botanical extracts against Fusarium wilt of brinjal [17].

Despite this evidence base, systematic on-farm evaluation of locally available botanicals—benchmarked directly against both a synthetic seed dressing and an untreated control, and tested on seed lots drawn from the actual farmer seed system—remains scarce for okra in the Mount Cameroon region, and the traditional seed storage and pre-storage handling practices that determine seed health in this area have not previously been documented. Understanding how farmers currently store their seed, what treatments they apply prior to storage and how effective these are, and whether other safe, effective and affordable alternatives exist, is a necessary first step towards designing interventions that farmers can realistically adopt.

This study therefore combined a structured survey of traditional okra seed-handling practices across nine villages around Mount Cameroon with a parallel, replicated laboratory and screen-house bioassay comparing the seed-health outcomes of farmer-saved seed against seed produced under controlled conditions and treated with five locally sourced botanicals, a synthetic positive control (Calthio

C) and an untreated negative control. By pairing the descriptive survey with a mechanistic bioassay on seed lots representative of the very system being described, the study provides both an evidence base on current farmer practice and an assessment of locally available seed treatments requiring further validation before recommendation. The overall objective of this study was to elucidate traditional seed protection practices for okra around Mount Cameroon and to identify practical, farmer-accessible alternatives for improving seed health. Specifically, it aims to:

1) Characterise the okra seed storage practices of farmers in nine villages around Mount Cameroon and their effects on seed health.

2) Evaluate, under controlled conditions, the efficacy of five locally available botanical seed treatments against seed-borne insect pests, bacteria and fungi, relative to a synthetic seed dressing and an untreated control.

## 2. Materials and Methods

### 2.1. Study Area

The study was conducted in the Mount Cameroon Region, South-West Region of Cameroon, Central Africa, an area extending from the Atlantic coast to the highest peak in West and Central Africa. Mount Cameroon is centred at 4˚13'N, 9˚10'E and covers approximately 250,000 ha under a mosaic of land uses [18]. Volcanic soils have made the region a centre of both subsistence and commercial agriculture since the late nineteenth century [19]. The climate is humid tropical, modified by altitude; annual rainfall ranges from 2085 mm to over 10,000 mm and mean annual temperature is approximately 25˚C, decreasing by about 0.6˚C per 100 m of altitudinal rise [20]. The study location is shown in **Figure 1**.

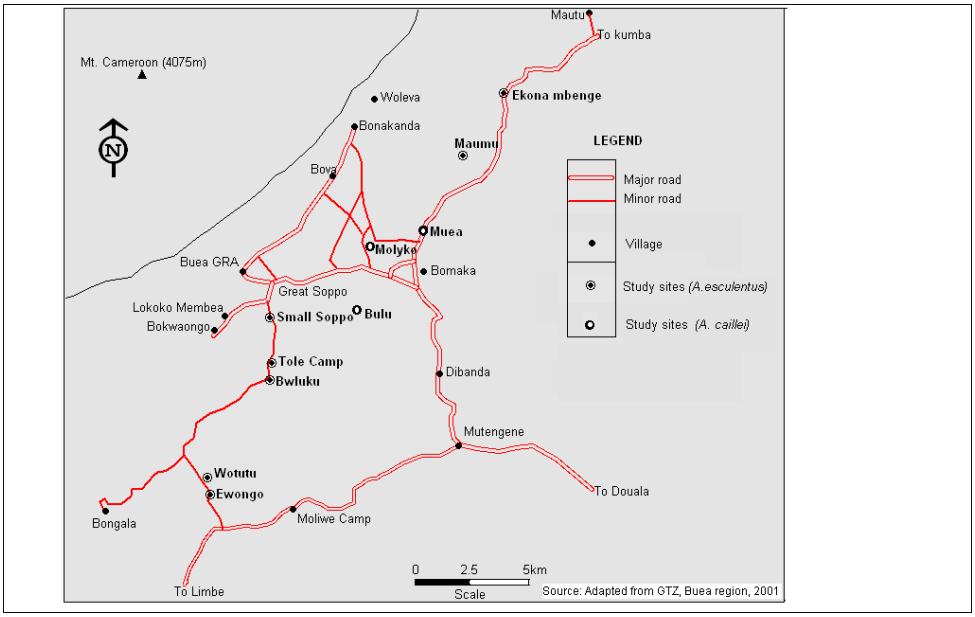



**Figure 1.** Location of the nine surveyed okra-producing villages around Mount Cameroon, Buea Sub-Division, South-West Region, Cameroon (adapted from GTZ, Buea, 2001).

The crop under study, *Abelmoschus esculentus* (L.) Moench (Malvaceae), is a robust, erect annual herb reaching 1 - 2 m in height, bearing solitary, regular flowers with superior ovaries (Figure 2(a)) and pubescent, ridged pods 10 - 30 cm long (Figure 2(b)). Mature seeds are round, greyish and 1.5 - 3 mm in diameter (Figure 2(c)) [15]. Within the study area farmers cultivate both A. esculentus and A. caillei, with A. esculentus predominating.




Figure 2. *Abelmoschus esculentus* (L.) Moench in the study area. (a) Flowering plant showing the characteristic solitary, superior-ovary flower; (b) developing pod at the harvestable immature stage; (c) mature, dried seed lot after threshing and winnowing.

## 2.2. Survey of Traditional Seed Systems

A cross-sectional survey was carried out in nine okra-producing villages around Mount Cameroon (Bulu, Ekona-Mbenge, Ewongo, Maumu, Molyko, Muea, Small Soppo, Tole and Wotutu), selected because okra is cultivated there predominantly by traditional smallholder methods. A structured questionnaire (reproduced in Appendix A) was designed to capture: type(s) of okra grown, sources of planting seed, state of seed sufficiency, economic significance of seed trade, seed preservation and viability-testing practices, treatments applied prior to storage, and the demographic profile of respondents. The instrument was pre-tested on ten farmers in Muea and Maumu villages and amended accordingly before deployment. The finalised questionnaire was administered face-to-face to 94 okra farmers across the nine villages (Table 1), each interview conducted in the local lingua franca by the lead investigator to minimise translation error. Data were analysed using descriptive statistics (frequencies, percentages) in Microsoft Excel® 2010 and MINITAB® Version 16 (Minitab Inc., State College, PA, USA). Botanical materials and culture-media compositions are presented in Table 2 and Table 3.

Table 1. Number of questionnaires administered per surveyed village (n = 94 farmers, nine villages around Mount Cameroon).

| Village | Respondents (n) | Proportion of sample |
|---|---|---|
| Bulu | 6 | 6.4% |
| Ekona-Mbenge | 7 | 7.4% |
| Ewongo | 11 | 11.7% |
| Maumu | 5 | 5.3% |
| Molyko | 10 | 10.6% |
| Muea | 5 | 5.3% |

Continued

| | | |
|---|---|---|
| Small Soppo | 14 | 14.9% |
| Tole | 6 | 6.4% |
| Wotutu | 30 | 31.9% |
| Total | 94 | 100.0% |

Nine villages were surveyed around Mount Cameroon, Buea Sub-Division, South-West Region, Cameroon.

**Table 2.** Botanical species evaluated for the treatment of okra seed, with plant part used and local source.

| Botanical species | Code | Plant part used | Local source |
|---|---|---|---|
| Azadirachta indica A. Juss. | MI | Leaves | Limbe Botanical Garden |
| Vernonia amygdalina Delile | RE | Leaves | Farmland, Buea Town |
| Lantana camara L. | MO | Leaves | Farmlands, Buea Town |
| Carica papaya L. | KA | Leaves | Buea Town |
| Capsicum annuum L. | FR | Fruits | Buea Central Market |

Calthio C (chlorpyrifos-ethyl 25% + thiram 25%, w/w) was included as a synthetic positive control (code CY); untreated seeds constituted the negative control (code LI).

**Table 3.** Composition of culture media used for seed-borne fungal (PDA) and bacterial (NA) isolation.

| Medium/component | Quantity | Notes |
|---|---|---|
| Potato dextrose agar (PDA), 1 L, pH 5.6 | | |
| Potato extract | 40 g | PDA (Sigma, USA), 1 L distilled water |
| Dextrose | 20 g | PDA (Sigma, USA), 1 L distilled water |
| Agar-agar | 18 g | PDA (Sigma, USA), 1 L distilled water |
| Nutrient agar (NA), 1 L, pH 6.8 | | |
| Gelatin peptone | 5 g | NA (Sigma, USA), 1 L distilled water |
| Beef extract | 3 g | NA (Sigma, USA), 1 L distilled water |
| Agar-agar | 15 g | NA (Sigma, USA), 1 L distilled water |

Both media were sterilised by autoclaving at 121 ˚C and 15 psi for 15 min prior to use.

## 2.3. Seed Sources for the Laboratory and Screen-House Bioassay

Two categories of seed lot were used for the treatment bioassay. Farmer-saved seed was purchased from participating farmers around Mount Cameroon. The source protocol records samples of *Abelmoschus esculentus* and *A. caillei*, bulked for testing, but does not map the species composition of each bioassay lot to individual treatments. Own-produced seed, identified in the study records as A. esculentus, was raised from part of the farmer-saved material at the University of Buea research plots. Lot identifiers and species proportions were not recorded; the two

sources therefore are not treated as species-matched lots. A 900 $m^2$ plot was cleared, raked and cleared of debris; raised beds 3.5 m long and 1 m wide were prepared, and seeds were sown at 4 - 5 seeds per hole in three staggered rows per bed at 0.8 m triangular spacing and 0.04 m depth. Mocap® 10G (10% ethoprophos) was applied at 5 $kg{\cdot}ha^{-1}$ to control crickets, seedlings were thinned at three weeks after emergence, and urea was applied at 100 $kg{\cdot}ha^{-1}$ in three split applications. Weeds were controlled manually as needed and supplementary irrigation was applied every two days. Pods were allowed to mature and turn brown on the plant, harvested, sun-dried for three days, threshed and the seeds cleaned by winnowing.

## 2.4. Evaluation of Seed Characters and Baseline Seed Quality

### 2.4.1. Moisture Content

Moisture content was determined gravimetrically on 150 seeds per seed source in three replicates of 50 seeds each, placed in 9 cm glass Petri dishes. Empty dishes were weighed ($M_1$); 50 seeds were added and the dish plus seeds weighed ($M_2$); the dishes were then oven-dried at 103˚C ± 1˚C for 18 ± 1 h, cooled in a desiccator, and re-weighed ($M_3$). Moisture content (%) was calculated as

$$100\times\frac{M_2-M_3}{M_2-M_1}.$$

### 2.4.2. 100-Seed Weight

The 100-seed weight was determined from eight replicates of 100 seeds drawn from each working sample, each replicate weighed to two decimal places on an analytical balance; the mean of the eight replicates gave the 100-seed weight, following [21] procedure.

### 2.4.3. Seed Viability (Germination Test)

Viability was assessed by the standard germination test. Three layers of filter paper were placed in single-compartment 9 cm glass Petri dishes and moistened to saturation with distilled water. Fifty seeds were placed on the moistened paper per dish, with ten assay replicates stated in the source protocol; the protocol does not establish ten independently treated storage units for each seed source × treatment × storage-time combination, and incubated at 24˚C ± 1˚C for seven days. Percentage germination was computed using the standard formula:

$$\text{germination}\left(\%\right)=100\times\frac{\text{number of seeds germinated}}{\text{total seeds tested}}.$$

## 2.5. Botanical Treatments and Application

Seed samples of both sources were treated with five locally available botanicals (Table 2) plus a synthetic positive control and an untreated negative control, giving seven treatments in total.

Fresh botanical material was washed under running tap water and air-dried under shade for three days, then ground to a fine powder and sieved through a 3 mm

nylon sieve (Capsicum annuum fruit was similarly sieved to remove lumps). Calthio C was used as supplied in powdered form. Each botanical powder was applied at 45 g·kg$^{-1}$ seed as a 45% (w/v) aqueous slurry: the slurry was placed in a tin, the appropriate quantity of seed added, and the tin agitated for five minutes to ensure uniform coating. Coated seeds were air-dried under shade for two days and stored in air-tight containers at ambient laboratory temperature. Samples were drawn from each treatment × seed-source combination at 4, 8, 12 and 16 weeks after treatment and evaluated for insect damage, viability and fungal/bacterial infection using the methods described below. The independently treated storage batch/container, rather than an individual seed or assay dish, is the relevant experimental unit for treatment effects. Monthly samples and assay dishes were not assumed to be independent storage-treatment replicates.

## 2.6. Seed Health Assessment

### 2.6.1. Seed-Borne Fungi—Blotter Method

Fifty seeds per sample were placed on moistened filter paper in 9 cm Petri dishes, spaced to avoid mutual contact, and incubated for seven days under alternating 12 h light/12h dark cycles at 20˚C ± 2˚C. Petri dishes were examined under a compound microscope for fungal growth; wet mounts of each fungal morphotype were prepared in lacto-phenol cotton blue and examined at ×10, ×40 and ×100 magnification. Fungal identity was confirmed using current taxonomic treatments based on spore shape, arrangement and mycelial septation [22] [23]. Incidence (%) of each fungal species was calculated as

$$100\times\frac{\text{number of seeds infected by that fungus}}{\text{total seeds examined}}.$$

### 2.6.2. Seed-Borne Fungi—Potato Dextrose Agar (PDA) Method

Incubation on PDA complemented the blotter test. Potato dextrose agar (8.5 g commercially compounded medium; Sigma, USA) was dissolved in 200 mL distilled water, autoclaved at 121˚C and 15 psi for 15 min, and cooled to 50˚C before dispensing 20 mL aseptically into each of ten Petri dishes and allowing to solidify for 20 min. Seeds were surface-disinfected by soaking for 1 min in 1% sodium hypochlorite and rinsed through three changes of sterile distilled water. Thirty disinfected seeds per sample were plated onto the medium with flamed forceps, dishes sealed with Parafilm®, and incubated at 20˚C ± 5˚C for four days before examination for fungal growth. Colonies were photographed and matched against current taxonomic and identification references [24]-[26]; wet mounts in lacto-phenol cotton blue were examined at ×100 for confirmatory identification of spore morphology.

### 2.6.3. Isolation and Characterisation of Seed-Borne Bacteria

Nutrient agar (28 g·L$^{-1}$; Sigma, USA) was dissolved in distilled water in a conical flask, covered with cotton wool and aluminium foil, and sterilised at 121˚C and 15 psi for 15 min [27]. After cooling to approximately 45˚C, 15 - 20 mL of medium

was dispensed per Petri dish. Seeds were surface-disinfected as above (1% sodium hypochlorite, 1 min, three rinses in sterile distilled water); five seeds were plated per dish in five replicates and incubated at 35˚C for 48 h. Bacterial isolates were characterised by colony morphology and Gram-stain reaction using the standard Gram-staining protocol: a smear was prepared, heat-fixed, flooded with crystal violet (20 s), rinsed, treated with Lugol's iodine mordant (1 min), decolourised with 70% ethanol (5 s), rinsed, counter-stained with safranin (30 s), rinsed and air-dried. A drop of immersion oil was applied and slides examined under a light microscope at ×100 (oil immersion, effectively ×1000 total magnification on the compound scope used). Isolates retaining crystal violet (purple) were scored Gram-positive; isolates taking up the safranin counter-stain (pink) were scored Gram-negative.

### 2.7. Assessment of Insect Damage and Seed Weight Loss

At each 4-weekly sampling interval, seed samples from each treatment × source combination were visually inspected for external evidence of insect feeding damage (perforations, frass). The number of visibly insect-damaged seeds per sample was recorded, and the sample was weighed before and after manual removal of damaged seed to estimate percentage weight loss attributable to insect damage, relative to the base sample weight for each seed source (farmer-saved: 226.04 g; own-produced: 177.6 g working sample weights).

### 2.8. Statistical Analysis

Survey data were summarised using descriptive statistics (frequencies and percentages). For the bioassay, the effect of treatment, storage time and their interaction on seed viability was tested separately for each seed source (own-produced and farmer-saved) using two-way analysis of variance (ANOVA), followed by Tukey's honestly significant difference (HSD) post-hoc test for mean separation at the 5% probability level; means sharing at least one common letter are not significantly different at $P < 0.05$. Bacterial colony counts, which departed from normality, were compared among treatments and between seed sources using the non-parametric Kruskal-Wallis H-test (adjusted for ties). Mean insect damage and mean weight loss of insect-damaged seed were compared between the two seed sources using independent-samples t-tests. All analyses were performed in MINITAB® Version 16 (Minitab Inc., USA) at a significance threshold of $\alpha = 0.05$. Assay dishes are measurement units.

## 3. Results

### 3.1. Socio-Demographic Profile of Okra Farmers

A total of 94 farmers across the nine surveyed villages responded to the questionnaire (Table 1); their socio-demographic profile is shown in Figure 3. Female farmers predominated (60.6% female vs 39.4% male), as shown in Figure 3(c). Age distribution was skewed towards older, more experienced growers: farmers

aged ≥ 50 years and 40 - 49 years each accounted for 30.9% of respondents, while farmers below 20 years made up only 2.1% (Figure 3(a)), and this age skew was broadly consistent across surveyed villages, with older age brackets dominant in most locations (Figure 3(d)). Educational attainment was modest: 46.8% of respondents had only primary education and 16% had received no formal education, whereas 3.2% had attained university level and 1.1% had specific agricultural-school training (Figure 3(b)), a pattern that likewise held across villages, with primary-level attainment predominating in most surveyed communities (Figure 3(e)). Most respondents were experienced growers: 38.3% had ≥ 10 years of okra-farming experience, and only 18.1% had fewer than 3 years.

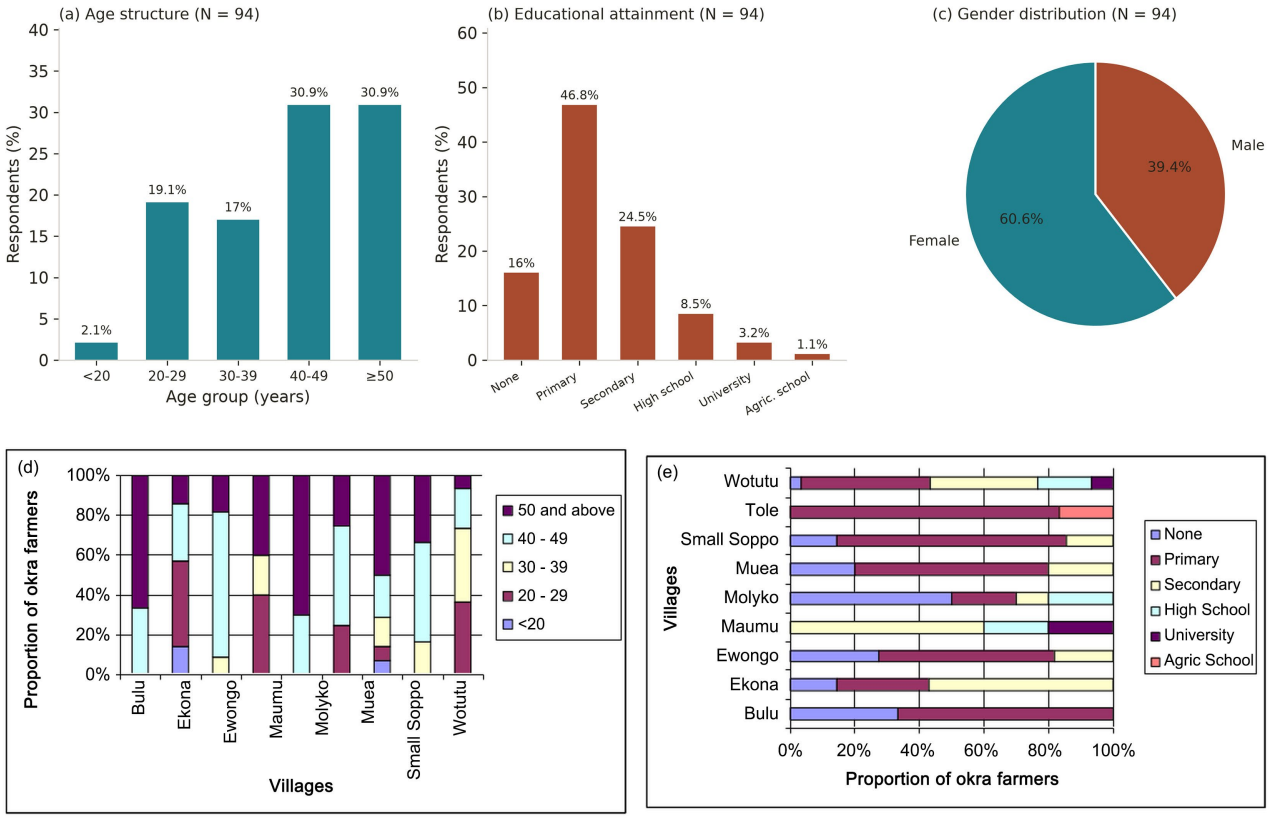



Figure 3. Socio-demographic profile of surveyed okra farmers (n = 94) around Mount Cameroon. (a) Age structure overall; (b) educational attainment overall; (c) gender distribution; (d) age-group distribution by surveyed village; (e) educational-attainment distribution by surveyed village.

## 3.2. Traditional Seed Sourcing, Viability Testing and Storage Practices

Seed sourcing was overwhelmingly farmer-saved: 48% of farmers relied solely on seed saved from the previous crop, and a further 32% combined previous-crop seed with purchases from local markets, giving a combined 96% of farmers using previous-crop seed in some combination with other sources; only 3% relied exclusively on local-market purchases and 1% on gifts from friends alone (Figure 4(a)). Before storing seed, farmers overwhelmingly used a flotation test to assess

viability (86.2%), with far fewer relying on colour change (4.3%), seed shape (2.1%) or a growing-on test (7.4%) (Figure 4(b)). Seed was predominantly stored in jute bags kept in a barn (85.1%); storage in gallons within a barn (8.5%), in airtight containers (4.3%), or in airtight containers with an added insecticide (1.1%) were all minority practices (Figure 4(c)). When storage spoilage occurred, it most often combined multiple symptoms: perforation holes plus colour change plus visible mould accounted for 31% of reported spoilage, and holes plus mould plus colour change plus rodent damage a further 25%, while single-symptom spoilage (holes only) was reported by only 8.7% of farmers (Figure 4(d)). Farmers who produced excess seed most commonly gave it away to friends (39%) or sold part while gifting the remainder (39%), with outright sale of all excess reported by 22% (Figure 4(e)). Seed use itself was dominated by consumption of the smaller share and sale of the larger share of the harvested pod/seed crop (94.6%), while total on-farm consumption (3.2%) or predominant sale with minor consumption (2.1%) were minority patterns (Figure 4(f)).

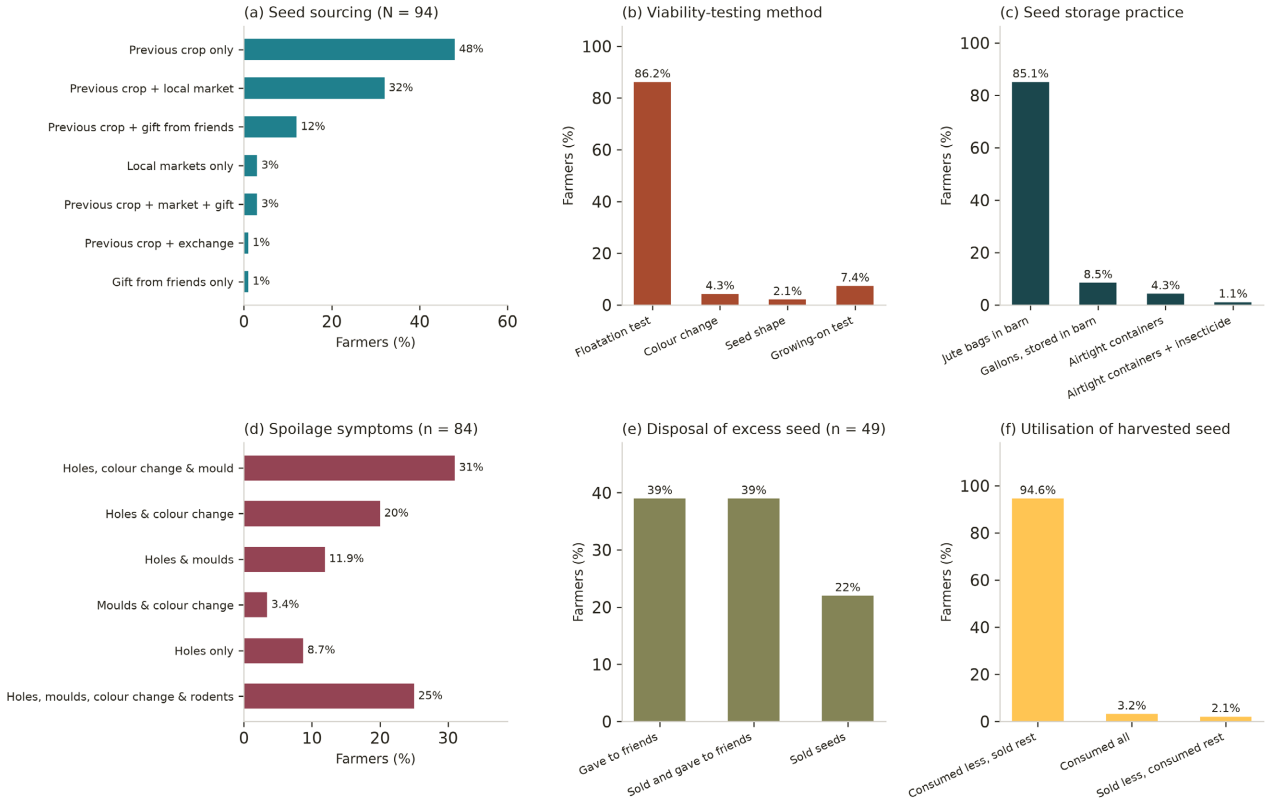



Figure 4. Traditional okra seed-management practices reported by surveyed farmers (n = 94). (a) Seed sourcing strategy; (b) pre-storage viability-testing method; (c) storage method; (d) reported symptoms of storage spoilage; (e) disposal of excess seed; (f) use of the harvested crop.

### 3.3. Seed Quality and Germination Performance of Own-Produced and Farmer-Saved Seed

Before the treatment bioassay was established, the two seed sources differed mark-

edly in baseline quality (Table 4). Farmer-saved seed had substantially higher moisture content, a higher 100-seed weight, but dramatically lower initial germination than own-produced seed. These differences are not attributed specifically to storage because the source categories were not matched for species composition or production history.

Table 4. Baseline quality attributes of farmer-saved and own-produced okra seed lots prior to treatment application.

| Seed source | Moisture content (%) | 100-seed weight (g) | Initial germination (%) before storage |
|---|---|---|---|
| Farmer-saved seeds | 14.7 | 5.65 | 15 |
| Own-produced seeds | 11.7 | 4.44 | 60.2 |

Values are means from eight (100-seed weight) or three (moisture content) replicate determinations per seed source; initial germination is the percentage of 50 seeds germinating in 10 replicate dishes prior to any treatment or storage.

For own-produced seed, two-way ANOVA showed a significant effect of treatment on germination percentage over the 16-week storage period (Table 5). Untreated seed and seed treated with the synthetic dressing Calthio C sustained the highest mean viability (34.9% and 34.0% respectively), not significantly different from Capsicum annuum (33.6%) or Azadirachta indica (31.9%) (Tukey HSD, $P > 0.05$). This lack of a significant difference neither establishes equivalence nor demonstrates improved germination over untreated seed. Vernonia amygdalina gave the lowest mean viability (21.4%), significantly lower than all other treatments except Carica papaya (25.5%) and Lantana camara (27.6%).

Table 5. Mean (±SD) germination percentage of own-produced okra seed by treatment and storage duration, with Tukey HSD mean-separation letters.

| Treatment | Week 4 | Week 8 | Week 12 | Week 16 | Overall mean |
|---|---|---|---|---|---|
| Calthio C | 35.0 ± 1.83 | 33.3 ± 3.56 | 32.0 ± 4.52 | 35.8 ± 1.72 | 34.0 a |
| Untreated | 32.7 ± 2.40 | 35.2 ± 0.70 | 32.7 ± 2.03 | 39.0 ± 1.15 | 34.9 a |
| Capsicum annuum | 29.5 ± 4.50 | 30.8 ± 1.50 | 34.2 ± 2.61 | 40.0 ± 1.98 | 33.6 a |
| Azadirachta indica | 32.7 ± 2.40 | 29.2 ± 2.30 | 33.5 ± 1.63 | 32.2 ± 1.99 | 31.9 ab |
| Lantana camara | 29.5 ± 1.82 | 27.2 ± 1.78 | 29.5 ± 2.50 | 24.2 ± 1.30 | 27.6 bc |
| Carica papaya | 31.0 ± 1.86 | 25.7 ± 2.42 | 19.5 ± 1.48 | 25.7 ± 0.95 | 25.5 cd |
| Vernonia amygdalina | 25.7 ± 1.86 | 13.3 ± 2.35 | 23.5 ± 3.08 | 23.0 ± 1.41 | 21.4 d |

Means, SD values and Tukey letters are reproduced as reported. The protocol states ten 50-seed assay replicates but does not establish independent storage-batch replication per treatment × time point. Reported overall means sharing no letter were separated by Tukey HSD ($\alpha = 0.05$; reported df = 5.42). These groupings are retained and should be interpreted subject to the replication limitation in Section 2.8.

For farmer-saved seed, viability at the outset of the storage trial was already low

(15% initial germination; Table 4) and declined further over the 16-week period across all treatments (Table 6). Calthio C sustained significantly higher mean viability (9.2%) than every botanical treatment and the untreated control (Tukey HSD, $P < 0.05$), none of which differed significantly from one another (4.0% - 6.2%). Germination trajectories for both seed sources are shown in Figure 5.

Table 6. Mean (±SD) germination percentage of farmer-saved okra seed by treatment and storage duration, with Tukey HSD mean-separation letters.

| Treatment | Week 4 | Week 8 | Week 12 | Week 16 | Overall mean |
|---|---|---|---|---|---|
| Calthio C | 14.3 ± 1.69 | 9.0 ± 2.48 | 9.5 ± 0.76 | 4.2 ± 0.98 | 9.2 a |
| Capsicum annuum | 9.5 ± 1.52 | 5.7 ± 1.33 | 3.7 ± 0.80 | 4.2 ± 0.98 | 5.8 b |
| Lantana camara | 5.0 ± 1.24 | 6.7 ± 1.50 | 5.5 ± 0.05 | 5.2 ± 1.01 | 5.6 b |
| Untreated | 7.2 ± 1.58 | 10.5 ± 1.93 | 5.2 ± 0.65 | 1.8 ± 1.64 | 6.2 b |
| Azadirachta indica | 7.3 ± 0.92 | 2.3 ± 0.62 | 5.3 ± 0.88 | 1.8 ± 1.64 | 5.3 b |
| Carica papaya | 6.0 ± 1.03 | 6.2 ± 1.54 | 3.2 ± 0.31 | 4.3 ± 0.96 | 4.9 b |
| Vernonia amygdalina | 8.0 ± 0.82 | 3.7 ± 0.67 | 0.7 ± 0.21 | 3.5 ± 0.62 | 4.0 b |

Means, SD values and Tukey letters are reproduced as reported. The protocol states ten 50-seed.Reported overall means sharing no letter were separated by Tukey HSD ($\alpha = 0.05$; reported df = 5.42). These groupings should be interpreted subject to the replication limitation in Section 2.8.

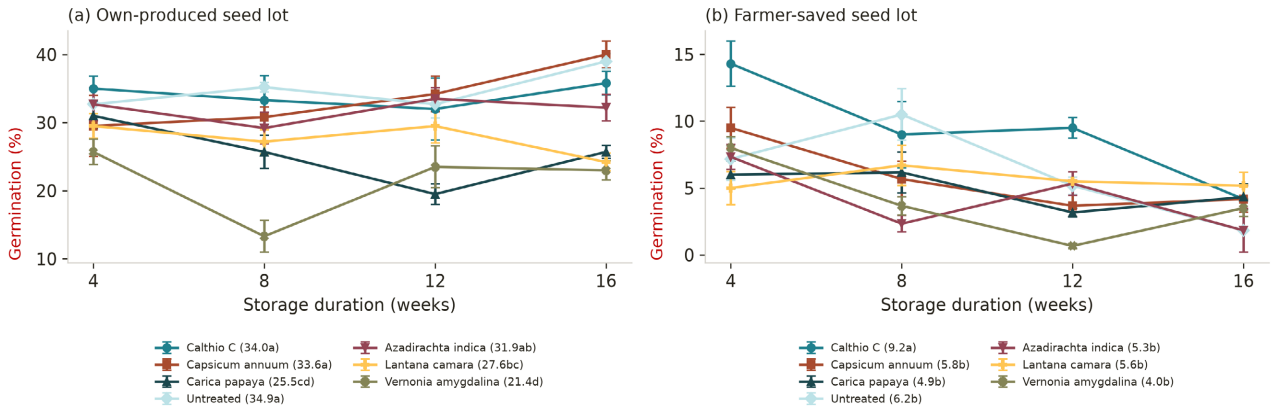



Figure 5. Mean germination percentage of (a) own-produced and (b) farmer-saved okra seed over 16 weeks of storage, by seed treatment. Error bars show the reported SD; Values are percentages, see Section 2.8 for the replication limitation.

### 3.4. Effect of Seed Treatments on Seed-Borne Bacteria

Gram-positive rods, Gram-positive cocci, and mixed rod–coccus populations were recovered from both seed sources at varying incidence depending on treatment (Table 7). Calthio C-treated seed yielded no bacterial growth from either seed source, confirming its antibacterial as well as antifungal action. Untreated (control) and Capsicum annuum-treated farmer-saved seed showed the highest incidence of Gram-positive rods (100% of plated seed each). A Kruskal-Wallis test on bacterial colony counts showed a significant effect of treatment (Table 8; H =

17.94, df = 5, P = 0.003) and of seed source (Table 9; H = 8.72, df = 1, P = 0.003), with own-produced seed carrying a significantly higher median bacterial colony count (median = 2) than farmer-saved seed (median = 1). All recovered isolates were Gram-positive; representative morphotypes are shown in Figure 6.

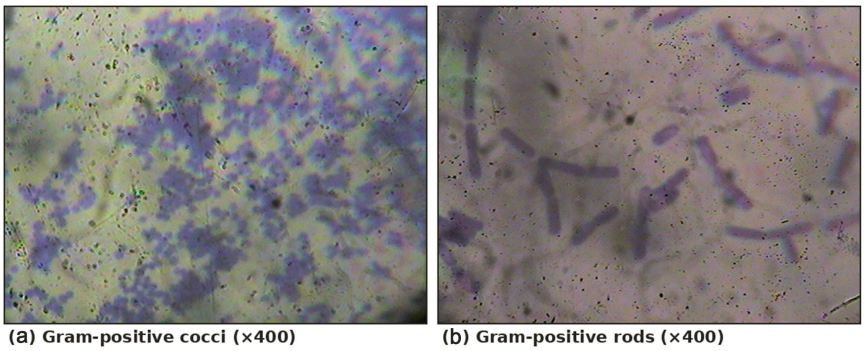



Figure 6. Representative Gram-stained seed-borne bacterial isolates (×400, oil immersion). (a) Gram-positive cocci in clusters; (b) Gram-positive rods.

Table 7. Incidence (%) of Gram-positive bacterial morphotypes recovered from own-produced and farmer-saved okra seed, by treatment.

| Treatment | Rods (own) | Cocci (own) | Rods + Cocci (own) | Rods (farmer) | Cocci (farmer) | Rods + Cocci (farmer) |
|---|---|---|---|---|---|---|
| Calthio C (+control) | 0% | 0% | 0% | 0% | 0% | 0% |
| Capsicum annuum | 100% | 0% | 0% | 100% | 0% | 0% |
| Carica papaya | 0% | 0% | 100% | 80% | 20% | 0% |
| Azadirachta indica | 0% | 0% | 100% | 80% | 0% | 20% |
| Lantana camara | 0% | 0% | 100% | 0% | 60% | 40% |
| Vernonia amygdalina | 0% | 100% | 0% | 60% | 0% | 40% |
| Untreated (−control) | 80% | 0% | 20% | 100% | 0% | 0% |

Incidence (%) = proportion of plated seed (n = 5 seeds × 5 replicate dishes) yielding the stated morphotype on nutrient agar after 48 h at 35˚C.

Table 8. Kruskal-Wallis test of bacterial colony counts by seed treatment.

| Treatment | N | Median | Average rank | Z |
|---|---|---|---|---|
| Capsicum annuum | 10 | 1 | 20 | −2.08 |
| Carica papaya | 10 | 1.5 | 35 | 0.89 |
| Azadirachta indica | 10 | 2 | 38 | 1.49 |
| Lantana camara | 10 | 2 | 41 | 2.08 |
| Vernonia amygdalina | 10 | 1 | 26 | −0.89 |
| Untreated | 10 | 1 | 23 | −1.49 |
| Overall | 60 | — | 30.5 | — |

H = 17.94, df = 5, P = 0.003 (adjusted for ties).

Table 9. Kruskal-Wallis test of bacterial colony counts by seed source.

| Seed source | N | Median | Average rank | Z |
|---|---|---|---|---|
| Farmer-saved seeds | 30 | 1 | 25 | −2.44 |
| Own-produced seeds | 30 | 2 | 36 | 2.44 |
| Overall | 60 | — | 30.5 | — |

H = 8.72, df = 1, P = 0.003 (adjusted for ties).

### 3.5. Insect Damage and Seed Weight Loss by Treatment and Seed Source

Visible insect feeding damage and associated seed-weight loss were recorded for both seed sources across all treatments over the 16-week storage period (Table 10). An independent-samples t-test (Table 11) showed that farmer-saved seed sustained significantly greater insect damage than own-produced seed (mean 7.43 vs 2.57 damaged seeds across seven treatment entries; t = 2.75, df = 11, P = 0.019). The weight-loss analysis reported no significant source difference (mean 0.18% vs 0.12%; t = 1.41, df = 6, P = 0.207).

Table 10. Insect-damaged seed count and estimated weight loss (relative to base sample weight) by treatment and seed source.

| Treatment | Farmer-saved: damaged (n) | Farmer-saved: weight loss | Farmer-saved: % loss | Own-produced: damaged (n) | Own-produced: weight loss | Own-produced: % loss |
|---|---|---|---|---|---|---|
| Azadirachta indica | 9 | 0.2 g | 0.09% | 2 | 0.1 g | 0.06% |
| Vernonia amygdalina | 3 | 0.1 g | 0.04% | 1 | 0.1 g | 0.06% |
| Lantana camara | 13 | 0.4 g | 0.18% | 0 | 0.0 g | 0.00% |
| Carica papaya | 4 | 0.1 g | 0.04% | 3 | 0.1 g | 0.06% |
| Capsicum annuum | 7 | 0.2 g | 0.09% | 4 | 0.1 g | 0.06% |
| Calthio C (+control) | 5 | 0.2 g | 0.09% | 0 | 0.0 g | 0.00% |
| Untreated (−control) | 11 | 0.3 g | 0.13% | 8 | 0.2 g | 0.11% |

Base sample weights: farmer-saved seed = 226.04 g; own-produced seed = 177.6 g.

$$\text{Percentage loss} = 100 \times \frac{\text{weight of insect} - \text{damaged seed removed}}{\text{base sample weight}}.$$

Table 11. Independent-samples t-test comparing insect damage and weight loss between farmer-saved and own-produced okra seed.

| Variable | Seed source | N | Mean | SE | t | df | P |
|---|---|---|---|---|---|---|---|
| Insect-damaged seeds (n per treatment entry) | Farmer-saved | 7 | 7.43 | 1.4 | 2.75 | 11 | P = 0.019 |
| | Own-produced | 7 | 2.57 | 1.1 | | | |
| Weight loss (%) | Farmer-saved | 5 | 0.18 | 0.037 | 1.41 | 6 | P = 0.207 |
| | Own-produced | 5 | 0.12 | 0.02 | | | |

For damaged-seed counts, N = 7 denotes treatment entries, not independently replicated seed-source lots. The weight-loss rows retain the original N = 5 summary and test statistics. See Section 2.8 for the limitation on independence.

### 3.6. Seed-Borne Fungi

Four fungal genera/species were recovered across treatments by the blotter and PDA methods: Fusarium oxysporum, Aspergillus flavus, Aspergillus fumigatus, Mucor sp., and Rhizopus stolonifer, frequently in mixed co-infections on a single seed (Table 12). Calthio C-treated seed showed complete absence of fungal recovery (0/0 isolations), confirming its efficacy as a fungicidal seed dressing. Among the botanicals, Azadirachta indica-treated seed carried the highest total fungal incidence (89 isolations), dominated by Fusarium oxysporum alone or in mixed infection with Aspergillus fumigatus and/or Mucor sp.; Vernonia amygdalina- and Capsicum annuum-treated seed carried the lowest total incidence among the botanicals (37 isolations each). The untreated control showed a broad spread across all recovered taxa, including the only isolations of Rhizopus stolonifer combined with other genera and the highest incidence of Aspergillus flavus (16 isolations) and Aspergillus fumigatus (5 isolations) recorded for any treatment. Representative fungal colonies and sporulation structures are shown in Figure 7.

Table 12. Incidence (number of isolations) of seed-borne fungal taxa recovered from okra seed by treatment, blotter and PDA methods combined.

| Fungal category | Calthio C (+control) | Capsicum annuum | Carica papaya | Azadirachta indica | Lantana camara | Vernonia amygdalina | Untreated (−control) |
|---|---|---|---|---|---|---|---|
| FO | 0 | 10 | 2 | 25 | 32 | 22 | 6 |
| Afl | 0 | 6 | 4 | 1 | 6 | 0 | 16 |
| AF | 0 | 1 | 0 | 0 | 2 | 0 | 5 |
| Mu | 0 | 7 | 24 | 2 | 0 | 4 | 10 |
| FO + Afl | 0 | 3 | 2 | 29 | 10 | 0 | 4 |
| FO + AF | 0 | 0 | 1 | 8 | 4 | 0 | 9 |
| FO + Mu | 0 | 1 | 9 | 14 | 1 | 9 | 3 |
| Afl + AF | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Afl + Mu | 0 | 1 | 0 | 0 | 1 | 0 | 4 |
| AF + Mu | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Afl + FO + Mu | 0 | 0 | 3 | 1 | 0 | 0 | 0 |
| AF + FO + Mu | 0 | 0 | 0 | 2 | 0 | 0 | 1 |
| Afl + AF + FO | 0 | 2 | 2 | 7 | 0 | 0 | 0 |
| RS | 0 | 6 | 2 | 0 | 0 | 2 | 3 |
| Total | 0 | 37 | 50 | 89 | 56 | 37 | 64 |

FO = Fusarium oxysporum; Afl = Aspergillus flavus; AF = Aspergillus fumigatus; Mu = Mucor sp.; RS = Rhizopus stolonifer. Compound category labels denote seeds from which two or three taxa were co-isolated. Values are counts of isolations from 30 seeds per treatment × seed-source combination (blotter method) plus 30 seeds per treatment × seed-source combination (PDA method), pooled across the two seed sources and four storage-time points.

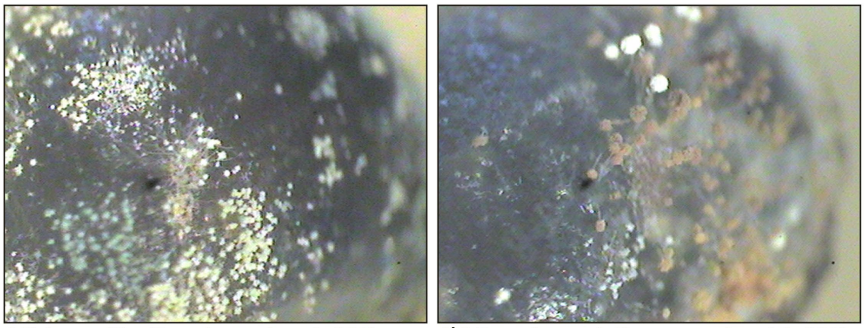



Figure 7. Representative seed-borne fungal colonies and sporulation structures (×100). (a) Aspergillus/Fusarium colony growth on potato dextrose agar; (b) fungal sporulation on the seed coat surface (blotter method).

### 3.7. Nutritional Composition of Okra Plant Parts

For context, the nutritional composition of the fresh fruit, edible leaf and mature seed of okra, compiled from the food-composition literature reviewed for this study, is summarised in Table 13. The mature seed is markedly richer in protein (20.23%) and fat (20%) than the fresh fruit or leaf, underscoring the seed's dual importance as both planting material and a potential food/feed resource, and reinforcing the economic significance to farmers of protecting seed quality during storage.

Table 13. Nutritional composition of fresh fruit, edible leaf and mature seed of okra (*Abelmoschus esculentus*), compiled from the food-composition literature.

| Component | Fresh fruit | Edible leaf | Mature seed |
|---|---|---|---|
| Protein | 2.1 g | 4.4 g | 20.23% |
| Fat | 0.2 g | — | 20% |
| Carbohydrate | 8 g | 11 g | 6-9% |
| Energy (per 100 g) | 36 kcal | 56 kcal | — |
| Water (per 100 g edible portion) | 88 mL | 81 g | — |
| Vitamins | A, C, E, K | A, C | C, B6 |
| Minerals | Ca, Fe, Zn, Cu, P, Mn | Ca, Fe | Cu, Fe, Mn, Zn |

Compiled from [28]-[30]—all cited here for the original food-composition determinations as reported in the source thesis; these primary nutrient-composition values are reproduced as originally documented rather than re-attributed to unrelated, more recent literature.

## 4. Discussion

### 4.1. Farmer Characteristics, Production Practices and the Seed System

Okra production around Mount Cameroon was found to be an important economic activity, with women constituting the majority (60.6%) of producers, consistent with earlier reports that vegetable production is predominantly a female

economic venture in this region [3]. In several villages (Bulu Camp, Ewongo, Molyko and Tole), okra was grown mainly for home consumption by a small number of older farmers, functioning as a food-security crop rather than a commercial enterprise, and young people were largely absent from production in these locations. Planting was concentrated in the late rains as an escape strategy from pest and disease pressure, with harvest timed to the dry season when scarcity raises farm-gate prices—a strategy that maximises household income from a low-input crop.

None of the 94 farmers interviewed considered specialised okra seed production a viable commercial venture, citing the absence of dedicated seed buyers and markets. This finding is consistent with [31], who reported the same disincentive among vegetable farmers in Buea and its environs, though the balance between own-seed-saving and market purchase reported elsewhere in the literature varies with local market access and organisation rather than reflecting a fundamental difference in farmer attitudes to seed enterprise [1]. Because okra production in the study area was carried out predominantly by farmers with only primary education (46.8% of respondents) or no formal education (16.0%), this is likely to explain in part the limited technical knowledge of proper seed storage and spoilage management observed during the survey.

No dedicated okra seed growers operated in the study area; the entire informal seed supply for the crop was therefore drawn from farmer-saved seed exchanged through personal networks, local markets, or gifts and exchange among neighbours. The finding that 48% of farmers obtained seed from their own previous crop, supplemented by other informal sources when this was insufficient, is in line with the broader literature on farmer seed systems in sub-Saharan Africa, which consistently documents own-seed-saving supplemented by informal exchange, gifting and local-market purchase as the dominant model for smallholder vegetable and legume crops [1], and is further corroborated by [32], who documented seed-saving from the previous crop as the dominant practice for vegetable and legume seed under small-scale production systems in East, Central and Southern Africa.

### 4.2. Storage, Treatment and Quality Outcomes

Farmers demonstrated some awareness of seed quality, evidenced by the widespread (86.2%) use of the floatation method, together with colour-change and growing-on tests, to screen for non-viable seed prior to planting. However, the near-universal reliance on jute bags stored in bans (traditional above-fireplace storage racks; 85.1% of respondents) exposed seed lots to conditions that promote both insect infestation and fungal proliferation. Farmers were generally unaware that intact dry pods can harbour adult and nymphal insect stages that continue to damage seed in storage, and that heat from the fire beneath the ban is insufficient to reduce seed moisture content to safe levels; seed at elevated moisture content in turn provides a favourable substrate for fungal colonisation. Only a single farmer (1.1% of respondents) reported any pre-storage pesticide treatment, and no farmer reported awareness of botanical seed-protectant options, despite the ready local availability of several of the plant materials evaluated in this study.

The poor physiological and health status of farmer-saved seed relative to seed produced under controlled conditions reflects a broader pattern in which the production, processing and marketing of vegetable seed in the informal sector is left to resource-poor, technically unskilled farmers [1]. Storage of unthreshed pods, in particular, generated a high proportion of inert material in farmer seed lots, a finding that parallels the continuing observation that informal seed-sector practices for indigenous and exotic vegetables across Africa remain heavily weighted toward low-input, low-technology handling [3].

The two seed sources differed markedly and significantly (paired t-test, $P = 0.000$) in all three baseline quality attributes measured. Farmer-saved seed carried a higher mean moisture content (14.7%) than own-produced seed (11.7%); comparably elevated moisture readings in farmer-handled seed of orphan and traditional vegetable crops have been associated with limited farmer access to reliably high-quality seed stock [6]. Although the internationally recommended moisture threshold for safe okra seed storage is below 10% [33], own-produced seed, while still above this threshold, was appreciably closer to the recommended value than farmer-saved seed, although the source comparison cannot isolate an effect of storage. The higher 100-seed weight recorded for farmer-saved seed (5.65 g versus 4.44 g for own-produced seed) may reflect moisture content, species composition or other source differences; because no authoritative reference standard for 100-seed weight in okra has yet been established, this parameter could not be benchmarked externally.

The initial germination percentage recorded for own-produced seed (60.2%) approached the internationally recommended minimum for commercial okra seed of ≥65% [33], whereas farmer-saved seed germinated at only 15%, far below this benchmark. This inverse relationship between seed moisture content and germination capacity is consistent with the physiological deterioration documented for other crop seeds under elevated moisture and repeated ageing [34], and directly corroborates the qualitative accounts volunteered by several respondents during the survey—for example, one farmer's description of an ad hoc, trial-and-error approach to distinguishing viable from non-viable seed lots ("we just throw the seeds, those that germinate fine, those that do not we repeat the process")—which independently confirms the low and inconsistent viability of farmer-saved seed documented quantitatively in this study.

### 4.3. Efficacy of Botanical Seed Treatments on Viability

The reported own-produced seed results do not demonstrate improved germination over untreated seed for Capsicum annuum or the other botanicals. Capsicum annuum (33.6%) shared a Tukey group with Calthio C (34.0%) and untreated seed (34.9%), but this is not an equivalence test. Antifungal activity reported in other crops [17] does not establish a germination benefit in the present bioassay. By contrast, Vernonia amygdalina treatment was associated with a decline in seed germination relative to the untreated control; this result is consistent with the al-

lelopathic inhibition of germination documented for foliage extracts of other plant families [35], suggesting that Vernonia amygdalina leaf material may carry phytotoxic secondary compounds that offset any antimicrobial benefit at the concentration applied in this study.

Treatment responses should be interpreted separately within each seed source. The lower initial germination of farmer-saved seed limits comparisons with own-produced seed, and species and production-history differences remain potential confounders. No botanical outperformed untreated seed in the reported germination comparisons. The results therefore identify candidates for further testing rather than establish a preventive or curative viability benefit.

### 4.4. Efficacy of Botanical Treatments against Seed-Borne Bacteria and Fungi

All isolated seed-borne bacteria were Gram-positive, comprising short rods, cocci, or a mixed rod-cocci morphology, a profile consistent with that reported by [31] for commercial vegetable seed sampled in Buea and its environs. Because Gram-positive bacterial morphotypes of this kind are not typically associated with aggressive seed-borne phytopathogenicity, their presence probably had limited direct effect on seed viability outcomes in this study, and their significant association with Azadirachta indica and Lantana camara treatment (Kruskal-Wallis, $P = 0.003$) most likely reflects differential surface microbial loads on the botanical plant material itself rather than a treatment-induced susceptibility of the seed.

The fungal results provide the clearest evidence in this study for the practical utility of botanical seed treatment. Complete absence of fungal recovery from Calthio C-treated seed of both sources confirmed the expected fungicidal efficacy of this synthetic seed dressing and validated it as an appropriate positive control against which the botanicals could be benchmarked. Four botanicals had lower recorded fungal-isolation totals than the untreated control (64): Capsicum annuum and Vernonia amygdalina, 37 each; Carica papaya, 50; and Lantana camara, 56. Azadirachta indica had a higher total (89), so a reduction cannot be claimed for every botanical. These descriptive counts show that antifungal activity reported elsewhere [16] [17] was not reproduced uniformly here. The fungal taxa recovered in this study—Fusarium oxysporum, Aspergillus flavus, Aspergillus fumigatus, Mucor sp. and Rhizopus stolonifer—correspond closely to taxa recognised as dominant agents of storage loss in cereal and legume seed by current taxonomic reviews [24], reinforcing the generality of these fungal genera as seed-storage risks across cereal, legume and vegetable seed alike. Azadirachta indica-treated seed nonetheless carried the highest total fungal incidence among the botanicals (89 isolations, dominated by Fusarium oxysporum alone or in mixed infection); this result does not support fungal suppression by neem under the tested conditions. Its reported insect-protectant activity elsewhere [13] [14] does not establish the mechanism behind the present germination results. Vernonia amygdalina and Capsicum annuum, by contrast, produced the lowest total fungal inci-

dence among the botanicals (37 isolations each), identifying these two materials as the more effective fungistatic options within the panel tested, notwithstanding the germination-suppressing effect noted for Vernonia amygdalina above.

### 4.5. Efficacy of Botanical Treatments against Insect Damage

Insect damage was significantly greater in farmer-saved seed than in own-produced seed (independent-samples t-test, mean 7.43 versus 2.57 damaged seeds across seven treatment entries; $t = 2.75$, $df = 11$, $P = 0.019$), while the associated percentage weight loss did not differ significantly between the two sources ($t = 1.41$, $df = 6$, $P = 0.207$). This pattern indicates that farmer-saved seed sustained a higher frequency of insect attack, consistent with prior infestation carried over from the poor on-farm storage conditions already noted, but that the proportional weight consequence of this damage, once expressed as a fraction of the (larger) farmer-saved sample base weight, was comparable in magnitude to that recorded for own-produced seed. Among the botanicals, Azadirachta indica, Vernonia amygdalina and Lantana camara were the most effective at limiting insect damage in own-produced seed, a result that corroborates the field efficacy against insect-vector populations recently reported for neem and other leaf-extract biopesticides applied directly to okra in West Africa [36], and is consistent with the broader recognition of botanical extracts as an eco-friendly alternative to synthetic insecticides for stored-product and field protection [37] [38]. In farmer-saved seed, by contrast, Lantana camara did not achieve the same level of insect-damage suppression, and even Calthio C-treated farmer-saved seed continued to sustain insect damage; these observations may reflect baseline infestation or other seed-source differences, but cannot be attributed specifically to storage history in the absence of species-matched, independently replicated lots.

### 4.6. Synthesis

Taken together, the survey and bioassay results converge on a consistent picture: the traditional okra seed system around Mount Cameroon operates entirely through informal, farmer-managed channels characterised by limited technical knowledge of seed-quality management, while farmer-saved and own-produced seed differed in measured quality; the comparison does not isolate the effects of storage practices. The bioassay recorded lower fungal-isolation totals for four botanicals, but not neem, relative to untreated seed. It did not establish a botanical germination advantage over untreated seed or equivalence to Calthio C. Further independently replicated testing is needed before botanical seed treatments can be recommended on that basis.

## 5. Conclusions and Practical Implications

### 5.1. Conclusions

This study characterised the traditional okra seed system operated by farmers in nine villages around Mount Cameroon and evaluated, under controlled condi-

tions, the efficacy of five locally available botanicals against seed-borne insect pests, bacteria and fungi, benchmarked against a synthetic seed dressing (Calthio C) and an untreated control. Farmers in the study area were found not to be dedicated seed growers: okra was cultivated primarily as a food-security vegetable crop, and farmers retained only the quantity of seed required for the subsequent planting season, obtained overwhelmingly (96%) from their own previous crop supplemented by informal exchange, gifting and local-market sources. Except for a single respondent who applied a pesticide, farmers did not treat seed prior to storage, and none reported awareness of botanical seed-protectant alternatives.

Farmer-saved okra seed was of markedly poorer health status than seed produced and handled under controlled (own-produced) conditions, as measured jointly by moisture content, 100-seed weight and initial germination percentage (paired t-test, $P = 0.000$). The surveyed storage practices may contribute to deterioration, but the bioassay comparison cannot separate storage effects from species composition, initial quality or production history.

Botanical responses differed by endpoint. Capsicum annuum did not outperform untreated seed in the reported germination comparisons, and shared Tukey grouping with Calthio C for own-produced seed does not establish equivalence. Fungal-isolation totals were lower than the untreated total for four botanicals, whereas neem had a higher total. These findings support further evaluation of locally available treatments, not an overall efficacy ranking or a validated replacement for synthetic seed dressings.

### 5.2. Practical Implications

The survey supports attention to seed selection, cleaning, drying and storage in extension activities. However, the present source comparison does not isolate the contribution of individual storage practices. Capsicum annuum and the other botanicals should undergo independently replicated testing with species-matched lots, clearly defined storage units and untreated controls before routine recommendation. The reported results do not establish a botanical viability benefit over untreated seed or an immediately validated replacement for Calthio C.

## Acknowledgements

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## Author Contributions

Frederick Tilili Moleye: Conceptualization, Methodology, Investigation, Formal

analysis, Data curation, Writing—original draft.

## Data Availability Statement

The survey and bioassay data supporting the findings of this study are available from the corresponding author upon reasonable request.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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