

## Article

# Effects of Production and Distribution Factors on Improved Seed Systems in Nigeria: Implications for Scaling Climate Resilient Production and Food Systems

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**Abstract:** This study examines the effects of production and distribution factors on improved seed systems in Nigeria and their implications for scaling climate resilient production and food systems, because production and distribution factors of improved seed and planting materials are major determinants of food and livelihood security. In this study, the interactions among these factors were examined using secondary data from the National Seed Council of Nigeria over 12 years. The variables covered are the number of seed companies, agro-dealers, quantity of foundation, certified breeder, and price of hybrid and open-pollinated seeds of maize, rice, sorghum, millet, wheat, cowpea, soybean, and groundnut. Principal component analysis extracted six components underlying seed production and distribution as Factor 1 (non-hybrid), Factor 2 (certification), Factor 3 (foundation), Factor 4 (prices), and Factor 5 (distribution), which accounted for a cumulative 89.51% variance. The correlation matrix shows that the quantity of certified open-pollinated maize seed is the most highly correlated variable, followed by certified lowland rice seed varieties, price of open-pollinated maize seed, and price of rice seeds. The findings on the production and distribution factors for improved seed imply that farmers will have low adaptive capacity in the use of climate resilient production and food systems.

**Keywords:** climate resilience; seeds; food security; distribution; availability



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## 1. Introduction

Agriculture in many African countries has been marked by prevailing scenarios of decreasing availability of food, land, water, and energy resources, as well as changes associated with climatic factors, dietary patterns, and technologies (Stringer et al., 2021). Miller et al. (2023) stated that the food production revolution in Africa can be achieved through seed security, which translates to food security by overcoming unstable seed supply, changing climate, and increasing threats of disease and pests, by enhancing farming households' access to adequate quantities of quality seeds and plant materials of adapted varieties at all times. A major response to these scenarios is the intervention to increase access to better quality inputs to close the yield gap between farmers' fields and the actual potential of planting materials (Fraser et al., 2016). Agricultural transformation has always hinged on the use of high-yielding varieties (HYV) and, more recently, climate-resilient planting materials; however low adoption has been reported (Martey et al., 2020; Vercillo et al., 2020).

Food security, nutrition, livelihoods, and environmental sustainability are ensured by the functional seed sector as the most crucial production input (Duncan, et al., 2021) The promotion of increased productivity, food and nutrition security, and resilience among smallholder farmers is dependent on the availability and access to improved seeds (Ruane et al., 2022). The favourableness of soil, climatic, biotic, and abiotic factors would amount to no effects if the quality of seeds and planting materials is low through poor access to improved seeds, fake and recycled seeds leading to low yields (Breen et al., 2024). Good quality seeds are essential for profitable farming in the food production systems, and the challenge of improved seed supply must be tackled to ensure availability, accessibility, affordability, and sustainability for smallholders (Ojiewo et al., 2020; Sperling et al., 2021). The lack of effective improved seeds and planting materials system has led to limited agricultural productivity (Martey et al., 2020), prevented structural transformation (Miller et al., 2023), stagnated yields, neglect of vegetative reproduced crops by the private

sector, complex seed multiplication and distribution requirements and low perceived commercial value (Tadesse et al., 2017). A responsive seed system enhances the diversification of production systems to cope with climate change, reduces the use of pesticides and fertilizers through complementarities, improves resilience with ecosystem services, and enhances income (Joshi et al., 2019). Seed, as the cornerstone of food security, contributes to food systems but is contingent on the seed system that influences the production and distribution (Breen et al., 2024). The improved seeds are produced through a dedicated production channel, with a specific package of practices, with desirable characteristics to local cultivars that give higher yields, are resistant to pest attacks, and require less water supply. Access to seeds and information on improved seeds leads to an increase in yields, production costs, net returns per hectare, and a reduction in poverty incidence (Manda et al., 2025).

The importance of an improved seed system can be attributed to the focus of development and humanitarian practitioners (Martey et al., 2020), increasing yields, yield stability, food security, profitability, and reducing poverty in smallholder farming by exponentially translating seed into food. The process of improved seed production consists of the selection of breeding lines, Identification of promising genotypes, Development of new strains, and evaluation of their performance, through value in cultivation and use to develop distinctness, uniformity, and stability characteristics, seed production, variety maintenance/maintenance breeding, seed quality (genetic purity, physical and physiological quality; Sendekie, 2020; Sundareswaran et al., 2023); Seed health, Seed Quality Assurance through regulation, maintenance, upgradation and enhancement, Genetic improvement, registration for multiplication, field inspection, seed sampling, testing and seed Certification (Kimani, 2025; Gatto et al., 2025). Muthamilarasan and Prasad (2021) noted that all areas of seed improvement require extensive coordination, ranging from genetic diversity, breeding, seed production, seed germinability and vigor, seed marketing, and delivery to the application of sound approaches by the farmers. Vegetative propagation enhances farmers' use of recycled planting materials, but enforcement of property rights is difficult and consequently low returns on investment in improved planting materials through quality control and certification (Wossen et al., 2024). According to Joshi et al. (2019), seed certification is an important step in seed production and marketing, which is usually carried out to maintain high-quality seed standards and make the same available to farmers for maintaining good and quality yields.

Globally, farmers' sources of seeds and planting materials are neighbors, relatives, friends, seed cooperatives/associations, national extension agencies, national seed companies, multinational seed companies, and international gene banks. These sources span the local to international level and are interconnected through multiple linkages and interdependencies (Westengen & Brysting, 2014). It must be, however, noted that there are several intermediaries and varied degrees of access among farmers for each of the sources. The access is also affected by cost, quality, timeliness, availability, and other preferences. Farmers, therefore, explore a combination of sources with different capital assets available to them (Sperling et al., 2021). Several interventions on seeds and planting materials have attempted to increase the capacity for seed multiplication at the personal and communal level; however, the technical limitations have restricted such interventions to open-pollinated varieties.

The seed systems are often fraught with fake and counterfeit due to urgent and unplanned needs arising from shortages of quantity demanded. Community seed banks, as another mechanism of intervention, have been supported technically, organizationally, and financially by development agencies and complement individual farmers and groups that produce and sell seed following a quality assurance scheme outside the formal systems as intermediaries (Mulesa et al., 2021). Seed banks hold the key to food security and climate change mitigation to alter the trend of losing more than 600 plant species and the extinction of more than 93% of food seed varieties (Wossen et al., 2024).

The availability of improved quality seeds is important for attaining good yields with a significant impact on the farmers' production potential; however, the informal seed system constitutes and dominates about 75% of the seed market. The distribution of improved seeds has not been able to catch up with the pace of releases of improved varieties, over the last ten years, in Kenya, over two hundred maize varieties were released however varieties on farmers' fields were between 15 to 20 years (Ayiecho & Nyabundi, 2025; Obebo & Coyne, 2023); in Ethiopia, 25 common bean varieties were released with a mean varietal turnover of 19 years (Manda et al., 2025).

Even though improved seed is a crucial path for attaining increased yield potential (Obebo & Coyne, 2023), the dominance of the public sector of the upstream seed supply constrains the accessibility of early-generation seeds due to a lack of sufficient capacity within National Agricultural Research Systems (Mastenbroek et al., 2021). In the last two decades, an increase in the number of seed value-chain actors has led to greater seed production, delivery, and quality, albeit not at the level commensurate with the demand (Barriga & Fiala, 2020). The institutional framework to promote the use of improved seeds in Nigeria includes the National Agricultural Seeds Council (NASC), the ANCHOR borrowers' scheme, the Agricultural Transformation Agenda Special

Program, and the Seed Entrepreneurs Association of Nigeria (SEEDAN; Onyeneke, 2021; Iliyasu & Lawal, 2020). Smallholder farm households acquire their seeds through unofficial channels such as fellow farmers and local markets (Chiemela et al., 2021), while only 5 to 10 percent of cultivated land is planted with improved seeds and this has resulted in low yield whereas the use of improved seed varieties can boost crop yield by about 35% (Takeshima et al., 2022; Akanbi, et al. 2022).

HarvestPlus discovered, developed, and delivered biofortified seeds and planting materials to farmers and sequentially engaged farmers by scaling operations through marketing, and finally, anchored biofortification in local food systems for long-term sustainability (Foley et al., 2021). The seed systems are classified as farm-saved seed, community-based, public companies, commercial companies, and closed value chains. Alternative seed systems include seed that is produced by local farmers under financial and technical support from non-government organizations (NGOs) and breeding centers. The intermediary seed system combines attributes of both the formal and the informal seed systems. Smallholder farmers often demand small quantities of seed, exclude remote areas unreached by formal systems, have limited financial resources to purchase certified seed, and have diversified and unpredictable seed demand (McGuire & Sperling, 2016). Private sector participation in the seed sector has been enhanced by several regulations, time and cost investments, and the incentives of intellectual property rights (Miller et al., 2023); on which companies have leveraged economies of scale for vertical integration with other agro-inputs and closing the innovation gap of responding to seeds of crops, geography and market of interest (Deconinck, 2020).

Ojiewo et al. (2020) outlined the principles of mainstreaming improved seeds as a clear theory of change, robust policy environment, regional integration, institutional framework, availability of early generation seed (EGS) elimination of commercial seed class, institutional capacity building, promotion of crop utilization, linkages to market, income security, dietary diversification, resilience, women and youth empowerment, multi-stakeholder platforms and well-defined seed and adoption roadmaps. Several authors listed the seed marketing and distribution constraints to include lack of infrastructure, poor extension support systems, ineffective promotional campaigns, seed prices, market control, poor awareness of varieties and hybrids, monopolistic distribution, and unaffordability of complementary inputs.

Improved seeds have huge potential to enhance food and nutrition security; however, good quality seed availability is not always ensured, and distribution networks are often neglected in the rhetoric of market forces. Improved seed is one of the most important inputs for increasing agricultural production and plays a major role in the spread of improved technology essential for increasing agricultural productivity. Therefore, making high-quality seed available to Nigerian farmers is necessary for the transformation of the predominantly subsistence agricultural production system to achieve a meaningful increase in agricultural productivity in the country.

However, crop production output depends to a large extent on the quality of seed made available and planted by farmers. According to NASC and SEEDAN (2020), the major seed sector challenges are seed production systems and other dependent constraints such as service provision, seed market development, revenue generation and reinvestment, seed sector coordination, and seed sector regulation and management. These are manifested in multi-dimensional scenarios. NASC and SEEDAN (2020) reported that the seed gap in 2020 for Maize HV, Maize OPV, Cowpea, and Groundnut was 90%, -7%, 80%, and 94% respectively. The Maize OPV market is oversaturated, which explains the -7%, implying overproduction and increased availability that lead to reduced prices.

A major hindrance to improved agricultural practices has been the limited availability and accessibility of improved seed and planting materials to farmers, a problem often attributed to the general supply chain and the seed value chain, while overlooking the inherent challenges in seed production and distribution. A major gap addressed by this study is that several types of research on the adoption of improved seeds have focused on constraints at the farmers' level (Ainissyifa et al., 2018), socioeconomic and demographic issues (Atilaw et al., 2016; Ainissyifa et al., 2018; Kansa et al., 2019), and agroecology and intensification complexities (Quarshie et al., 2021), with little or no attention on the production and distribution factors of improved seed systems.

This paper explores the underlying seed production and distribution factors in order to contribute to knowledge on the improvement of seed production and distribution for improved availability and access to end users. The main objective of this study, therefore, was to examine the effects of production and distribution factors on improved seed systems in Nigeria and their implications for scaling climate resilient production and food systems.

## 2. Materials and Methods

The study was carried out in Nigeria with a wide range of agroecological zones and arable land, making agriculture account for 45% of the GDP and providing employment for at least 60% of the population, fully or partially. The great cultural diversity and agroecological diversity influence the farming system and dietary patterns, and practices across the country. Despite its

contribution to the economy, Nigeria's agricultural sector is limited by the unmet demand for improved seeds—particularly major staple food crops—high production costs, poor distribution of inputs, limited financing, high post-harvest losses, and poor access to markets. Secondary data was used in this study and was extracted and cleaned from the data collected by the National Seed Council of Nigeria for the 2023 survey /covering the six geo-political zones of Nigeria. The secondary data used for this study were based on the inclusion criteria of production and distributive factors within the last two agricultural seasons in Nigeria. The secondary data from the National Seed Council of Nigeria cover 12 years on the number of seed companies, agro-dealers, quantity of foundation, certified breeder, and price of hybrid and open-pollinated seeds of maize, rice, sorghum, millet, wheat, cowpea, soybean, and groundnut. The actual data of the volume recorded over the years under review were extracted from the data archive of the National Seed Council. Data were analyzed using Statistical Package for the Social Sciences (SPSS) Version 29 to analyze and compare the data collected. Descriptive statistics were computed for the variables (Table 1). Principal Components Analysis was conducted to extract the components underlying the data, and the correlation matrix was examined to assess the interrelationships among variables. The principal component analysis was applied to simplify complex, high-dimensional data sets in relation to production and distribution factors on improved seed systems. The analytical tools applied were based on the need to simplify complex datasets by reducing dimensionality while retaining important patterns and relationships. It does this by identifying the most important directions of variance (principal components) in the data, and then projecting the data onto these directions. This results in a smaller set of uncorrelated variables that capture the majority of the data's variation.

The Principal Components Analysis, as specified by Koutsoyiannis (1972), is presented as follows:

Given variables ( $X$ s, the original variables of the composite production and distribution factors)

$X_1 \dots X_p$  : measured in "n" factors

$P_1 \dots P_p$ : the principal components, which are uncorrelated linear combinations of the original variable,  $X_1 \dots X_p$ , given as:

$$\begin{aligned} P_1 &= \alpha_{11}X_1 + \alpha_{12}X_2 + \dots + \alpha_{1p}X_p \\ P_2 &= \alpha_{21}X_1 + \alpha_{22}X_2 + \dots + \\ P_p &= \alpha_{p1}X_1 + \alpha_{p2}X_2 + \dots + \alpha_{pp}X_p \end{aligned} \quad (1)$$

The component loadings were chosen on the condition that the principal components were not related, and that the first component would account for the maximum possible proportion of the total variation in the original variables. The PCA helps to filter out principal components that have low variance and high noise, which can help reveal the underlying structure and patterns in the data.

**Table 1.** Description of independent and dependent variables.

<b>Seed parameters C- certified, F- foundation, B- Breeder</b>	<b>Unit (MT)</b>	<b>N - years</b>	<b>Mini- mum</b>	<b>Maximum</b>	<b>Mean</b>	<b>Std. De- viation</b>
Maize HybridC	Quantity	12	1,137.0	4,639.0	2,823.1	922.8
Maize OPVC	Quantity	12	1,781.0	71,145.0	25,450.3	24,576.1
Rice LowlandC	Quantity	12	965.0	90,439.0	32,522.3	31,551.8
Rice UplandC	Quantity	12	219.0	2,790.0	1,218.8	885.6
SorghumC	Quantity	12	199.0	2,845.0	1,164.6	888.6
MilletC	Quantity	12	98.0	1,002.0	401.7	321.2
WheatC	Quantity	12	0.0	250.0	73.3	84.7
CowpeaC	Quantity	12	50.0	1,448.0	354.3	444.5
SoybeanC	Quantity	12	151.0	3,278.0	1,122.4	950.6
GroundnutC	Quantity	12	15.0	586.0	235.4	194.3
MaizeF	Quantity	12	0.0	2,631.0	613.4	920.5
RiceF	Quantity	12	0.0	1,624.0	272.3	532.3
SorghumF	Quantity	12	0.0	157.0	23.5	48.2
MilletF	Quantity	12	0.0	16.0	2.0	5.0
WheatF	Quantity	12	0.0	37.0	6.8	13.3
CowpeaF	Quantity	12	0.0	63.0	10.2	19.6
SoybeanF	Quantity	12	0.0	157.0	32.8	58.4
GroundnutF	Quantity	12	0.0	105.0	11.9	30.0
MaizeB	Quantity	12	0.0	298,700.0	60,610.0	85,518.7
RiceB	Quantity	12	0.0	114,900.0	41,641.7	39,785.1
SorghumB	Quantity	12	0.0	28,300.0	5,609.6	9,372.2
MilletB	Quantity	12	0.0	6,000.0	987.5	1,752.7
WheatB	Quantity	12	0.0	7,000.0	1,733.3	2,786.1
CowpeaB	Quantity	12	0.0	9,600.0	3,133.3	3,618.6
SoybeanB	Quantity	12	0.0	12,100.0	4,725.0	4,646.0
GroundnutB	Quantity	12	0.0	37,240.0	7,445.8	11,265.2
Maize HybridP	Price	12	155.0	400.0	250.7	86.7
Maize OPVsP	Price	12	125.0	370.0	214.3	81.4
RiceP	Price	12	149.0	400.0	239.7	82.4
SorghumP	Price	12	116.0	350.0	198.8	67.4
MilletP	Price	12	77.0	400.0	206.7	100.3
CowpeaP	Price	12	150.0	600.0	295.0	139.8
SoybeanP	Price	12	132.0	850.0	279.8	196.3
GroundnutP	Price	12	238.0	700.0	398.7	155.7
No companies	Actual number	12	0.0	51.0	9.8	15.1
companies /state	Actual number	12	1.0	11.0	4.8	3.2
Agrodealers	Actual number	12	1.0	48.0	16.4	14.3

### 3. Results

The results of the Principal Component Analysis (PCA) of Effects of production and distribution factors on improved seed systems are in Table 2. Five factors were extracted due to the Kaiser criterion, which was used to select the underlying types and the number of components explaining the data. All variables in each of the extracted components that had Eigen values, which are a measure of explained variance, of less than one, while variables with factor loadings greater than or equal to  $\pm 0.300$  were considered in the depiction of the components. Similarly, a factor loading significantly contributes to the derived component of the study if it exceeds 0.30; thus, all the items explaining each derived component on the scale were expressed properly on the PCA.

**Table 2.** Principal Analysis Components estimates

Variables labels	Variable description	1	2	3	4	5	Communalities
M_OPVC	Maize OPVC	.679					.793
R_LC	Rice LowlandC	.749					.938
R_UC	Rice UplandC	.648					.865
S_C	SorghumC		.526				.786
M_C	MilletC		.522				.827
Gnut_C	GroundnutC		.657				.833
M_F	MaizeF		.551				.988
R_F	RiceF			-.713			.939
S_F	SorghumF			-.768			.948
M_F	MilletF			-.788			.999
W_F	WheatF			-.725			.954
Soy_F	SoybeanF			-.737			.800
Gnut_F	GroundnutF				-.833		.959
M_B	MaizeB				-.694		.963
M_OPVP	Maize OPVsP				.885		.987
R_P	RiceP				.857		.982
S_P	SorghumP				.882		.990
Mi_P	MilletP				.927		.951
Cow_P	CowpeaP				.829		.813
Soy_P	SoybeanP				.874		.886
Gnut_P	GroundnutP				.645		.758
Comp_N	No companies					.694	.852
Agro_D	Agrodealers					-.603	.775

According to Otitoju and Enete (2016) “only variables with factor loadings of  $\pm 0.346$  and above at 10% overlapping variance were used in naming the factors and significant at 1% level of probability; thus, variables that have factor loading of less than  $\pm 0.346$  were not used while variables that loaded in more than one constraint were also discarded”. The squared multiple correlations between each item and all other items that are communalities show the relationship between each variable and all other variables; it also shows the association between variables. In this study, GroundnutP (0.758) is the least explained by the analysis. The extracted components for production and distribution factors on improved seed systems are described as Factor 1 (non-hybrid), Factor 2 (certification), Factor 3 (foundation), Factor 4 (prices) and Factor 5 (distribution), which accounted for 53.02%, 16.24%, 10.59%, 5.24%, 4.41 of the variances respectively; with a cumulative 89.51% variance.

The results of the correlation matrix of production and distribution factors on improved seed systems in Nigeria are presented in Table 3. Positive correlation signifies a direct relationship, and negative correlation reflects an inverse relationship.

**Table 3.** Correlation matrix of production and distribution factors on improved seed systems.

	M_OPVC	R_LC	R_UC	S_C	M_C	Gnut_C	M_F	R_F	S_F	M_F	W_F	Soy_F	Gnut_F	M_B	M_OPVP	R_P	S_P	Mi_P	Cow_P	Soy_P	Gnut_P	Comp_N	Agro_D
M_OPVC	1																						
R_LC	<b>0.58*</b>	1																					
R_UC	<b>0.62*</b>	<b>0.95**</b>	1																				
S_C	0.16	0.18	0.10	1																			
M_C	0.35	<b>0.69*</b>	<b>0.59*</b>	0.30	1																		
Gnut_C	<b>0.72**</b>	<b>0.77**</b>	<b>0.71*</b>	0.17	0.47	1																	
M_F	0.12	<b>0.60*</b>	0.47	<b>0.58*</b>	<b>0.79**</b>	0.34	1																
R_F	<b>-0.69*</b>	<b>-0.67*</b>	<b>-0.65*</b>	-0.36	-0.40	<b>-0.62*</b>	-0.42	1															
S_F	<b>-0.66*</b>	-0.51	-0.49	0.02	-0.17	-0.42	-0.07	0.43	1														
M_F	<b>-0.73**</b>	-0.49	-0.48	-0.08	-0.33	-0.42	-0.18	0.44	<b>0.95**</b>	1													
W_F	<b>-0.72**</b>	-0.41	-0.40	-0.18	-0.46	-0.37	-0.26	0.39	<b>0.82**</b>	<b>0.95**</b>	1												
Soy_F	<b>-0.65*</b>	-0.52	-0.52	-0.24	-0.33	-0.49	-0.25	<b>0.76**</b>	<b>0.67*</b>	<b>0.73**</b>	<b>0.71*</b>	1											
Gnut_F	<b>-0.74**</b>	-0.57	-0.55	-0.14	-0.32	-0.50	-0.20	<b>0.63*</b>	<b>0.92**</b>	<b>0.95**</b>	<b>0.88**</b>	<b>0.91**</b>	1										
M_B	<b>-0.66*</b>	-0.40	-0.39	-0.09	-0.37	-0.34	-0.19	0.24	<b>0.88**</b>	<b>0.95**</b>	<b>0.94**</b>	0.52	<b>0.81**</b>	1									
M_OPVP	0.38	0.54	0.41	<b>0.71**</b>	0.31	0.47	0.49	-0.56	-0.54	-0.51	-0.42	-0.47	-0.56	-0.44	1								
R_P	0.36	0.48	0.34	<b>0.70*</b>	0.25	0.42	0.43	-0.52	-0.53	-0.50	-0.41	-0.45	-0.54	-0.43	<b>0.99**</b>	1							
S_P	0.35	0.55	0.40	<b>0.73**</b>	0.36	0.46	<b>0.58*</b>	-0.52	-0.51	-0.49	-0.41	-0.45	-0.53	-0.43	<b>0.98**</b>	<b>0.97**</b>	1						
Mi_P	0.44	<b>0.65*</b>	0.48	<b>0.58*</b>	0.44	<b>0.61*</b>	<b>0.59*</b>	<b>-0.61*</b>	<b>-0.60*</b>	<b>-0.58*</b>	-0.48	-0.54	<b>-0.63*</b>	-0.49	<b>0.95**</b>	<b>0.92**</b>	<b>0.96**</b>	1					
Cow_P	0.40	0.50	0.36	<b>0.60*</b>	0.22	0.45	0.50	-0.45	<b>-0.59*</b>	-0.55	-0.44	-0.44	-0.56	-0.48	<b>0.86**</b>	<b>0.83**</b>	<b>0.91**</b>	<b>0.88**</b>	1				
Soy_P	0.38	<b>0.67*</b>	0.52	<b>0.62*</b>	0.44	0.55	<b>0.73**</b>	<b>-0.59*</b>	-0.52	-0.51	-0.43	-0.51	-0.56	-0.42	<b>0.86**</b>	<b>0.82**</b>	<b>0.92**</b>	<b>0.93**</b>	<b>0.93**</b>	1			
Gnut_P	0.25	0.28	0.21	<b>0.61*</b>	0.13	0.21	0.18	-0.42	-0.38	-0.36	-0.30	-0.36	-0.41	-0.30	<b>0.83**</b>	<b>0.87**</b>	<b>0.74**</b>	<b>0.67*</b>	0.48	0.47	1		
Comp_N	0.13	0.26	0.08	0.45	0.15	0.28	0.22	-0.25	-0.51	-0.47	-0.3	-0.41	-0.50	-0.40	<b>0.83**</b>	<b>0.87**</b>	<b>0.80**</b>	<b>0.80**</b>	<b>0.66*</b>	<b>0.62*</b>	<b>0.80**</b>	1	
Agro_D	0.17	0.05	0.18	-0.29	0.02	-0.02	0.10	-0.24	-0.15	-0.19	-0.21	-0.20	-0.20	-0.15	-0.26	-0.27	-0.30	-0.18	-0.27	-0.08	-0.22	-0.37	1

#### 4. Discussion

These results affirm Bartlett's Test of Sphericity with a value of  $X^2 = 2,990.14$ ,  $p = 0.00$ , and Kaiser-Meyer-Olkin Measure of Sampling Adequacy of 0.93. The influence of the variables that belong to the extracted components explaining production and distribution factors on improved seed systems was measured by the weights of their factor loadings. The prominent items under the non-hybrid factor are Maize OPVC (.679), Rice LowlandC (.749), and Rice UplandC (.648). Quarshie et al. (2021) stated that the commercialization and adoption of improved varieties are hindered by early Generation Seeds value chain constraints among smallholder farmers; lack of knowledge about the seeds, socio-economic, and institutional factors influenced the adoption of OPVs (Sigigaba et al., 2021). Ayenan et al. (2021) reported that available seed varieties are predominantly open-pollinated and that private sector-mediated seed systems offered the higher potential for seed quality and profitability, with the community-based seed system showing the highest potential for ensuring the greatest access to seeds.

##### 4.1. Findings from Principal Component Analysis

For the certification Factor, the items are SorghumC (.526), MilletC (.522), GroundnutC (.657), MaizeF (.551). Ayenan et al. (2021) found that in Africa, Quality Declared Seed is an alternative seed quality assurance adapted to contexts where official seed regulatory bodies have limited resources to implement a complete certification scheme. Mamo et al. (2023) affirm that seeds from informal seed systems are less expensive because they do not go under the certification process, are distributed through Farmer-to-farmer exchange networks, and are thus readily available for farmers, however, Kuhlmann et al. (2023) stated that mandatory Value for Cultivation and Use (VCU) trials and state-controlled seed certification are the two examples of regulatory approaches that may work for cereals. Ayenan et al. (2021) reported that a lack of human and technical resources, understaffing in seed certification agencies, and weak collaboration between seed sector stakeholders are institutional factors hindering the production and delivery of high-quality seed to farmers. Kuhlmann et al. (2023) reported that a government-centered approach to seed quality control was adopted in many countries in sub-Saharan Africa without the requisite capacity for such. Similarly, a government-centred approach was applied to the neglected alternatives to certification, such as truth-in-labelling, self-certification, group quality assurance, quality-declared seed, and other approaches (Kuhlmann & Dey, 2021). Kuhlmann et al. (2023) found that in Nigeria, seed certification is mandatory for the formal seed sector, but not for registered vegetable varieties produced in the informal sector, which are only subject to minimum standards that have yet to be defined.

The foundation factor is composed of items such as RiceF (-.713), SorghumF (-.768), MilletF (-.788), WheatF (-.725), SoybeanF (-.737). Kimenyi (2014) stated that foundation seeds are critical for the promotion of better access to high-quality seeds which can be through farmer-led seed production of contract model, research model, and quality declared seed model for the acquisition of skills for establishment and management of seed production and marketing; while Walsh et al. (2015) found that community seed production improves formal and farmer seed system links, sustains transition into commercial entities, and linkage with publicly funded programs. The production and delivery of breeder and foundation seed is a key bottleneck in the performance of seed value chains in sub-Saharan Africa (Integrated Seed System Development Africa, 2015). However, Chivasa et al. (2022) and Rutsaert et al. (2021) reported that the unavailability of early-generation seed, breeder, pre-basic, and basic seed is considered a major bottleneck in seeds and varietal replacement.

The prices factor included GroundnutF (-.833), MaizeB (-.694), which were inversely correlated. Langyintuo (2020) found that seed prices are a major impediment to farmers' access to improved seeds and inputs. Thomas (2020) found that cost limits the use of improved seeds and consequently limits the productivity level. However, other price factors positively correlated are Maize OPVsP (.885), RiceP (.857), SorghumP (.882), MilletP (.927), CowpeaP (.829), SoybeanP (.874), GroundnutP (.645). Branca et al. (2022) found that access to extension services, land, credit, and input and output markets impact the adoption of improved seeds; while Dunjana et al. (2022) reported that Availability and access to improved seeds determine household food and livelihood security.

The distribution factor is composed of two variables that includes number of companies (.694), Small and medium enterprises occupy space in Africa's agricultural input value chains, involving seed companies and input agro-dealers that facilitate the distribution of improved farm inputs, extension information and post-harvest handling services to smallholder farmer (Alliance for a Green Revolution in Africa, 2017; Das et al., 2019). Ncube et al. (2023) found that local seed systems contribute to household seed security through timely and effective distribution networks that offer several choices and alternatives. Kaliba et al. (2021) stated that agricultural projects that

enhance access to improved seeds generate a positive and sustainable effect on food security and poverty alleviation. The other variable in the distribution factors is agrodealers (-.603). Haug et al. (2023) reported that effective distribution of improved seeds enhances the multiple expectations of seed systems outcomes; while Doody (2023) stated that last mile delivery of stress-tolerant and nutritious seeds addresses the impacts of climate change, pests and diseases, shocks on food systems, by enhancing access to a diverse range of seeds means they can choose the best varieties to suit their needs and their local environment. The distribution factors is enhanced according to Bernard et al. (2023) that unless combined with interventions to maintain soil fertility, policies to promote modern seed varieties may come at the cost of important losses in biodiversity and Myeni and Moeletsi (2023) stated that the adoption of improved seed varieties was driven mostly by factors such as easy and stable access to seeds.

#### 4.2. Findings of the Correlation Matrix

The matrix shows that certified open-pollinated maize seed is the most highly correlated variable, showing significant relationships with 10 other variables in the production and distribution factors of improved seed systems. These are  $R_{LC}$ ,  $r = 0.581$ ,  $p < 0.05$ ;  $R_{UC}$ ,  $r = 0.616$ ,  $p < 0.05$ ;  $Gnut_C$ ,  $r = 0.716$ ,  $p < 0.05$ . Thijssen et al. (2015) noted that integrated seed sector development as an inclusive approach through local seed business that recognizes and builds upon a diversity of seed systems and complements farmers' practices, for increased farmers' access to quality seeds of superior varieties; and Vernooij et al. (2019) stated that resilient seed systems are critical to sustainable food systems connected to diverse cultural and culinary traditions, and promote diet diversity and health, thus responsive to climate change food and nutrition security, and agricultural biodiversity enhancement. The other variables have inverse relationship and these are:  $R_F$ ,  $r = -0.695$ ,  $p < 0.05$ ;  $S_F$ ,  $r = -0.668$ ,  $p < 0.05$ ;  $M_F$ ,  $r = -0.732$ ,  $p < 0.05$ ;  $W_F$ ,  $r = -0.727$ ,  $p < 0.05$ ;  $Soy_F$ ,  $r = -0.659$ ,  $p < 0.05$ ;  $Gnut_F$ ,  $r = -0.741$ ,  $p < 0.05$  and  $M_B$ ,  $r = -0.661$ ,  $p < 0.05$ . Westengen and Brysting (2014) found that the value and importance of location-specific information about crop variety use are crucial to seed systems perspectives. Cacho et al. (2020) found that the participation of communities in the breeding, delivery, and adoption of resilient seeds would be enhanced by the establishment and maintenance of a flexible national seed sector.

In the matrix, certified lowland rice seed is correlated with 8 other variables of the production and distribution factors of improved seed systems, which include  $M_{OPVC}$ ,  $r = 0.581$ ,  $p < 0.05$ ;  $R_{UC}$ ,  $r = 0.959$ ,  $p < 0.05$ ;  $M_C$ ,  $r = 0.691$ ,  $p < 0.05$ ;  $Gnut_C$ ,  $r = 0.771$ ,  $p < 0.05$ . Choudhary and Kumar (2020) stated that improved seeds offer ample opportunities to adapt and respond to climate variabilities, while Kansime et al. (2021) found that seed production by farmers contributed to the increased availability of quality seeds, and quality-declared seeds were constrained by a lack of access to foundation seeds, inspections, and seed testing services. The other variables correlated are  $M_F$ ,  $r = 0.600$ ,  $p < 0.05$ ;  $R_F$ ,  $r = -0.670$ ,  $p < 0.05$ ;  $Mi_P$ ,  $r = 0.656$ ,  $p < 0.05$ ;  $Soy_P$ ,  $r = 0.670$ ,  $p < 0.05$ . The development of different seeds and varieties, and their delivery through a variety of models, recognize the existence of diverse demands and have implications for organizing and targeting the seed delivery system (Mausch et al., 2021).

Similarly, the quantity of sorghum foundation seeds is significantly correlated to 7 variables of the production and distribution factors of improved seed systems,  $M_F$ ,  $r = 0.959$ ,  $p < 0.05$ ;  $W_F$ ,  $r = 0.827$ ,  $p < 0.05$ ;  $Soy_F$ ,  $r = 0.671$ ,  $p < 0.05$ . The educational level, credit access, household income, extension services, and seed quality significantly and positively influenced farmers' selection of a formal seed distribution system, while the distance to the nearest seed distribution area negatively influenced the selection of a formal seed distribution system in the study areas (Wosene Minwagaw & Gobie Ejigu, 2021). Others are  $Gnut_F$ ,  $r = 0.916$ ,  $p < 0.05$ ;  $M_B$ ,  $r = 0.881$ ,  $p < 0.05$ ;  $Mi_P$ ,  $r = -0.604$ ,  $p < 0.05$ ;  $Cow_P$ ,  $r = -0.592$ ,  $p < 0.05$ . Ahmed et al. (2017) found complementarity of the adoption of improved seed and crop diversification. The utilization of improved seed was constrained by unaffordable prices of improved seed, limited financial capacity, untimely availability of improved seed, and lack of credit for seeds and fertilizer (Tarekegn & Mogiso, 2020).

In addition, the quantity of certified sorghum seeds is significantly correlated to  $M_F$ ,  $r = 0.577$ ,  $p < 0.05$ ;  $M_{OPVP}$ ,  $r = 0.712$ ,  $p < 0.05$ ;  $R_P$ ,  $r = 0.702$ ,  $p < 0.05$ ;  $S_P$ ,  $r = 0.731$ ,  $p < 0.05$ ;  $Mi_P$ ,  $r = 0.578$ ,  $p < 0.05$ ;  $Cow_P$ ,  $r = 0.603$ ,  $p < 0.05$ ;  $Soy_P$ ,  $r = 0.624$ ,  $p < 0.05$ ;  $Gnut_P$ ,  $r = 0.611$ ,  $p < 0.05$ . The trend of the relationship in the correlation matrix can be attributed to the use of some crops for market-oriented production, as well as the crops used in the farming system practices for intercrop and crop rotation, particularly in the cereal-legume combinations. The demand for seeds is also influenced by the use of different cereals as alternatives in the intercrop and crop rotation cycles. In Ethiopia, the pluralistic seed system development strategy enhanced the elimination of dysfunctions associated with the seed system but not the time lags associated with the informal seed system (Mulesa et al., 2021).

## 5. Implications for Scaling Climate Resilient Production and Food Systems

The findings have established the nexus among seed availability, distribution, climate resilience, and food systems. In this study, seed availability is the ability to supply sufficient quantities of quality seed to meet the needs of farmers. The availability of early generational seeds influences the critical connection between breeding activities and the eventual production and distribution of varieties to farmers. The timeliness, quantity, and accessibility factors, such as price and ease of purchase, would have a combined effect on response to climate change and the food systems. The food systems of the majority of farmers in Nigeria depend on the crop production practices to guarantee household food security and income generation for other essentials for their livelihoods. Cramer (2019) stated that a great deal of previous development funding on breeding new varieties and farmers' adoption notwithstanding, early-generation seed (EGS) availability continues to be limited by bottlenecks in the supply chain, particularly for non-hybrid varieties and less-commercialized food crops developed by public-sector institutions. The provision of farmers with access to the latest, improved germplasm plays a major role in adapting agricultural systems to climate change, while the adoption of improved varieties with climate resilient traits stimulates private sector interest and investment in seed systems (Das et al., 2019). The seed system interventions promote the distribution of climate-resilient varieties, diffusion of nutrient-dense varieties, increased speed of delivering new varieties, reaching the last-mile areas and populations, and maintenance of performance in high-stress contexts.

## 6. Conclusions

The analysis of the trend of production and distribution of improved seeds over a 12-year period has explored the nexus of seed availability, distribution, climate resilience, and food systems. The production and distribution factors influence response to climate change and food security, because seed security is food security, while seed insecurity undermines subsequent production. The extracted components for production and distribution factors on improved seed systems are non-hybrid, certification, foundation, prices, and distribution. The matrix shows that certified open-pollinated maize seed is the most highly correlated variable, showing significant relationships with 10 other variables in the production and distribution factors of improved seed systems. The availability of seed in sufficient quantities and quality to meet the needs of farmers would promote the replacement of old varieties with varieties with climate-resilient traits that are crucial in responding to the incidences of climate change. The study concludes that the availability of foundation, breeder, and certified seeds, in addition to the number of seed companies, agro-dealers, influences improved seed availability. The concerted efforts of role players in the seed systems, such as breeders, seed producers, governmental and non-governmental extension workers, drive the development, release, and rapid adoption of improved seeds towards contributing to food and income security of farming households and mitigation of climate change effects. This study recommends actionable policy interventions covering strengthening farmer seed systems, improving seed quality and availability, promoting equitable access to improved varieties, and supporting the seed sector.

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## Abbreviations

HYV	High-yielding varieties
NGO	Non Governmental Organisation
NASC	National Seed Council
SEEDAN	Seed Association of Nigeria
OPV	Open Pollinated Variety
HV	Hybrid Variety
EGS	Early-Generation Seed

## References

- Ahmed, M. H., Geleta, K. M., Tazeze, A., Mesfin, H. M., & Tilahun, E. A. (2017). Cropping systems diversification, improved seed, manure and inorganic fertilizer adoption by maize producers of eastern Ethiopia. *Journal of Economic Structures*, 6, 31. <https://doi.org/10.1186/s40008-017-0093-8>
- Ainissyifa, H., Wulan, E. R., Muhyiddin, A., & Ramdhani, M. A. (2018). Innovation and technology diffusion in agricultural sector. *IOP Conference Series: Materials Science and Engineering*, 434, 012247. <https://iopscience.iop.org/article/10.1088/1757-899X/434/1/012247/pdf>
- Akanbi, S.-U. O., Mukaila, R., & Adebisi, A. (2022). Analysis of rice production and the impacts of the usage of certified seeds on yield and income in Côte d'Ivoire. *Journal of Agribusiness in Developing and Emerging Economies*, 14(2), 234–250. <https://doi.org/10.1108/JADEE-04-2022-0066>
- Alliance for a Green Revolution in Africa. (2017). *Seeding an African Green revolution: The PASS journey*. <https://agra.org/wp-content/uploads/2018/02/PASS-Book-web.pdf>
- Atilaw, A., Alemu, D., Bishaw, Z., Kifle, T., & Kaske, K. (2016). Early generation seed production and supply in Ethiopia: Status, challenges and opportunities. *Ethiopian Journal of Agricultural Sciences*, 27(1), 99–119. <https://www.researchgate.net/publication/312530797>
- Ayenan, M. A. T., Aglingo, L. A., Zohoungbogbo, H. P. F., N'Danikou, S., Honfoga, J., Dinssa, F. F., Hanson, P., & Afari-Sefa, V. (2021). Seed systems of Traditional African Vegetables in Eastern Africa: A systematic review. *Frontiers in Sustainable Food Systems*, 5. <https://doi.org/10.3389/fsufs.2021.689909>
- Ayiecho, P. O., & Nyabundi, J. O. (2025). Varietal release, seed multiplication, distribution and quality control. In *Conventional and contemporary practices of plant breeding* (pp. 381–388). Springer Cham. [https://doi.org/10.1007/978-3-031-74998-8\\_22](https://doi.org/10.1007/978-3-031-74998-8_22)
- Barriga, A., & Fiala, N. (2020). The supply chain for seed in Uganda: Where does it go wrong? *World Development*, 130, 104928. <https://doi.org/10.1016/j.worlddev.2020.104928>
- Bernard, T., Lambert, S., Macours, K., & Vinez, M. (2023). Impact of small farmers' access to improved seeds and deforestation in DR Congo. *Nature Communications*, 14, 1603. <https://doi.org/10.1038/s41467-023-37278-2>
- Branca, G., Cacchiarelli, L., Haug, R., & Sorrentino, A. (2022). Promoting sustainable change of smallholders' agriculture in Africa: Policy and institutional implications from a socio-economic cross-country comparative analysis. *Journal of Cleaner Production*, 358, 131949. <https://doi.org/10.1016/j.jclepro.2022.131949>
- Breen, C., Ndlovu, N., McKeown, P. C., & Spillane, C. (2024). Legume seed system performance in sub-Saharan Africa: Barriers, opportunities, and scaling options. A review. *Agronomy for Sustainable Development*, 44, 20. <https://doi.org/10.1007/s13593-024-00956-6>
- Cacho, O. J., Moss, J., Thornton, P. K., Herrero, M., Henderson, B., Bodirsky, B. L., Humpenöder, F., Popp, A., & Lipper, L. (2020). The value of climate-resilient seeds for smallholder adaptation in sub-Saharan Africa. *Climatic Change*, 162, 1213–1229. <https://doi.org/10.1007/s10584-020-02817-z>
- Chiemela, C. J., Chiemela, S. N., Mukaila, R., Ukwuaba, I. C., & Nwokolo, C. C. (2021). Effects of COVID-19 on small-scale agribusiness in Enugu State, Nigeria. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, 21(3), 255–263. [https://managementjournal.usamv.ro/pdf/vol.21\\_3/Art28.pdf](https://managementjournal.usamv.ro/pdf/vol.21_3/Art28.pdf)
- Chivasa, W., Worku, M., Teklewold, A., Setimela, P., Gethi, J., Magorokosho, C., Davis, N. J., & Prasanna, B. M. (2022). Maize varietal replacement in Eastern and Southern Africa: Bottlenecks, drivers and strategies for improvement. *Global Food Security*, 32, 100589. <https://doi.org/10.1016/j.gfs.2021.100589>
- Choudhary, R. R., & Kumar, D. (2020). Climate change impacts and climate-resilient crop varieties. *Vigyan Varta*, 1(5), 28–30. <https://www.researchgate.net/profile/Raju-Choudhary-4/publication/344496135>
- Cramer, L. K. (2019). Access to early generation seed: Obstacles for delivery of climate-smart varieties. In T. S. Rosenstock, A. Nowak, & E. Girvetz (Eds.), *The climate-smart agriculture papers: Investigating the business of a productive, resilient and low emission future* (pp. 87–98). Springer Cham. [https://doi.org/10.1007/978-3-319-92798-5\\_8](https://doi.org/10.1007/978-3-319-92798-5_8)
- Doody, A. (2023, May 23). *Accelerating delivery of stress-tolerant, nutritious seed in Eastern and Southern Africa*. CIMMYT. <https://www.cimmyt.org/news/accelerating-delivery-of-stress-tolerant-nutritious-seed-in-eastern-and-southern-africa/>
- Das, B., Van Deventer, F., Wessels, A., Mudenda, G., Key, J., & Ristanovic, D. (2019). Role and challenges of the private seed sector in developing and disseminating climate-smart crop varieties in eastern and southern Africa. In T. S. Rosenstock, A. Nowak, & E. Girvetz (Eds.), *The climate-smart agriculture papers: Investigating the business of a productive, resilient and low emission future* (pp. 67–78). Springer Cham. [https://doi.org/10.1007/978-3-319-92798-5\\_6](https://doi.org/10.1007/978-3-319-92798-5_6)
- Deconinck, K. (2020). Concentration in seed and biotech markets: Extent, causes, and impacts. *Annual Review of Resource Economics*, 12, 129–147. <https://doi.org/10.1146/annurev-resource-102319-100751>
- Duncan, N., de Silva, S., Conallin, J., Freed, S., Akester, M., Baumgartner, L., McCartney, M., Dubois, M., & Sellamuttu, S. S. (2021). Fish for whom?: Integrating the management of social complexities into technical investments for inclusive, multi-functional irrigation. *World Development Perspectives*, 22, 100318. <https://doi.org/10.1016/j.wdp.2021.100318>
- Dunjana, N., Dube, E., Chauke, P., Motsepe, M., Madikiza, S., Kgakatsi, I., & Nciizah, A. (2022). Sorghum as a household food and livelihood security crop under climate change in South Africa: A review. *South African Journal of Science*, 118(9/10). <https://doi.org/10.17159/sajs.2022/13340>
- Foley, J. K., Michaux, K. D., Mudyahoto, B., Kyazike, L., Cherian, B., Kalejaiye, O., Ifeoma, O., Ilona, P., Reinberg, C., Mavindidze, D., & Boy, E. (2021). Scaling up delivery of biofortified staple food crops globally: Paths to nourishing millions. *Food and Nutrition Bulletin*, 42(1), 116–132. <https://doi.org/10.1177/0379572120982501>
- Fraser, E., Legwegoh, A., Krishna, K. C., CoDyre, M., Dias, G., Hazen, S., Johnson, R., Martin, R., Ohberg, L., Sethuratnam, S., Sneyd, L., Smithers, J., Van Acker, R., Vansteenkiste, J., Wittman, H., & Yada, R. (2016). Biotechnology or organic? Extensive or intensive? Global or local? A critical review of potential pathways to resolve the global food crisis. *Trends in Food Science and Technology*, 48, 78–87. <https://doi.org/10.1016/j.tifs.2015.11.006>
- Gatto, M., Borus, D., Malit, J., Kihui, E., Barker, I., Echessa, L., Soto-Torres, J., & Meyer, A. (2025). *Digital revolution in farmer fields: VarScout Unveils Kenya's varietal landscape – The case of potato*. International Potato Center. <https://cgspage.cgiar.org/server/api/core/bitstreams/641572a4-bb16-462c-a0f9-b8c673d783ea/content>

- Haug, R., Hella, J. P., Mulesa, T. H., Kakwera, M. N., & Westengen, O. T. (2023). Seed systems development to navigate multiple expectations in Ethiopia, Malawi and Tanzania. *World Development Sustainability*, 3, 100092. <https://doi.org/10.1016/j.wds.2023.100092>
- Iliyasu, I., & Lawal, S. (2020). Nigeria's self-sufficiency in rice and wheat: An evaluation of Growth Enhancement Support Scheme and Anchor Borrower program. *Pakistan Journal of Humanities and Social Sciences*, 8(1), 1–9. <https://doi.org/10.52131/pjhss.2020.0801.0096>
- Integrated Seed System Development Africa. (2015) *Access to foundation seed of varieties in the public domain*. <https://www.kit.nl/wp-content/uploads/2018/08/Access-to-foundation-seed-of-varieties-in-the-public-domain.pdf>
- Joshi, K. D., Conroy, C., & Witcombe, J. R. (2019). Agriculture, seed, and innovation in Nepal: Industry and policy issues for the future. *Gates Open Research*, 3, 232. <https://doi.org/10.21955/gatesopenres.1115308.1>
- Kaliba, A. R., Gongwe, A. G., Mazvimavi, K., & Yigletu, A. (2021). Impact of adopting improved seeds on access to broader food groups among small-scale sorghum producers in Tanzania. *SAGE Open*, 11(1). <https://doi.org/10.1177/2158244020979992>
- Kansanga, M., Andersen, P., Kpienbaareh, D., Mason-Renton, S., Atuoye, K., Sano, Y., Antabe, R., & Luginaah, I. (2019). Traditional agriculture in transition: Examining the impacts of agricultural modernization on smallholder farming in Ghana under the new Green Revolution. *International Journal of Sustainable Development & World Ecology*, 26(1), 11–24. <https://doi.org/10.1080/13504509.2018.1491429>
- Kansiime, M. K., Bundi, M., Nicodemus, J., Ochieng, J., Marandu, D., Njau, S. S., Kessy, R. F., Williams, F., Karanja, D. Tambo, J. A. & Romney, D. (2021). Assessing sustainability factors of farmer seed production: A case of the Good Seed Initiative project in Tanzania. *Agriculture & Food Security*, 10, 15. <https://doi.org/10.1186/s40066-021-00289-7>
- Kimani, P. M. (2025). Advances in breeding for enhanced iron and zinc concentration in common bean in eastern Africa. *Journal of Experimental Botany*, 76(5), 1390–1407. <https://doi.org/10.1093/jxb/eraf009>
- Kimenye, L. (2014). *Improving access to quality seeds in Africa*. CABI Study Brief 7. <http://dx.doi.org/10.1079/CABICOMM-64-57>
- Kuhlmann, K., & Dey, B. (2021). Using regulatory flexibility to address market informality in seed systems: A global study. *Agronomy*, 11(2), 377. <https://doi.org/10.3390/agronomy11020377>
- Kuhlmann, K., Francis, T., Thomas, I., & Schreinemachers, P. (2023). Laws and regulations enabling and restricting Africa's vegetable seed sector. *International Journal of Agricultural Sustainability*, 21(1). <https://doi.org/10.1080/14735903.2023.2210005>
- Koutsoyiannis, A. (1972). *Theory of econometrics* (2nd ed.). McGraw-Hill Publishers.
- Langyintuo, A. (2020). Smallholder farmers' access to inputs and finance in Africa. In S. Gomez y Paloma, L. Riesgo, & K. Louhichi (Eds.), *The role of smallholder farms in food and nutrition security* (pp. 133–152). Springer Cham. [https://doi.org/10.1007/978-3-030-42148-9\\_7](https://doi.org/10.1007/978-3-030-42148-9_7)
- Mamo, T., Singh, A., Mahama, A. A., & Suza, W. (2023). Seed systems and certification. In W. Suza, & K. Lamkey (Eds.), *Crop improvement*. Iowa State University Digital Press. <https://doi.org/10.31274/isudp.2023.138>
- Manda, L., Idohou, R., Agoyi, E. E., Agbahoungba, S., Salako, K. V., Agbangla, C., Adomou, A. C., & Assogbadjo, A. E. (2025). Progress of in situ conservation and use of crop wild relatives for food security in a changing climate: A case of the underutilised *Vigna Savi*. *Frontiers in Sustainability*, 6. <https://doi.org/10.3389/frsus.2025.1453170>
- Martey, E., Etwire, P. M., & Kuwornu, J. K. M. (2020). Economic impacts of smallholder farmers' adoption of drought-tolerant maize varieties. *Land Use Policy*, 94, 104524. <https://doi.org/10.1016/j.landusepol.2020.104524>
- Mastenbroek, A., Sirutyte, I., & Sparrow, R. (2021). Information barriers to adoption of agricultural technologies: Willingness to pay for certified seed of an open pollinated maize variety in Northern Uganda. *Journal of Agricultural Economics*, 72(1), 180–201. <https://doi.org/10.1111/1477-9552.12395>
- Mausch, K., Almekinders, C. J. M., Hambloch, C., & McEwan, M. A. (2021). Putting diverse farming households' preferences and needs at the centre of seed system development. *Outlook on Agriculture*, 50(4), 356–365. <https://doi.org/10.1177/003072702111054111>
- McGuire, S., & Sperling, L. (2016). Seed systems smallholder farmers use. *Food Security*, 8, 179–195. <https://doi.org/10.1007/s12571-015-0528-8>
- Miller, T., Mikiciuk, G., Kisiel, A., Mikiciuk, M., Paliwoda, D., Sas-Paszt, L., Cembrowska-Lech D, Krzemińska, A., Koziol, A., & Brysiewicz, A. (2023). Machine learning approaches for forecasting the best microbial strains to alleviate drought impact in agriculture. *Agriculture*, 13(8), 1622. <https://doi.org/10.3390/agriculture13081622>
- Mulesa, T. H., Dalle, S. P., Makate, C., Haug, R., & Westengen, O. T. (2021). Pluralistic seed system development: A path to seed security. *Agronomy*, 11(2), 372. <https://doi.org/10.3390/agronomy11020372>
- Muthamilarasan, M., & Prasad, M. (2021). Small millets for enduring food security amidst pandemics. *Trends in Plant Science*, 26(1), 33–40. <https://doi.org/10.1016/j.tplants.2020.08.008>
- Myeni, L., & Moeletsi, M. E. (2023). Assessing the adoption of improved seeds as a coping strategy to climate variability under smallholder farming conditions in South Africa. *South African Journal of Science*, 119(9/10). <https://doi.org/10.17159/sajs.2023/15001>
- National Agricultural Seeds Council & Seed Entrepreneurs Association of Nigeria. (2020). *National seed road map for Nigeria*. [https://seedcouncil.gov.ng/wp-content/uploads/2020/03/National-Seed-Road-Map\\_Nigeria-NASC-Adopted.pdf](https://seedcouncil.gov.ng/wp-content/uploads/2020/03/National-Seed-Road-Map_Nigeria-NASC-Adopted.pdf)
- Ncube, B. L., Wynberg, R., & McGuire, S. (2023). Comparing the contribution of formal and local seed systems to household seed security in eastern Zimbabwe. *Frontiers in Sustainable Food Systems*, 7. <https://doi.org/10.3389/fsufs.2023.1243722>
- Obebo, F., & Coyne, D. (2023). *A scoping study of vegetable seedling systems in urban and peri-urban areas of Nairobi, Kenya*. Consultative Group for International Agricultural Research. <https://cgspace.cgiar.org/server/api/core/bitstreams/907bc5f1-afa2-4bbd-b9c3-7f1b699f4d21/content>
- Ojiewo, C. O., Omoigui, L. O., Pasupuleti, J., & Lenné, J. M. (2020). Grain legume seed systems for smallholder farmers: Perspectives on successful innovations. *Outlook on Agriculture*, 49(4), 286–292. <https://doi.org/10.1177/0030727020953868>

- Onyeneke, R. U. (2021). Does climate change adaptation lead to increased productivity of rice production? Lessons from Ebonyi State, Nigeria. *Renewable Agriculture and Food Systems*, 36(1), 54–68. <https://doi.org/10.1017/S1742170519000486>
- Otitoju, M. A., & Enete, A. A. (2016). Climate change adaptation: Uncovering constraints to the use of adaptation strategies among food crop farmers in South-west, Nigeria using principal component analysis (PCA). *Cogent Food & Agriculture*, 2(1), 1178692. <https://doi.org/10.1080/23311932.2016.1178692>
- Quarshie, P. T., Abdulai, A.-R., & Fraser, E. D. G. (2021). Africa's "seed" revolution and value chain constraints to early generation seeds commercialization and adoption in Ghana. *Frontiers in Sustainable Food Systems*, 5. <https://doi.org/10.3389/fsufs.2021.665297>
- Ruane, A. C., Vautard, R., Ranasinghe, R., Sillmann, J., Coppola, E., Arnell, N., Cruz, F. A., Dessai, S., Iles, C. E., Saiful Islam, A. K. M., Jones, R. G., Rahimi, M., Carrascal, D. R., Seneviratne, S. I., Servonnat, J., Sörensson, A. A., Sylla, M. B., Tebaldi, C., Wang, W., & Zaaboul, R. (2022). The climatic impact-driver framework for assessment of risk-relevant climate information. *Earth's Future*, 10(11), e2022EF002803. <https://doi.org/10.1029/2022EF002803>
- Rutsaert, P., Donovan, J., & Kimenju, S. (2021). Demand-side challenges to increase sales of new maize hybrids in Kenya. *Technology in Society*, 66, 101630. <https://doi.org/10.1016/j.techsoc.2021.101630>
- Sendekie, Y. (2020). Review on; Seed genetic purity for quality seed production. *International Journal of Scientific Engineering and Science*, 4(10), 1–7. <https://ijses.com/wp-content/uploads/2020/10/92-IJSES-V4N8.pdf>
- Sigigaba, M., Mdoda, L., & Mditshwa, A. (2021). Adoption drivers of improved open-pollinated (OPVs) maize varieties by smallholder farmers in the Eastern Cape Province of South Africa. *Sustainability*, 13(24), 13644. <https://doi.org/10.3390/su132413644>
- Sperling, L., Gallagher, P., McGuire, S., & March, J. (2021). Tailoring legume seed markets for smallholder farmers in Africa. *International Journal of Agricultural Sustainability*, 19(1), 71–90. <https://doi.org/10.1080/14735903.2020.1822640>
- Stringer, L. C., Mirzabaev, A., Benjaminsen, T. A., Harris, R. M. B., Jafari, M., Lissner, T. K., Stevens, N., & Tirado-von Der Pahlen, C. (2021). Climate change impacts on water security in global drylands. *One Earth*, 4(6), 851–864. <https://doi.org/10.1016/j.oneear.2021.05.010>
- Sundareswaran, S., Ray Choudhury, P., Vanitha, C., & Yadava, D. K. (2023). Seed quality: Variety development to planting—An overview. In M. Dadlani & D. K. Yadava (Eds.), *Seed Science and Technology: Biology, production, quality* (pp. 1–16). Springer Singapore. [https://doi.org/10.1007/978-981-19-5888-5\\_1](https://doi.org/10.1007/978-981-19-5888-5_1)
- Tadesse, Y., Almekinders, C. J. M., Schulte, R. P. O., & Struik, P. C. (2017). Tracing the seed: Seed diffusion of improved potato varieties through farmers' networks in Chencha, Ethiopia. *Experimental Agriculture*, 53(4), 481–496. <https://doi.org/10.1017/S001447971600051X>
- Takeshima, H., Abdolaye, T., Andam K. S., Edeh, H. O., Fasoranti, A., Haile, B., Kumar, P. L., Nwagboso, C., Ragasa, C., Spielman, D. J., & Wossen, T. (2022). *Seed certification and maize, rice and cowpea productivity in Nigeria: An insight based on nationally representative farm household data and seed company location data*. International Food Policy Research Institute. <https://doi.org/10.2499/p15738coll2.136474>
- Tarekegn, K., & Mogiso, M. (2020). Assessment of improved crop seed utilization status in selected districts of Southwestern Ethiopia. *Cogent Food & Agriculture*, 6(1), 1816252. <https://doi.org/10.1080/23311932.2020.1816252>
- Thijssen, M. H., Borman, G., Verhoosel, K., Mastenbroek, A., & Heemskerck, W. (2015). Local seed business in the context of integrated seed sector development. In C. O. Ojiewo, S. Kugbei, Z. Bishaw, & J. C. Rubyogo (Eds.), *Community seed production* (pp. 39–45). Food and Agriculture organization of the United Nations & International Crops Research Institute for the Semi-Arid Tropics.
- Thomas, M. A. H. (2020). *Improving crop yields in sub-Saharan Africa - What does the East African data say*. International Monetary Fund. <https://doi.org/10.5089/9781513546223.001>
- Vercillo, S., Weis, T., & Luginaah, I. (2020). A bitter pill: Smallholder responses to the new green revolution prescriptions in northern Ghana. *International Journal of Sustainable Development & World Ecology*, 27(6), 565–575. <https://doi.org/10.1080/13504509.2020.1733702>
- Vernooy, R., Bessette, G., & Otieno, G. (Eds.). (2019). *Resilient seed systems: Handbook*. Bioversity International. <https://hdl.handle.net/10568/103498>
- Walsh, S., Remington, T., Kugbei, S., & Ojiewo, C. O. (2015). Review of community seed production practices in Africa part 2: Lessons learnt and future perspective. In C. O. Ojiewo, S. Kugbei, Z. Bishaw, & J. C. Rubyogo (Eds.), *Community seed production* (pp. 29–38). Food and Agriculture organization of the United Nations & International Crops Research Institute for the Semi-Arid Tropics.
- Westengen, O. T., & Brysting, A. K. (2014). Crop adaptation to climate change in the semi-arid zone in Tanzania: The role of genetic resources and seed systems. *Agriculture & Food Security*, 3, 3. <https://doi.org/10.1186/2048-7010-3-3>
- Wosene Minwagaw, G., & Gobie Ejigu, W. (2021). Determinants of seed distribution system: The case of Womberma District, North West Ethiopia. *Advances in Agriculture*, 2021, 3656320. <https://doi.org/10.1155/2021/3656320>
- Wossen, T., Spielman, D. J., Alene, A. D., & Abdoulaye, T. (2024). Estimating seed demand in the presence of market frictions: Evidence from an auction experiment in Nigeria. *Journal of Development Economics*, 167, 103242. <https://doi.org/10.1016/j.jdevco.2023.103242>

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