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Breeding or Adoption? Groundnut Varietal Age and Farm Performance in Northern Ghana

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ABSTRACT

Are farmers reluctant to adopt new groundnut varieties, or are breeding programs failing to address the needs of smallholder farmers in sub-Saharan Africa (SSA)? Breeding programs and sustainable seed systems that support the development and delivery of new elite varieties are crucial for improving smallholder welfare. This study addresses this challenge by analyzing farm household survey data from 540 groundnut farmers to examine the relationship between groundnut varietal age, yield, farm income, and profit in the Guinea Savannah agroecology of Ghana. Despite recent advancements in groundnut breeding, 16% of farmers continue to grow varieties that are more than 10 years old. Key factors influencing this include distance to seed shops, farming experience, access to all-weather roads, electricity, and geographic location. After accounting for the endogeneity of varietal age, the findings show that older varieties are associated with lower yield, revenue, farm income, and profit, with productivity serving as the mediating channel. The main policy implication is that improving seed accessibility should be a priority, through the expansion of decentralized seed production and distribution networks for certified seeds and the establishment of community-level seed enterprises. Additional strategies, such as investing in mobile seed distribution programs and encouraging private sector participation in groundnut seed marketing, could further enhance access to and adoption of new varieties.

JEL Classification: I31, O13, Q12, Q18

1 | Introduction

Agriculture remains a critical sector for economic growth, food security, and poverty reduction in sub-Saharan Africa (SSA). Recent projections by the Food and Agriculture Organization of the United Nations indicate that the global quest to end hunger, food insecurity and malnutrition by the end of this decade is far offtrack (FAO et al. 2024). By 2030, an estimated 582 million people are projected to be chronically undernourished, the majority (53%) of whom will be concentrated in Africa (FAO et al. 2024), where climate change and variability will further exacerbate the fight against hunger by slashing crop yields (Mason-D'Croz et al. 2019). The development and dissemination of new crop varieties is crucial for adapting extant cropping systems to climate change and for agricultural productivity growth in the developing world (Atlin et al. 2017). However, the slow pace of varietal turnover—the rate at which farmers replace older crop varieties with newly improved ones—continues to limit productivity gains. The uptake of the new crop varieties has strikingly remained low, especially in SSA (Atlin et al. 2017). Such continued overreliance on old and obsolete crop varieties not only results in yield decline or stagnation and poor climate change adaptation (Ray et al. 2012) but also further heightens the vulnerability of farm households to pest and disease outbreaks (Chivasa et al. 2022).

Smale et al. (1998) underscore the importance of varietal turnover as an indicator of the impact of plant breeding programs via genetic improvements in crop yield or other desirable attributes. Defined as the "replacement by farmers of an older variety with a more recently developed improved variety, a process that entails a genetic change," varietal turnover is known to significantly contribute to sustained crop yield over time (Spielman and Smale 2017) and the resilience of cropping systems to climate change (Atlin et al. 2017). Also, due to genetic deterioration (Krishna et al. 2014), varietal age tends to have a significant negative effect on crop yield (Smale et al. 2008; Smale and Olwande 2014). Whiles an average varietal age below 10 years is indicative of progress in plant breeding, that close to 20 years suggests that modern crop varieties do not compete well with older varieties (Walker and Alwang 2015). Despite the importance of varietal turnover to productivity gains, farm households in SSA still cultivate crop varieties that are older than 20 years (Atlin et al. 2017). For instance, the most popular groundnut variety cultivated by farmers in Ghana is the "Chinese variety," a variety released in 1980 that is over 44 years ago. Even for a crop like maize, the average varietal turnover in Ghana is 23 years (Ragasa et al. 2013, 2014). This begs the question whether farm households are just reluctant in taking up modern crop varieties or breeding programs have failed to meet the needs or address the binding constraints of farm households in SSA?

The literature shows that low adoption of improved crop varieties is inadequate extension and information flow, socioeconomic and demographic barriers, poorly aligned varietal traits with farmers' preferences, limited involvement of farmers in breeding, and weak seed system infrastructure (Koomson et al. 2024; Amoako et al. 2023; Tanko et al. 2023; Puozaa et al. 2021). In Ghana, adoption has been low, leading to low varietal turnover. Lack of government funding for research institutions has impeded the development of new varieties consistent with the preferences of farmers; thus, the average age of varieties remains high (Puozaa et al. 2021; Poku et al. 2018). Despite these challenges, there has been progress in groundnut breeding programs aimed at developing new varieties with funding support from international organizations. Nevertheless, the minimum breeding period under conventional breeding spans from 5 to 7 years and can extend to 8–10 years if multiple cycles of field evaluation and adaptability trials are required (Owusu-Akyaw et al. 2019). The time period, coupled with the weak scaling and intentional seed delivery efforts, limits adoption among smallholder farmers and further increases the average varietal age.

In this study, we investigate the relationship between groundnut average varietal age, expressed as the years since the commercial release of a groundnut variety, on groundnut yield, revenue, farm income, and profit. Growing evidence has underscored the important contribution of improved groundnut varieties to both welfare and farm outcomes in SSA (Tabe-Ojong et al. 2023; Melesse et al. 2023; Lokossou et al. 2022; Kassie et al. 2011). In terms of welfare outcomes, improved groundnut cultivars have been shown to significantly alleviate poverty by raising household income (Kotu et al. 2022; Lokossou et al. 2022; Kassie et al. 2011); boost food security (Melesse et al. 2023; Kassie et al. 2011); and increase consumption and commercialization (Tabe-Ojong et al. 2023).

Albeit important, evidence is scarcely accessible on the relationship between average varietal age and household welfare and farm outcomes in general, and that of groundnut cultivars in particular. The handful of studies that have explored this linkage either focused on outcomes such as yield and food security (De Groote and Omondi 2023; Sharma et al. 2024) or on crops such as maize (De Groote and Omondi 2023) and potato (Sharma et al. 2024). For instance, evidence by De Groote and Omondi (2023) indicates that varietal turnover exerts a small but significant effect on crop yield and household food security in Kenya, with younger maize varieties tending to yield 4 kg/ha/year more. In this study, we add value to these existing studies on varietal turnover by considering a broader range of outcome variables such as yield, revenue, farm income, and profit. Our study focused on groundnut, a leguminous crop. As a legume, the crop also contributes to farm outcomes such as increased productivity by augmenting soil fertility through biological nitrogen fixation and soil moisture conservation (Yusuf et al. 2009; Sanginga 2003). This may translate into reduced need for synthetic fertilizers (Stagnari et al. 2017), thereby lowering farm production costs.

The choice of groundnut is more appropriate for this study, given the value this legume can add to agricultural production in the more drier Guinea Savannah agroecology, where annual rainfall is relatively lower and more erratic (Issahaku et al. 2016). The top five groundnut-producing regions in Ghana are those located in the savannah agroecology (MoFA 2022), perhaps due to the crop's potential to contribute to reduced vulnerability of farm households in the savannah agroecology to weather-related shocks (Kotu et al. 2022). This agroecology is highly susceptible to the adverse effects of climate change (Segnon et al. 2021; Midgley and Thuiller 2011). In Ghana, groundnut is cultivated mainly as food and for cash income (MoFA 2022; Jolly et al. 2008). However, current yield levels on smallholder fields remain at 53% of potential (MoFA 2022). This accentuates the need for an improved understanding of the contribution of varietal turnover to crop yields, revenue, farm income, and profit.

Our contribution to the literature is threefold. First, we extend the limited body of knowledge on the potential effect of varietal age by accounting for endogeneity, to establish a more robust association between varietal age and welfare outcomes. Second, compared to prior studies, we consider a broader range of outcome variables and identify the potential mechanism through which average varietal age influences the outcome variables. Most previous studies failed to test the potential mechanisms. The outcome of the analysis can serve as entry points for future interventions to improve welfare outcomes. Finally, we conducted a heterogeneity analysis to guide development practitioners and policymakers on which categories of farmers to prioritize for training and other interventions that address the use of old varieties. Most of the previous studies ignore such analysis given that average varietal age may not influence the entire sample the same. With government limited budget, the outcome of the study will guide government efforts toward improving livelihoods of farm households. The findings can also serve as a guide for other countries with similar agroecological and socio-economic conditions.

We organize the remaining segments of the paper as follows: Section 2 provides a detailed background on the groundnut seed system in Ghana. This is followed by section 3 which details the data used for the analysis. Next, is Section 4, which outlines the empirical strategy of the study. The empirical results and discussion are provided in Section 5. Finally, Section 6 presents the conclusion and policy implications of the study.

2 | Background: Groundnut Seed Systems in Ghana

The structure of the groundnut seed system in Ghana significantly influences varietal turnover. It consists of multiple stakeholders operating within formal, semiformal, and informal seed systems, each playing a role in varietal development, multiplication, and dissemination (Figure 1). The formal seed system includes government agencies, research institutions, and private seed companies responsible for producing various classes of seeds. A significant contributor to this system is the Savanna Agricultural Research Institute of the Council for Scientific and Industrial Research (CSIR-SARI), which develops improved groundnut varieties with desirable traits such as high yield, disease resistance, and drought tolerance (Etwire et al. 2013). The formal seed system begins with breeder seeds produced by the research institutions that developed the variety. The breeder seed is further multiplied by organizations such as CSIR-SARI, accredited private seed companies with the technical competencies, and the Grains and Legumes Development Board (GLDB) of the Ministry of Food and Agriculture (MoFA) to produce foundation seed. The foundation seed is then distributed to seed companies and seed growers, who use it to produce certified seeds—the final class of seeds used by farmers for grain production. The Ghana Seed Inspection Directorate (GSID) under the MoFA oversees the quality control and certification of all seed classes in this system. Each seed lot or batch is certified after it has been tested and meets the minimum quality requirements for the respective class.

The semiformal seed system includes government agencies, farmer groups, innovation platforms, and development projects that facilitate community-based seed production (Puozaa et al. 2021). Though these actors enhance local seed access, the final seed produced for farmers is without formal certification.

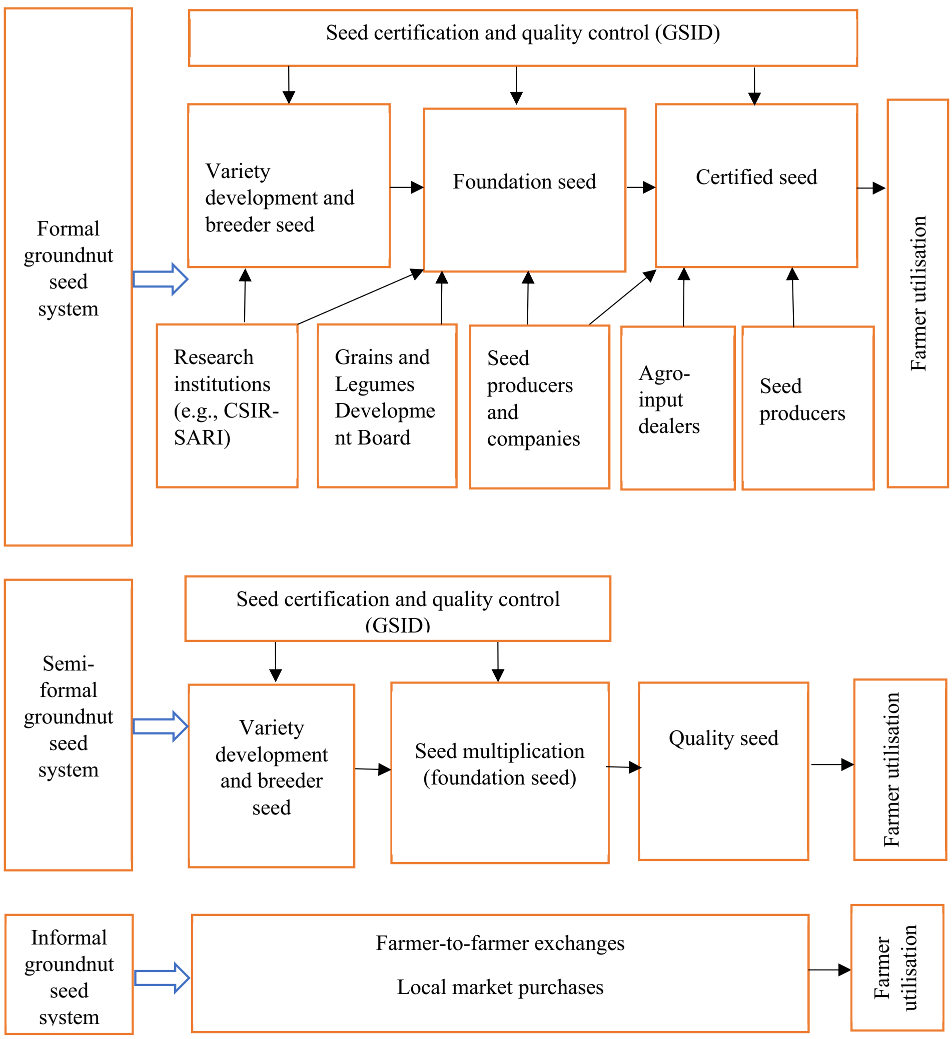

FIGURE 1 | Groundnut seed systems in Ghana.

In the semiformal system, the production of the first two seed classes (breeder and foundation seed) and sometimes certified seed is regulated by the GSID to ensure compliance with the quality standards for purity, germination rates, and seed health. Development programs, projects, and interventions frequently procure foundation seeds for farmer groups, innovation platforms, and cooperatives, enabling them to produce quality seeds for their members and sell the surplus to other farmers within the community and surrounding villages. These seeds, however, are not formally certified by the GSID. Often referred to as community seed production, the semiformal approach primarily targets locally significant food and cash crops.

The informal seed system is unstructured and unregulated, with its activities neither monitored nor supervised by any public or private institution. Rooted in traditional practices, this system enables farmers to manage and exchange crop seeds through local networks, markets, and social norms, reflecting the community's culture and heritage. Farmers typically acquire seeds through their own production, farmer-to-farmer exchanges, or local markets (Westengen et al. 2023). This system is particularly prevalent in rural areas where access to certified seeds is limited or nonexistent, often due to poor seed distribution networks from the formal sector and high costs (Ndjeunga et al. 2006). As a result, the informal seed system accounts for the majority of seeds planted by farmers. This is more so for crops like groundnut and other legumes. It also serves as a critical entry point for the broader value chain development of groundnuts in Ghana.

3 | Data and Descriptive Statistics

3.1 | Data

3.1.1 | Study Area and Sampling

The study utilizes survey data from key groundnut-producing districts in the Guinea Savannah agroecology of Ghana, comprising Northern, North East, Savannah, Upper East, and Upper West regions. The survey captures key information on household characteristics, access to social amenities and institutions, landholding and management practices, knowledge of improved groundnut varieties and utilization, distribution of harvest, crop varietal preferences, household assets, income, food and nonfood consumption, farm expenditure, and poverty.

Figure 2 illustrates the administrative regions of the study area and the use of old varieties across these regions. The North East region recorded the longest use of varieties for approximately, with seeds being 10 years. In comparison, the other regions reported an average varietal age of 6 years.

3.1.2 | Sampling

We determined the sample size using the formula proposed by Yamane (1967): $n = \frac{N}{(1+Ne^2)}$, where N is the population of farmers in the study area (northern Ghana), e is the desired margin of error (5%), and n is the required sample size. Based on the Ministry of Food and Agriculture (2022), the population of

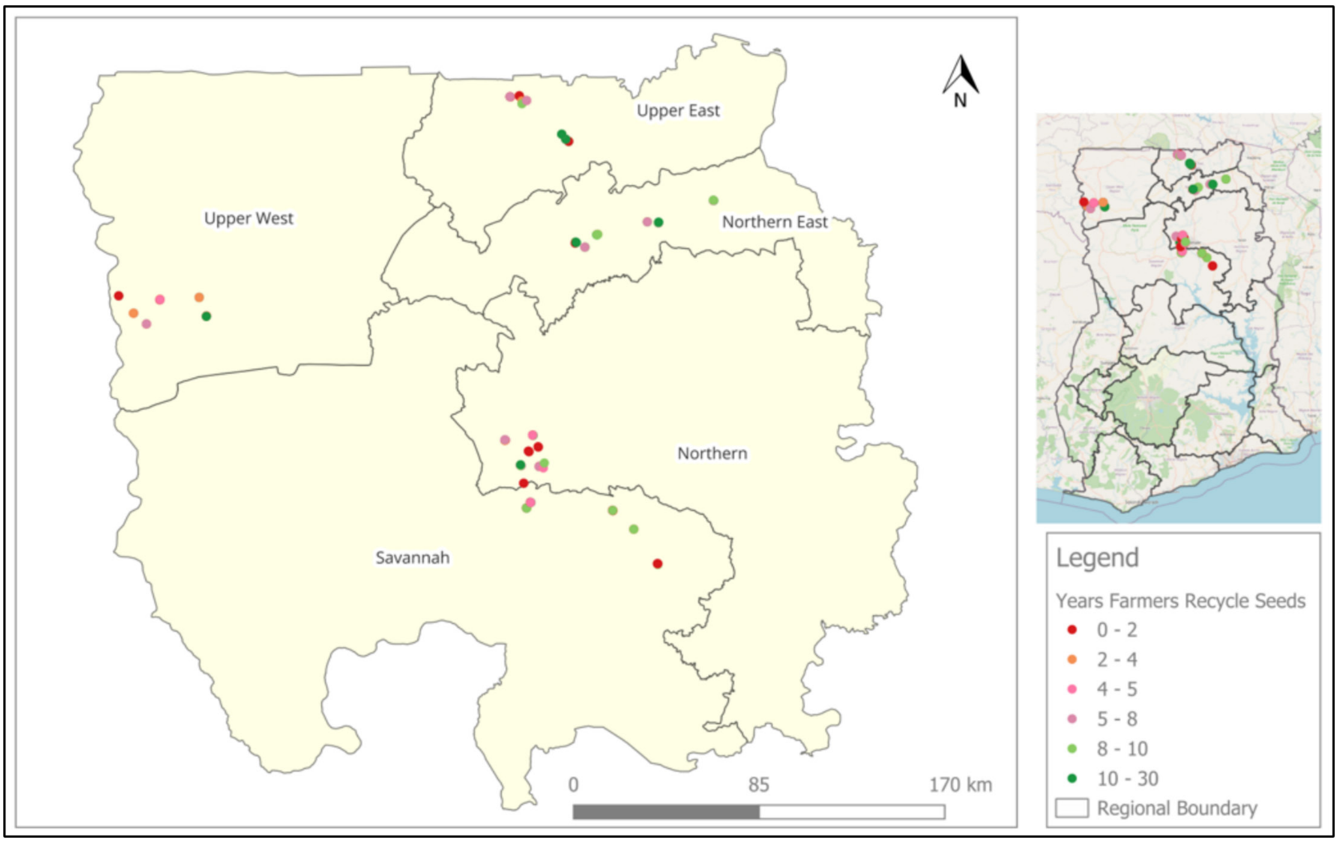

FIGURE 2 | Administrative map of the study area.

agricultural households in northern Ghana is 582,638. Using a 5% margin of error, the minimum required sample size is 400. However, to account for potential nonresponse and to further enhance the reliability of the estimates, we intentionally oversampled beyond this minimum.

While Yamane's formula provides a quick estimate for known populations, Salkind (1997) presents a more general expression for estimating sample sizes when proportions are being measured. Salkind's (1997) recommended formula for determining sample size for proportions is: $n = \frac{Z^2 p(1-p)}{e^2}$, where Z is the Z-value corresponding to the desired confidence level (1.96 for 95% confidence), Z is the estimated population proportion (commonly set at 0.50 to maximize variance), and e is the acceptable margin of error (0.05 in the study). Using a 95% confidence level and assuming maximum variability ($p = 0.50$), the minimum sample size is 384. Comparatively both methods yield similar results for large populations, but Salkind's approach is more flexible when estimating proportions under different confidence levels.

The sample of groundnut producers was drawn using a combination of purposive and simple random sampling techniques to select 540 farmers in northern Ghana. In the first stage, two districts were purposively chosen from each of the five regions in northern Ghana, based on the quantity of groundnut produced and the active presence of groundnut value chain actors. In the second stage, six communities were purposively selected from each district across the five regions in northern Ghana, considering factors such as accessibility and gender distribution. The selected communities have a long history of cultivating old varieties of groundnut. Within the selected communities, 18 groundnut producers were randomly chosen from a list of registered groundnut producers. In total, 540 groundnut producers were selected from 36 communities across 10 districts.

3.1.3 | Outcome and Policy Variables

The primary outcome variables for this study are groundnut yield, groundnut income, farm income, and profit. Groundnut productivity is calculated as the total quantity of groundnuts produced per unit area, expressed in kilograms per hectare. Groundnut income is determined by multiplying the quantity of groundnuts sold by the prevailing market price, expressed in Ghanaian cedi (GHS). Farm income is derived from the total revenue generated by all farm enterprises, including crops and livestock, and is expressed in Ghanaian cedi. Finally, groundnut profit is computed by subtracting the total cost of production (including land rental, fertilizer, seed, herbicides, pesticides, and labor) from the revenue generated by groundnut sales.

Following Brennan and Byerlee (1991), we constructed the treatment variable, WAA, as the weighted average age (WAA) of groundnut varieties. This is expressed as

$$WAA_i = \sum_i p_i R_i \tag{1}$$

where p_i is the area share of groundnut variety i to the total area covered by groundnut and the number of years (R_i) since the variety was released.

3.2 | Descriptive Statistics

Figures 3–6 present a nonparametric local polynomial regression examining the relationship between WAA and the outcome variables while controlling for regional fixed effects. Figure 3 shows the relationship between WAA and yield. The results indicate a positive relationship at lower WAA and an inverse relationship at higher WAA. However, the inverse relationship predominates, suggesting that yield declines with increased use of old varieties of groundnut. Similarly, Figure 4 illustrates the relationship between WAA and groundnut revenue, showing a positive association at lower WAA, which declines at higher WAA. Figure 5 demonstrates a comparable pattern for farm income, where lower WAA is associated with higher income compared to higher WAA. Lastly, Figure 6 depicts the relationship between WAA and profit, revealing a positive correlation at low WAA levels but a negative correlation at higher WAA levels.

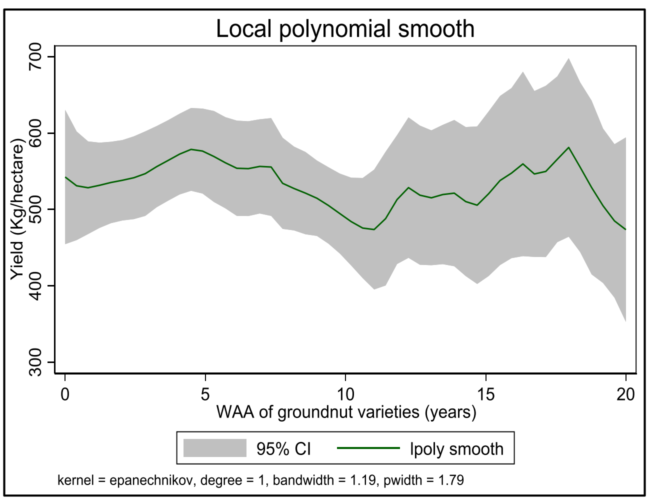

FIGURE 3 | Yield and WAA of groundnut varieties.

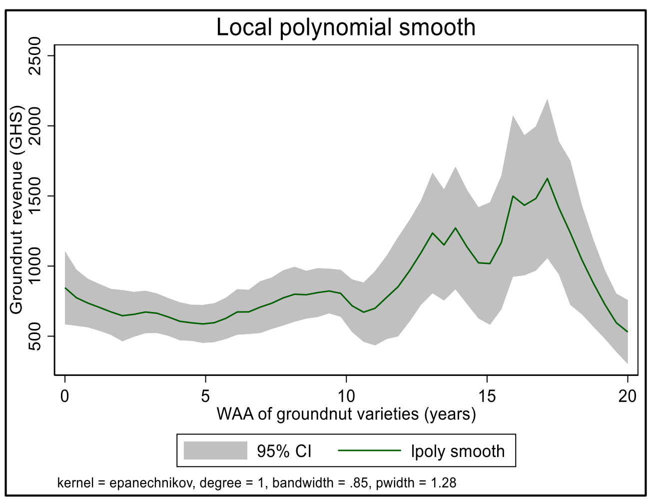

FIGURE 4 | Groundnut revenue and WAA of groundnut varieties.

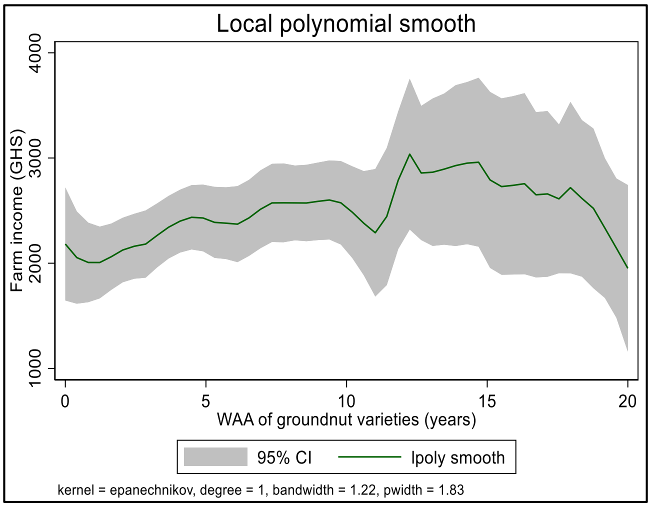

FIGURE 5 | Farm income and WAA of groundnut varieties.

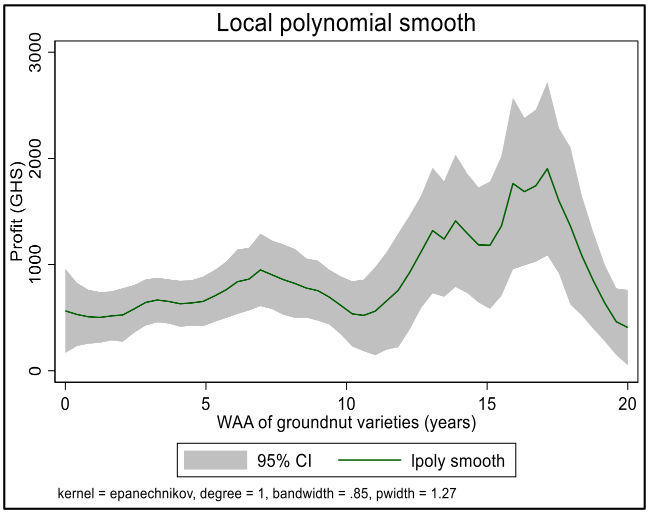

FIGURE 6 | Profit and weighted average age of groundnut varieties.

Figure 7 presents the groundnut varieties cultivated, their replacement age, and the corresponding average yields. Among the varieties, the "Chinese" groundnut variety is the oldest, followed by "Nkatiesari," "Manipintar," "Obolo," and "Samnut 22." In terms of yield, "Obolo" recorded the highest, followed by the "Chinese" variety, "Samnut 22," "Nkatiesari," and "Manipintar." These findings highlight that the relationship between longevity of use of groundnut variety and yield is variety-specific. For instance, while the "Chinese" variety is the oldest, it still achieved a relatively high yield, suggesting that longevity of a variety does not necessarily result in lower yields for all varieties. On the other hand, "Samnut 22," the relatively new variety, recorded the lowest average yield, indicating that factors beyond longevity of use—such as genetic characteristics (Table 1) or adaptability to local conditions—may play a more significant role in determining productivity.

Table 2 presents the descriptive statistics of the explanatory variables used in the regression analysis. The summary of the dependent variables reveals that the average groundnut yield is approximately 538 kg/ha, with corresponding revenue, farm income, and profit averaging GHS727 (US$127), GHS2,376 (US$415), and GHS689 (US$120), respectively. The data indicate that 58% of the respondents are male, with an average age of 41 years. On average, households consist of 10 members, including three female adults and two male adults. Farmers have an average of 3 years of formal education, 15 years of farming experience, and 11 years of cultivating groundnuts. About 22% and 5% of the farmers participated in groundnut training and received support from NGOs, respectively. The average cultivated land area is 2.7 ha. With reference to access to social amenities, about 83%, 70%, and 31% of the sampled farmers have access to all-weather roads, electricity, and functional markets. The average distance to the nearest input shop is 13 km, and 45.6% of farmers are members of cooperatives. The average risk aversion of farmers is 1.68, with 36.1% having access to cooperatives and 60% having access to groundnut management equipment. The regional distribution of the sampled farmers is also provided, highlighting their geographic representation.

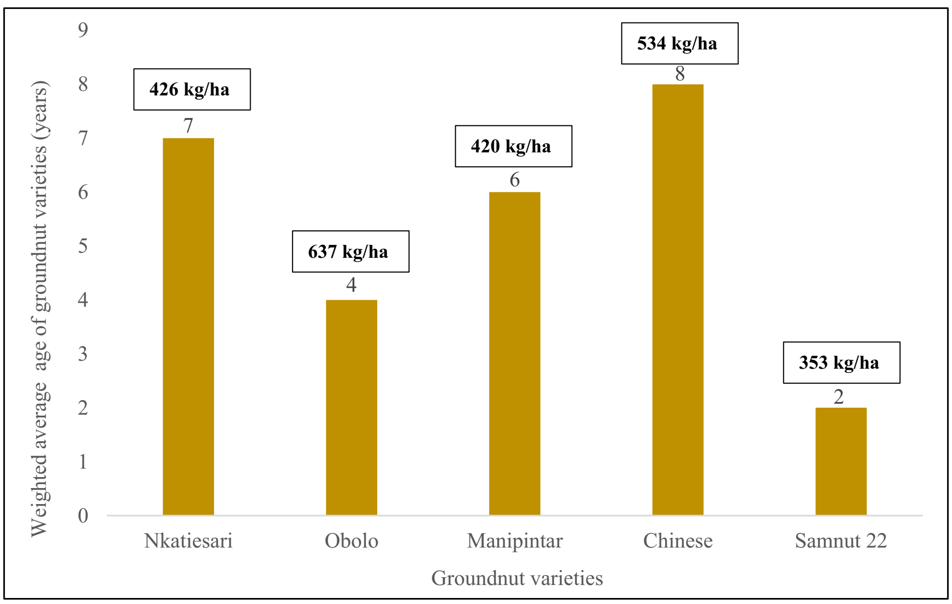

FIGURE 7 | Profit and weighted average age of groundnut varieties.

TABLE 1 | Varieties cultivated and their characteristics.

Name of variety	Year of release	Characteristics
Chinese	1980	Early maturing (90 days after planting), yield: 2 t/ha: suitable for confectionery, seed coat color: tan, 100 seed weight: 38 g, oil content: 35% oil. Adapted to the Guinea and Sudan Savannah Ecologies of Ghana
Manipintar	1986	High yielding and resistant to foliar diseases. Suitable for commercial oil extraction, maturity: 120 days, kernels contain about 47% oil. Adapted to the Guinea and Sudan Savannah Ecologies of Ghana
Nkatiesari	2005	Medium maturing: 110 days, yield: 2.6 t/ha, resistant to early and late leaf spot infections caused by *Cercospora arachidicola* S. Hori *and Cercosporidium personatum* (Berk. & Curt.) Deighton, respectively, oil content: 46%, seed coat color: tan, 100 seed weight: 50 g. Adapted to the Guinea and Sudan Savannah Ecologies of Ghana
Obolo	2012	Maturity: 120 days, yield: 2.7 t/ha, 100 seed weight: 80.8 g, oil content: 48%, seed coat color: tan. Adapted to the Savannah, Forest-Savannah Transition, Semi Deciduous Forest
Samnut 22	2001	Maturity: 120 days, high seed and forage yield, potential yield: 2.5 t/ha. Adapted to the Northern Guinea Savanna and Southern Guinea Savanna agroecological zones of Nigeria

4 | Empirical Strategy

4.1 | Baseline Estimation

The baseline model for estimating the effect of varietal age on welfare outcomes (Equation 2) is as follows:

$$Y_i = \theta + \phi WAA_i + \vartheta X_i + \varphi H_i + \eta_r + \upsilon_i \quad (2)$$

where Y_i is the welfare outcome variables (productivity, groundnut revenue, farm income, and profit); WAA_i is groundnut varietal age, which is measured as the weighted average age of groundnut varieties; X_i is a vector of control variables; H_i is farm characteristics; η_r is region fixed effects; and υ_i are random error terms. The parameter of interest ϕ measures the effect of groundnut variety turnover on the outcome variables. We hypothesized that groundnut varietal age is negatively associated ($\phi < 0$) with productivity, groundnut revenue, farm income, and profit.

We acknowledge that the estimation of ϕ in Equation (2) will be biased using OLS due to the endogeneity in the weighted average age of groundnut varieties.

4.2 | Instrumental Variable

We envisaged three sources of endogeneity: (1) reverse causality, (2) unobserved heterogeneity, and (3) measurement error. The latter is not a challenge in our study. However, unobserved heterogeneity and reverse causality are the main sources of endogeneity. For the unobserved heterogeneity, we controlled for several covariates in our model to reduce the extent of the bias. Regarding the reverse causality, we employed an instrumental variable (IV) in a two-stage least squares (2SLS) approach to account for the endogeneity issues in the construct of groundnut varietal age. Due to the residual endogeneity, we refrain from making any causality claims but rather the results should be interpreted as association.

We executed the IV estimation in two stages. The first stage (Equation 3) is estimated by regressing groundnut varietal age (WAA_i) on the proposed instrument (I_i), control variables (X_i), farm characteristics (H_i) and region fixed effects (ϑ_r) to obtain the estimated values of WAA ($\widehat{WAA_i}$). In the second stage, $\widehat{WAA}_i$ is included as a covariate in the outcome equations (Equation 4).

$$WAA_i = \alpha + \psi_1 I_i + \varphi H_i + \sum_n \psi_n X_{n,i} + \eta_r + \varepsilon_i \quad (3)$$

$$Y_i = \delta + \beta_1 \widehat{WAA}_i + \beta_2 H_i + \sum_n \psi_n X_{n,i} + \eta_r + \mu_i \quad (4)$$

The parameter of interest in the IV estimation is β_1. As previously stated, after controlling for endogeneity in groundnut varietal age, we expect a negative association between WAA, productivity, groundnut revenue, farm income, and profit. Our control variables include age, sex, marital status, female and male adults, education, faming experience, household size, participation in groundnut training, access to nongovernmental organizations (NGOs), all-weather road, market, membership in farmer-based organization, access to electricity, certainty equivalent measure of risk[1], and groundnut management. Table 2 reports detailed description of the control variables. Given that location plays a critical role in terms of access to infrastructure, inputs, markets, and other factors that may enhance groundnut variety turnover decisions, we accounted for region fixed effects.

We tested several instruments such as access to research institutions, extension services, and access to agricultural development projects due to their importance in the dissemination of agricultural technologies such as seeds. Although they are plausible candidates for instruments, the exclusion restriction

TABLE 2 | Descriptive statistics.

Variable	Variable description	Mean	Std. dev.
Yield	Groundnut yield (kg/ha)	538.538	352.026
Groundnut revenue	Groundnut revenue (GHS)	727.483	891.755
Farm income	Farm income (GHS)	2376.732	2184.064
Profit	Groundnut profit (GHS)	688.876	1394.625
Age	Age of farmer (years)	41.35	12.265
Sex	Male farmer (1 = yes)	0.576	0.495
Female adult	Number of female adults (number)	2.772	1.886
Male adult	Number of female adults (number)	2.428	1.683
Household size	Household size (number)	10.431	6.200
Education	Years of education (years)	2.77	4.085
Farming experience	Farming experience (years)	15.091	10.457
Groundnut farming	Years of groundnut cultivation (years)	10.67	8.158
Training	Participation in groundnut training (1 = yes)	0.219	0.414
NGO	Support from NGOs (1 = yes)	0.048	0.214
Road	Access to all-weather road (1 = yes)	0.833	0.373
Land	Area cultivated in 2019 (hectares)	2.723	2.464
Distance to seed shop	Distance to nearest input shop (kilometers)	12.797	11.953
Farmer cooperative	Member of farmer cooperatives (1 = yes)	0.456	0.498
Electricity	Access to electricity (1 = yes)	0.698	0.459
Market	Access to market (1 = yes)	0.311	0.463
Cooperative	Access to cooperatives (1 = yes)	0.361	0.481
Risk aversion	Risk aversion	1.679	3.388
Management	Access to groundnut management equipment (1 = yes)	0.602	0.490
Northern	Reside in Northern Region (1 = yes)	0.200	0.400
Savannah	Reside in Savannah Region (1 = yes)	0.200	0.400
North East	Reside in North East Region (1 = yes)	0.200	0.400
Upper East	Reside in Upper East Region (1 = yes)	0.202	0.402
Upper West	Reside in Upper West Region (1 = yes)	0.198	0.399

Note: Std. dev. is standard deviation. 1 USD = GHS5.7268 (*Source:* https://www.exchange-rates.org/exchange-rate-history/usd-ghs-2020).

was difficult to justify. This study relied on distance to the nearest input seed shop as a plausible instrument. Farmers that are close to seed input shops are more likely to buy seed given a reduction in their transaction cost relative to when they are distant from input shops. Empirical seed adoption literature supports that proximity to agrodealers significantly influences adoption speed and varietal turnover (Liverpool-Tasie et al. 2017; Bezu et al. 2014). While proximity to shops could theoretically affect farm productivity, in our context, shops primarily sell seed and small inputs rather than directly providing services that enhance productivity. By controlling for other input access variables (e.g., farmer cooperatives, extension contact), the only remaining channel through which distance influences farm revenue and income is via the likelihood of replacing old varieties. In some contexts, farmers may select seed outlets based on varietal preferences, potentially introducing endogeneity, as noted by Khed et al. (2024). In our study area, however, this concern is minimal. Input shops are few and generally located far from most farmers' fields, which limit farmers' ability to choose outlets based on varietal availability. Survey evidence further indicates that farmers typically purchase seeds from the nearest available shop. Therefore, the potential for endogeneity in our instrument due to outlet selection is substantially reduced in this context.

Farm productivity or income levels do not determine the geographic location of input shops, as shop placement is more influenced by broader market and road network considerations rather than individual farm performance. Groundnut seeds are bulky and often sourced locally; longer distances to seed sources make timely replacement with new varieties less likely. Older varieties persist more in remote areas due to higher transport costs, lower frequency of input deliveries, and weaker seed distribution networks. In view of the justification, we expect the instrument to influence the outcome variables only through the endogenous WAA variable. We tested the strength of the instrument based on a test proposed by Stock and Yogo (2005).

4.3 | Other Endogeneity-Correcting Models

We complement the IV with the control function approach (CFA) proposed by Wooldridge (2015) to check for the robustness of the estimates of WAA on the outcome variables. Second, we estimated the Lewbel 2SLS, which uses an internally generated instrument to correct for the endogeneity (Lewbel 2012). The Lewbel 2SLS is more robust in the presence of a weak instrument.

4.4 | Effects Heterogeneity

To gain a deeper insight into the heterogeneous relationship between WAA and the outcome variables across different groups, we employ quantile regression. This analytical approach enables the investigation of the influence of any covariate on the conditional distribution of the outcome variable in relation to the mean conditional value. The results derived from this analysis can provide valuable insights for policymaking tailored to efficiently address the distinct needs of diverse socioeconomic groups. Building upon Equation (5), we estimate the following model:

$$Y_i = X_i' \partial_\varphi + \mu_i, \left(y_i | X_i\right) = X_{h,d}' \partial_h \quad (5)$$

where $X_{h,d}$ is a vector of explanatory variables including WAA. $(Y_i \mid X_{h,d})$ is the conditional quantile of Y_i at quantile φ. We estimate the association between WAA and the outcome variables concentration using nine different quantiles ($\partial_\varphi = 0.10$, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, and 0.90) and using the same covariates as in the 2SLS regression.

5 | Empirical Results and Discussion

5.1 | Baseline Estimates of WAA on Yield, Income, Farm Income, and Profit

Table 3 presents the baseline estimates of the relationship between WAA, yield, groundnut revenue, farm income, and profit using the OLS estimator. The findings indicate that each additional year a groundnut variety is cultivated is associated with a 6-kg/ha decline in yield, while no statistically significant association is observed with revenue, farm income, or profit. Despite the lack of statistical significance, the results align with a priori expectations, suggesting that prolonged seed recycling is linked to declines in revenue, income, and profit. However, these estimates may be biased due to potential endogeneity in the longevity of using the same groundnut varieties, making the observed associations unreliable. To address this issue, we turn to an endogeneity-correcting model for more robust analysis.

Beyond WAA, yield is significantly influenced by the farmer's age, farming experience, access to electricity, and geographic location. Groundnut revenue is significantly affected by the farmer's sex, years of education, participation in groundnut training programs, field management practices, and location. Farm income is significantly associated with sex, farming experience, participation in groundnut training, access to all-weather roads, membership in farmer-based organizations, market access, and location.

5.2 | IV-2SLS Estimates of WAA on Yield, Groundnut Revenue, Farm Income, and Profit

Table 4 presents the instrumental variable results examining the association between WAA, yield, revenue, farm income, and profit while addressing endogeneity concerns in WAA. The first-stage results indicate a positive association between the distance to the nearest seed shop and varietal age. The result suggests that farmers are more likely to use old varieties of groundnut seeds if they live far from the seed shop. The *F*-statistics in the first-stage regressions exceed the threshold of 10, confirming that our instrument and WAA are not weakly associated (Stock and Yogo 2002). The robust score chi2 suggests that WAA is endogenous, indicating that failure to account for endogeneity may lead to a biased estimate.

The results show that each additional year of using the same groundnut variety is associated with a 56 kg/ha decline in yield (Column 1), a GHS163 (US$28) reduction in groundnut revenue (Column 2), a GHS267 (US$47) decrease in farm income (Column 3), and a GHS106 (US$19) drop in profit (Column 4). Varietal age often leads to a loss of genetic vigor. The repeated use of seeds reduces germination rates, resistance to diseases, and overall plant productivity. Lower output directly reduces the quantity of groundnuts available for sale, thereby decreasing revenue, farm income, and profit. Since yield is a primary determinant of revenue, any decline in yield negatively impacts overall financial returns (Shiferaw et al. 2014; Smale et al. 2013; Louwaars and De Boef 2012). In addition, poor seed quality from older crop varieties often requires higher investment in fertilizers, pesticides, and other inputs to mitigate the effects of lower seed vigor and susceptibility to pests and diseases (Tripp and Rohrbach 2001). These increased costs reduce profit margins. Varietal age may lead to lower quality outputs, which limit the ability to pursue higher value market opportunities, thus constraining revenue potential (Shiferaw et al. 2014; Smale et al. 2013; Louwaars and De Boef 2012). A study by Morris and Heisey (2003) shows that farmers who continue to use the same variety of seeds may face diminishing returns on inputs like labor and land. Reduced yield potential from older varieties means that the same amount of effort generates less output, reducing overall efficiency and profitability. Eshete et al. (2021) demonstrated

TABLE 3 | OLS estimates of varietal turnover on yield, revenue, and profit.

Variables	(1) Yield (kg/ha)	(2) Groundnut revenue (GHS)	(3) Farm income (GHS)	(4) Profit (GHS)
Weighted average age (years)	−5.707*	−6.161	−22.893	−11.919
	(2.991)	(6.114)	(16.192)	(9.638)
Age	−5.506***	−0.452	−18.893*	−10.934*
	(1.910)	(3.995)	(10.532)	(6.117)
Sex	−22.089	375.172***	1405.109***	386.536***
	(32.022)	(69.130)	(170.430)	(112.693)
Female adult	8.820	15.726	68.580	9.254
	(12.756)	(34.390)	(69.022)	(46.699)
Male adult	5.843	23.805	105.447	37.791
	(11.977)	(36.799)	(65.493)	(46.384)
HH size	−3.412	7.132	−4.952	6.390
	(4.620)	(13.613)	(26.755)	(17.467)
Education	5.516	20.137**	4.849	34.015**
	(3.807)	(9.845)	(21.950)	(14.558)
Experience	7.838***	4.508	37.777***	24.554***
	(2.469)	(5.289)	(12.508)	(7.789)
Training	−23.020	182.428*	439.212*	164.116
	(35.664)	(98.694)	(233.513)	(140.173)
NGO	71.219	133.859	228.256	127.223
	(62.259)	(143.976)	(371.408)	(237.930)
Road	36.225	−66.771	387.429*	108.834
	(45.069)	(102.602)	(199.533)	(139.690)
FBO	33.130	−133.596	374.301*	47.855
	(36.393)	(92.737)	(198.672)	(136.785)
Electricity	−84.154*	−123.658	−489.813**	−120.501
	(43.596)	(92.428)	(226.279)	(146.446)
Market	4.050	79.393	430.305**	−244.962**
	(34.110)	(71.392)	(185.089)	(123.861)
Risk aversion	−0.936	12.230	28.705	9.324
	(3.215)	(12.116)	(17.837)	(23.595)
Management	−8.944	252.215***	−3.844	259.788**
	(32.925)	(73.091)	(185.676)	(117.068)
Northern	40.809	432.206***	582.998**	918.706***
	(49.670)	(114.017)	(291.990)	(197.906)
Savannah	−0.488	377.470***	936.687***	889.206***
	(50.935)	(118.636)	(269.613)	(173.824)

(Continues)

TABLE 3 | (Continued)

Variables	(1) Yield (kg/ha)	(2) Groundnut revenue (GHS)	(3) Farm income (GHS)	(4) Profit (GHS)
North East	189.296***	682.760***	1471.565***	1379.624***
	(49.558)	(119.447)	(277.856)	(183.437)
Upper West	451.080***	875.077***	3059.795***	2177.079***
	(56.320)	(130.645)	(297.731)	(214.222)
Constant	566.631***	−239.979	−116.134	−884.378***
	(93.481)	(211.036)	(541.945)	(314.939)
Observations	540	540	540	540
R-squared	0.243	0.255	0.393	0.321

Note: Robust standard errors are in parentheses. 1 USD = GHS5.7268 (*Source:* https://www.exchange-rates.org/exchange-rate-history/usd-ghs-2020).
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

TABLE 4 | IV-2SLS estimates of varietal turnover on yield, revenue, and profit.

Variables	(1) Yield (kg/ha)	(2) Groundnut revenue (GHS)	(3) Farm income (GHS)	(4) Profit (GHS)
Weighted average age (years)	−56.260***	−162.609***	−266.871**	−105.579*
	(21.195)	(59.600)	(105.729)	(62.667)
Other controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
First stage				
Distance to seed shop	0.102***	0.102***	0.102***	0.102***
	(0.027)	(0.027)	(0.027)	(0.027)
Diagnostics				
F-value	15	15	15	15
Robust chi2	9.423***	14.167***	8.736***	2.823***
Observations	540	540	540	540

Note: All controls are the explanatory variables reported in Table 1. Robust standard errors are in parentheses. Table S1 shows the full results. 1 USD = GHS5.7268 (*Source:* https://www.exchange-rates.org/exchange-rate-history/usd-ghs-2020).
***$p < 0.01$
**$p < 0.05$.
*$p < 0.1$.

that continuous use of the same seed variety is linked to a yield reduction of up to 665 kg/ha in wheat. They further reported that while varietal age lowers production costs, the resulting gains in net income are minimal due to reduced yields. Using household surveys in Kenya spanning 21 years, De Groote and Omondi (2023) found that relatively young maize varieties have a moderate impact on yield and food security. Similarly, Sharma et al. (2024) showed that young potato varieties are negatively associated with yield.

5.3 | Heterogeneity Analyses

In this section, we explore whether the association between varietal age and the outcome variables differs across heterogeneous groups. Table 5 presents the results of the association between varietal age and the outcome variables based on risk status (risk averse and risk loving). The negative association between WAA and the outcome variables is significant only among risk-averse farmers. Risk-averse farmers are more likely to prefer strategies that minimize their exposure to uncertainty and financial loss. For example, risk-averse farmers are often cautious about investing in agricultural inputs (fertilizers, pesticides, and improved seeds), even if these investments could increase productivity (Fisher and Snapp 2014; Dercon and Christiaensen 2011). Therefore, they are more likely to continue to use relatively old groundnut varieties, which subsequently reduce their yield, revenue, and profit. In Table 6, the results show that the negative association between WAA and the outcome variables is more noticeable in adult-headed households with no significant effect in youth-headed households.

Figures 8–11 show the distribution association between WAA and the outcomes based on quantile regression (refer to Table S5 for the complete results). The results show that farmers in the high quantile of yields ($\partial_{\varphi} = 0.50$ to 0.90) recorded significant yield decline due to using old varieties of groundnuts. The results suggest that high productivity farmers tend to reduce their yield significantly when they cultivate old varieties of groundnuts. The highest yield decline is observed for farmers within the 50th quantile yield (Figure 8). Figure 9 shows that high earners from groundnut sales ($\partial_{\varphi} = 0.70$) experience the most statistically significant decline in revenue when they use old groundnut varieties. We did not find any statistically significant decline in groundnut revenue due to varietal age of groundnut for farmers below the highest groundnut revenue (i.e., $\partial_{\varphi} < 0.70$). The lack of significant negative effects on farmers earning below certain thresholds suggests that lower income or less-profitable farmers may either be less sensitive to seed quality issues or are operating under different production constraints. Figure 10 illustrates that

TABLE 5 | IV-2SLS estimates of varietal turnover on yield, revenue, and profit by risk status.

Variables	(1) Yield (kg/ha)	(2) Groundnut revenue (GHS)	(3) Farm income (GHS)	(4) Profit (GHS)
Panel A. Risk-averse farmers				
Weighted average age (years)	−52.804**	−152.882***	−301.648***	−134.147**
	(21.031)	(57.523)	(108.862)	(66.488)
Other controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
First stage				
Distance to seed shop	0.125***	0.125***	0.125***	0.125***
	(0.033)	(0.033)	(0.033)	(0.033)
Diagnostics				
F-value	14	14	14	14
Observations	438	438	438	438
Panel B. Risk lover farmers				
Weighted average age (years)	−20.018	−95.768	25.278	−76.320
	(26.277)	(63.156)	(100.069)	(62.043)
Other controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
First stage				
Distance to seed shop	0.109**	0.109**	0.109**	0.109**
	(0.045)	(0.045)	(0.045)	(0.045)
Diagnostics				
F-value	6	6	6	6
Observations	102	102	102	102

Note: All controls are the explanatory variables reported in Table 1. Robust standard errors are in parentheses. 1 USD = GHS5.7268 (*Source:* https://www.exchange-rates.org/exchange-rate-history/usd-ghs-2020).
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

high farm income earners (i.e., $\partial_\varphi \geq 0.50$) recorded significant decline in farm income when they use old varieties of groundnut. However, farmers within the 70th and 80th farm income quantile recorded the highest farm income decline while the highest farm income earners ($\partial_\varphi = 0.90$) recorded the lowest farm income due to cultivating old varieties of groundnut. This may indicate that top earners have better risk mitigation strategies, diversified income sources, reducing the adverse effects on their farm income. The largest income declines are concentrated between the 70th and 80th quantiles highlight a vulnerable middle-income group that lacks the resilience of the highest earners but still experiences significant economic exposure. Figure 11 shows that high profitable farmers ($\partial_\varphi = 0.70$) experience the most statistically significant decline in profit due to using old varieties of groundnut. We did not find any statistically significant decline in groundnut revenue due to cultivating old groundnut varieties for farmers across the other quantiles.

The results suggest that the economic consequences of using old varieties of groundnut are disproportionately felt by the most successful farmers. In summary, these findings highlight the need for differentiated agricultural policies to address seed quality issues. Policies focusing on providing better seed technology and support for farmers facing the highest economic impacts could enhance productivity while reducing income disparities.

5.4 | Robustness and Sensitivity Checks

We conducted several robustness checks to confirm the stability and reliability of the estimated association between

TABLE 6 | IV-2SLS estimates of varietal turnover on yield, revenue, and profit by age cohort.

Variables	(1) Yield (kg/ha)	(2) Groundnut revenue (GHS)	(3) Farm income (GHS)	(4) Profit (GHS)
Panel A. Older adults	−48.119**	−131.745**	−265.120***	−105.763*
Weighted average age (years)	(21.278)	(52.631)	(100.987)	(61.533)
Other controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
First stage				
Distance to seed shop	0.088*	0.088*	0.088*	0.088*
	(0.049)	(0.049)	(0.049)	(0.049)
Diagnostics				
F-value	15	15	15	15
Observations	345	345	345	345
Panel B. Youth				
Weighted average age (years)	−65.786	−196.050	−135.588	−66.150
	(42.357)	(127.686)	(181.142)	(106.697)
Other controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
First stage				
Distance to seed shop	0.109**	0.109**	0.109**	0.109**
	(0.045)	(0.045)	(0.045)	(0.045)
Diagnostics				
F-value	3	3	3	3
Observations	195	195	195	195

Note: All controls are the explanatory variables reported in Table 1. Robust standard errors are in parentheses. 1 USD = GHS5.7268 (*Source:* https://www.exchange-rates.org/exchange-rate-history/usd-ghs-2020).
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

WAA and the outcome variables. The first robustness check was conducted based on the CFA. Table 7 reports the control function estimates of WAA on yield, groundnut revenue, farm income, and profit. Consistent with the IV-2SLS results, we find that high WAA reduced yield, groundnut revenue, farm income, and profit by 56 kg/ha, GHS163 (US$28), GHS267 (US$47), and GHS106 (US$19), respectively. Second, we performed the Lewbel 2SLS method using both internal and external instruments. The results are presented in Table 8. Consistent with the IV-2SLS and CFA, we find that WAA is associated with a 17 kg/ha decrease in yield, GHS25 decline in groundnut revenue, GHS83 (US$14) decline in revenue, and GHS106 (US$19) decline in profit. Compared across models, the magnitude of the coefficient on WAA in the Lewbel 2SLS is consistently lower compared to the standard IV-2SLS and CFA. The results indicate the negative association between WAA and the outcome variables is robust across different endogeneity-correcting models.

5.5 | Mediation Analysis

Table 9 presents the mediation analysis results, examining productivity as the channel through which varietal age affects revenue, farm income, and profit. In Column 1, older groundnut varieties are associated with a GHS 163 reduction

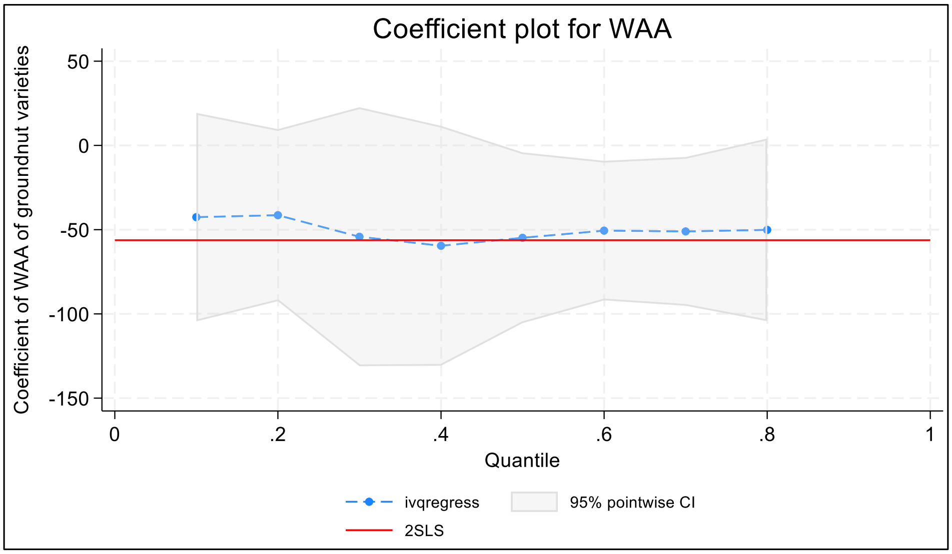

FIGURE 8 | Effect estimates for WAA quantile regression (yield). The full results are presented in Table S2. The controls used in the regression are presented in Table 1.

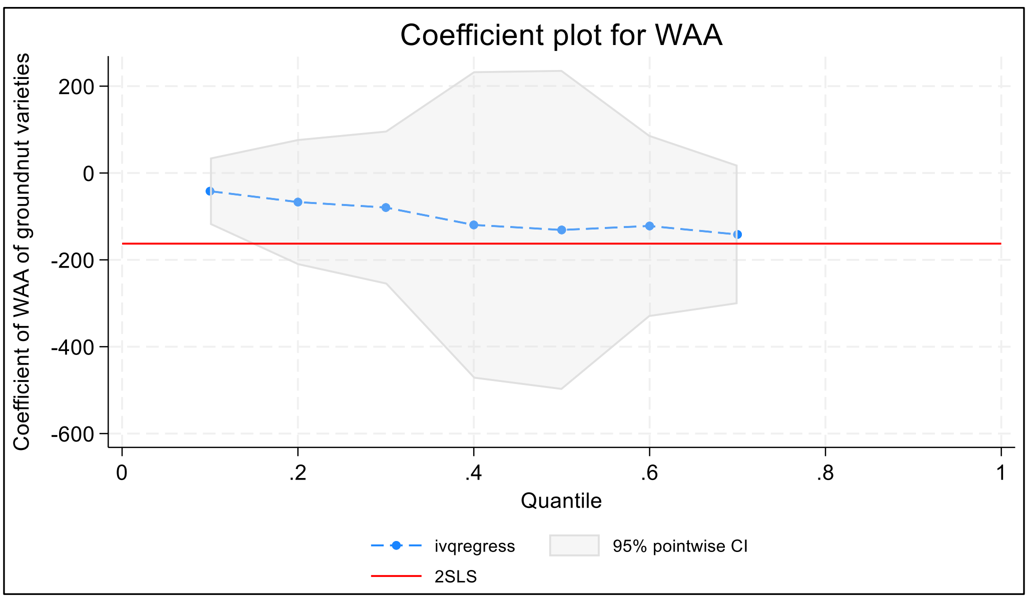

FIGURE 9 | Effect estimates for WAA quantile regression (groundnut revenue). The full results are presented in Table S3. The controls used in the regression are presented in Table 1.

in revenue (total effect). Once productivity is controlled for, varietal age no longer shows a significant direct effect on revenue. The significant indirect effect indicates that the revenue loss is primarily transmitted through reduced productivity, suggesting that productivity declines from older varieties account for most of the revenue drop. Column 2 shows that older varieties are linked to a GHS 267 reduction in farm income (total effect). This negative effect is fully mediated by productivity, as evidenced by a significant indirect effect and a nonsignificant direct effect. In Column 3, older varieties are associated with a GHS 106 decline in profit. After accounting for productivity, the direct effect of varietal age is insignificant. While the productivity variable itself is statistically nonsignificant, its relatively large magnitude suggests that much of the effect still operates through productivity.

The mediator percentages (99%–107%) show that nearly all of the economic losses from older varieties are

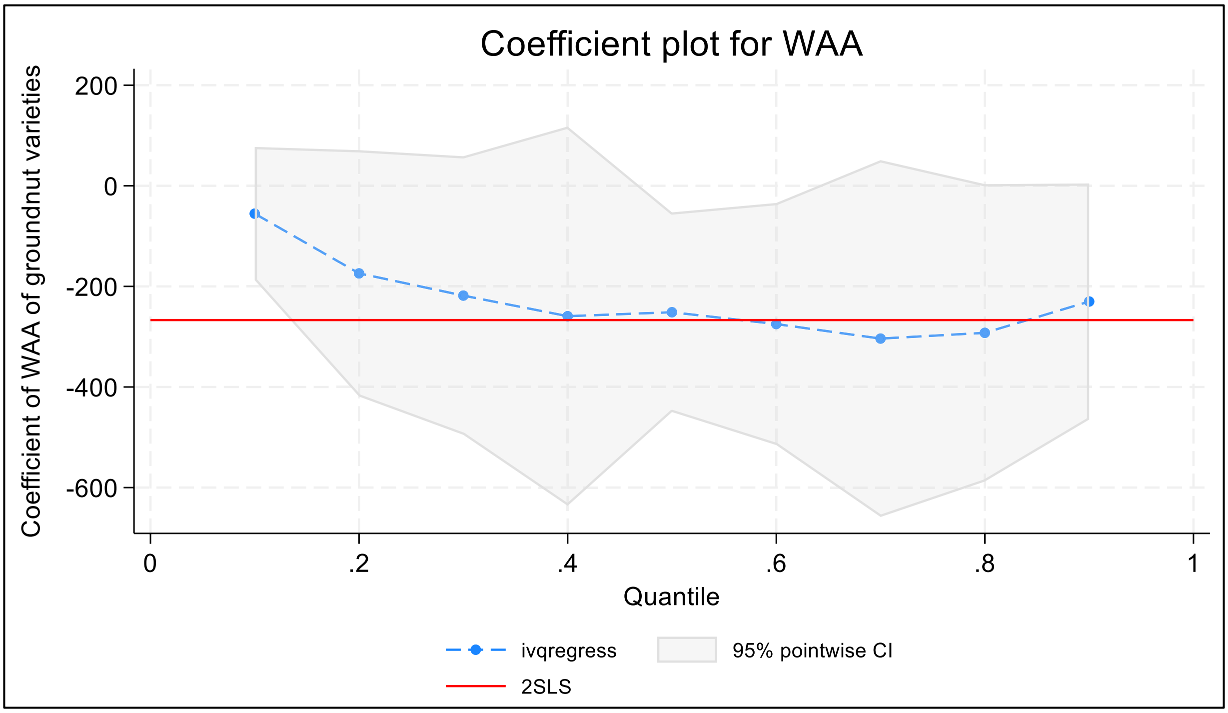

FIGURE 10 | Effect estimates for WAA quantile regression (farm income). The full results are presented in Table S4. The controls used in the regression are presented in Table 1.

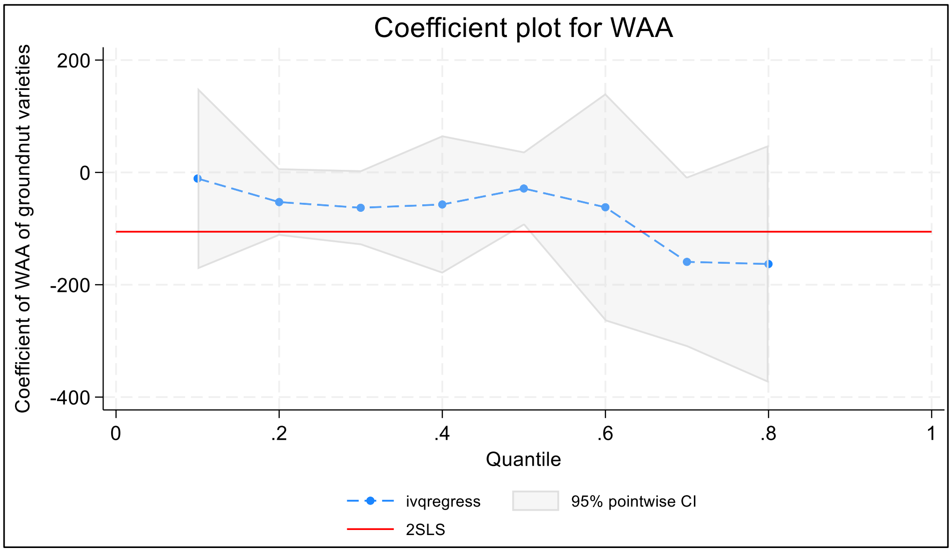

FIGURE 11 | Effect estimates for WAA quantile regression (profit). The full results are presented in Table S5. The controls used in the regression are presented in Table 1.

TABLE 7 | Control function estimates of varietal turnover on yield, revenue, and profit.

Variables	(1) Yield (kg/ha)	(2) Groundnut revenue (GHS)	(3) Farm income (GHS)	(4) Profit (GHS)
Weighted average age (years)	−56.260***	−162.609***	−266.871***	−105.580*
	(15.971)	(40.661)	(81.008)	(56.180)
Residual	52.268***	161.759***	252.259***	96.840*
	(16.170)	(41.302)	(81.602)	(57.729)
Other controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
First stage				
Distance to seed shop	0.102***	0.102***	0.102***	0.102***
	(0.026)	(0.026)	(0.026)	(0.026)
Diagnostics				
F-value	15	15	15	15
Observations	540	540	540	540

Note: All controls are the explanatory variables reported in Table 1. Robust standard errors are in parentheses. The full results are presented in Table S6. 1 USD = GHS5.7268 (*Source:* https://www.exchange-rates.org/exchange-rate-history/usd-ghs-2020).
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

TABLE 8 | Lewbel 2SLS estimates of varietal turnover on yield, revenue, and profit.

Variables	(1) Yield (kg/ha)	(2) Groundnut revenue (GHS)	(3) Farm income (GHS)	(4) Profit (GHS)
Weighted average age (years)	−16.671***	−24.906**	−83.420**	−31.525**
	(5.373)	(9.859)	(32.423)	(14.756)
Other controls	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
First stage				
Distance to seed shop	0.082***	0.082***	0.082***	0.082***
	(0.022)	(0.022)	(0.022)	(0.022)
Diagnostics				
Kleibergen–Paap Wald rk *F*-statistic	11	11	11	11
Observations	540	540	540	540

Note: All controls are the explanatory variables reported in Table 1. Robust standard errors are in parentheses. Kleibergen–Paap rk Wald *F*-statistic: Tests the weakness of the instruments. If this statistic is low (compared to critical values provided by Stock–Yogo thresholds or other relevant benchmarks), it suggests weak instruments. The full results are presented in Table S7. 1 USD = GHS5.7268 (*Source:* https://www.exchange-rates.org/exchange-rate-history/usd-ghs-2020).
***$p < 0.01$.
**$p < 0.05$.

TABLE 9 | Linear IV mediation analysis of groundnut productivity.

Variables	(1) Groundnut revenue	(2) Farm income	(3) Profit
WAA	11.503	4.652	−1.344
	(10.369)	(21.311)	(11.873)
Groundnut yield	3.095***	4.826**	1.853*
	(0.949)	(1.951)	(1.087)
Testing of mediation			
Total effect	−162.609***	−266.871***	−105.580*
	(52.681)	(100.872)	(60.025)
Direct effect	11.503	4.652	−1.344
	(10.370)	(21.311)	(11.873)
Indirect direct	−174.112**	−271.523*	−104.235
	(76.668)	(143.342)	(70.653)
Mediator percentage	107%	102%	99%
Observations	540	540	540

Note: All controls are the explanatory variables reported in Table 1. Robust standard errors are in parentheses. 1 USD = GHS5.7268 (*Source:* https://www.exchange-rates.org/exchange-rate-history/usd-ghs-2020).
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

productivity-driven. Replacing outdated groundnut varieties with newer, higher yielding ones could therefore substantially boost productivity and, in turn, increase farm revenues and incomes.

6 | Conclusion and Policy Implications

This study provides empirical evidence on the effects of prolonged use of groundnut varieties on yield, revenue, farm income, and profitability among groundnut farmers in Ghana. Using farm household survey data and applying instrumental variable regression, we find that the extended use of groundnut varieties is associated with a decline in groundnut productivity and the economic outcomes at farmers' level. These results remain robust across various methods addressing endogeneity concerns. Furthermore, the negative association on these outcomes is more pronounced among risk-averse farmers and adult household heads. These groups require targeted interventions to improve their seed choices and farming decisions.

The duration of using groundnut variety is primarily influenced by the distance to the nearest seed input shop. Farmers living farther from these shops are more likely to continuously use old varieties of groundnut, particularly in rural areas with poor infrastructure. The increased travel distance imposes higher financial burdens and adds to the effort and uncertainty associated with purchasing relatively new varieties of groundnut, thus leading farmers to use old varieties of groundnut. This combination of factors ultimately leads to long-term negative effects on yield and profitability.

The implications of our findings are sixfold. First, we emphasize the need for decentralized seed markets to expand the availability and geographic reach of certified seed outlets, particularly in rural and farming communities with inadequate infrastructure. The introduction of mobile seed vendors in these areas would also reduce transaction costs associated with seed purchases and improve access to certified seeds. Leveraging agro-dealer networks is necessary to improve last-mile seed distribution, especially in remote areas. Promotion of alternative marketing like mobile and digital platforms would go a long way to bridge the gap between seed companies and farmers.

Second, strengthening agricultural extension services is essential to raising awareness about the long-term economic costs of seed recycling and the benefits of using certified seeds. Training programs should be tailored to address the needs of risk-averse farmers and adult household heads, who are more adversely affected by seed recycling. The use of radio, SMS, and other digital extension tools to provide farmers with near real-time information on seed availability and agronomic practices will further improve farmers' access to information and increase their likelihood to acquire new seeds.

Third, enhancing existing risk-sharing mechanisms, such as crop insurance and input financing schemes, and developing new ones are critical to reducing the financial risks associated with purchasing improved seeds. These instruments should be specifically designed to target risk-averse farmers, providing them with greater confidence to invest in certified seeds. Fourth, encouraging participatory breeding involving farmers in the selection and evaluation of new groundnut varieties can ensure that released varieties meet local preferences for yield, taste, disease resistance, maturity period, and resilience to climate variability. Fifth, monitoring varietal age at the farm level based on regular tracking of the average age of varieties in farmers' fields can serve as an early warning for productivity decline, helping policymakers respond proactively. Finally, our findings indicate that it is essential for policy alignment and stakeholder engagement for seed sector development. Tailored seed policies focusing on high-earning and midlevel income farmers, who face significant losses from seed recycling, should be promoted. Tailored interventions, including subsidies or improved access to high-quality seeds and specialized training in seed management, would maximize the impact of agricultural productivity policies and enhance overall efficiency. Lastly, support research on seed systems to inform policies that address adoption barriers and ensure sustained varietal turnover.

Although our results are robust to various alternative specifications addressing endogeneity, we cannot fully rule out endogeneity concerns due to potential omitted variables correlated with both varietal age and the outcome variables. Therefore, our findings should be interpreted as correlations rather than causal relationships. Nevertheless, the correlations identified in this study represent a valuable step toward understanding the mechanisms through which varietal age influences productivity, revenue, farm income, and profit.

Due to data limitations, we were unable to investigate the specific pathways driving these effects, highlighting an important direction for future research.

Acknowledgments

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Ethics Statement

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The authors will make the data available upon request.

Endnotes

[1] Risk aversion is constructed following the approach proposed by Krah et al. (2018). We elicit farmers' responses using a certainty-equivalent risk preference measure:

"Assume you were offered the opportunity to lock in a certain price for your 'current crop' in the last crop year." What is the lowest price for which you would forward contract to eliminate all price risk for the "current crop?"

Based on this, we construct a risk measure as: $\delta_i^{CE} = \frac{\text{Lowest price to lock in contract}}{\text{expected price}}$. Groundnut farmers with $\delta_i^{CE} < 1$ are classified as risk averse, those with $\delta_i^{CE} = 1$ as risk neutral, and the those with $\delta_i^{CE} > 1$ as risk loving.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** IV-2SLS estimates of WAA on yield, revenue, and profit (full results). **Table S2:** Effect estimates for WAA quantile regression (yield). **Table S3:** Effect estimates for WAA quantile regression (groundnut revenue). **Table S4:** Effect estimates for WAA quantile regression (farm income). **Table S5:** Effect estimates for WAA quantile regression (profit). **Table S6:** CF estimates of varietal turnover on yield, revenue and profit (full results). **Table S7:** Lewbel 2SLS estimates of varietal turnover on yield, revenue, and profit (full results).