Food consumption–production response to agricultural policy and macroeconomic change in Nigeria

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Abstract
Achieving agricultural transformation and farmer resilience in resource-dependent developing countries like Nigeria is complicated by volatile macroeconomic conditions, which disrupt agricultural supply chains through income, foreign exchange, and risk-mitigation effects. This study examines the food consumption–production linkage in Nigeria at a time when the national Agricultural Transformation Agenda was implemented and an economic crisis was unfolding. Many farm households responded to expected shocks by planting more staple foods for own consumption at the expense of agricultural commercialization, income growth, and dietary diversification. A policy initiative to improve access to modern farm inputs appeared to mitigate these adverse effects.

KEYWORDS
agricultural policy, agricultural transformation, consumption-production linkage, dietary diversity, Nigeria

JEL CLASSIFICATION
O13; Q12; Q18

Given the limited potential for industrialization in sub-Saharan Africa (SSA), agricultural growth is widely viewed as a more viable avenue for sustainable economic growth and poverty reduction in the region in the near term (Arndt et al., 2016; McMillan et al., 2014;...
Rodrik, 2018). Agricultural growth may enhance diversification of an economy and reduce reliance on food imports, especially in countries dependent on natural resources with high poverty rates and large farm populations, such as Nigeria. Yet, boosting agricultural productivity and modernizing farming require substantial structural policy reforms and large public investments (Binswanger-Mkhize & Savastano, 2017; Jayne et al., 2010, 2019). From the 1980s to the early 2000s, SSA lagged behind other developing regions in implementing agricultural policy reforms and increasing public agricultural expenditures (World Bank, 2007). In recent years, however, there has been evidence of a shift in African policymakers’ priorities toward greater support for agriculture and agricultural transformation. Multilateral pledges, such as the 2003 Maputo Declaration, and national agricultural strategies such as Nigeria’s Agricultural Transformation Agenda (ATA; 2011–15) and its successor, the Agriculture Promotion Policy (APP; 2016–20), exemplify such changes (FAO, 2003; FMARD, 2011, 2016).

As support for agriculture from African policymakers has risen, so has concern over the impact of agricultural transformation on the food security of farm households, particularly smallholders, who rely on own production for food (Mottaleb et al., 2015). Policies promoting agricultural intensification and commercialization typically lead to farmers’ specializing in production of a few profitable crops (Pingali & Rosegrant, 1995). Such specialization, however, reduces farm households’ food self-sufficiency and increases their dependence on potentially dysfunctional or imperfect food markets. This could have adverse effects on household diets and nutritional status.

The relationship between the diversity of farm households’ diets and agricultural production patterns has been well documented for several SSA countries. Recent studies using nationally representative household surveys analyze cross-sectional data or short panel data (e.g., from survey waves within a period of 1 or 2 years). The results from such studies provide only a snapshot of conditions at one point in time and therefore do not capture changes in the study context, such as a country’s macroeconomic conditions or the policy environment, over the medium and long term. Their usefulness for policymakers is therefore limited. Examples include studies by Jones et al. (2014) on Malawi, Sibhatu et al. (2015) on Ethiopia and Malawi (and other countries with no representative sample), Ecker (2018) on Ghana, and Dillon et al. (2015) and Ayenew et al. (2018) on Nigeria. Using two rounds of cross-sectional data spanning over a period of 7 years, Ecker (2018) found that production diversification—along with income growth—is strongly associated with increased dietary diversity among farm households in Ghana, which is at a less advanced stage of agricultural transformation than Nigeria.1 This is consistent with the Dillon et al. (2015) study, which found that both crop production diversity and agricultural revenue had positive but relatively small effects on household dietary diversity in Nigeria. Ayenew et al. (2018) further showed that, within an agricultural year, production diversity was positively and significantly associated with dietary diversity in the post-harvest (PH) season but not in the post-planting (PP) season, possibly due to the time lag between planting and harvesting of food crops.

Results from studies in another strand of the literature, including by Bachewe et al. (2018), Barrett et al. (2017), and Otsuka and Kijima (2010), suggest that agricultural policies supporting uptake and efficient use of modern inputs, for instance, can strengthen agricultural transformation processes, emphasizing the importance of a country’s macroeconomic and fiscal conditions for modernizing agricultural production and marketing. But there is little robust evidence on the dietary implications of such policies. For example, several studies have analyzed the performance of Nigeria’s Growth Enhancement Scheme (GES)—the main policy initiative of the ATA. These studies have focused on the GES’s distributional efficiency (e.g., Takeshima &
Liverpool-Tasie, 2015) and agricultural productivity and household welfare effects among GES-supported farmers (e.g., Wossen et al., 2017) but have not examined its effects on food production and consumption behavior, especially among the wider farm household population.

There is a knowledge gap at the intersection of these two strands of literature: How do farm households adjust their food consumption and production patterns in response to changes in agricultural policy and macroeconomic conditions, and what are the dietary implications of such adjustments? Using the case of Nigeria’s ATA, this study addresses that gap by examining household panel data from a three-wave survey that coincided with the lifetime of the ATA. The results may be particularly useful for agricultural policymakers and policy analysts in Nigeria and other countries dependent on natural resources in Africa, where the food security of farm households is a main goal of agricultural policy.

**STUDY CONTEXT**

Nigeria is Africa’s leading petroleum producer and has the largest proven natural gas reserves on the continent (EIA, 2019). Oil rents and, to a lesser extent, gas rents are the federal government’s primary source of revenue. State and local governments, and especially those in more rural regions of the country, rely primarily on direct transfers from the federal government for revenue (Salami, 2011). Thus, with consistent oil production volumes and limited government borrowing, government sector expenditures and their distribution across levels of government fluctuate with the global oil and gas prices. General macroeconomic outcomes, therefore, highly influence the availability of funds for agricultural policy implementation.

Oil and gas rents account for an important but volatile share of the country’s gross domestic product (GDP), fluctuating between 3% and 18% during 2011–2018. Agriculture’s share of GDP, however, hovers consistently around 21% (World Bank, 2019). Its share of total employment is even higher—36.6% in 2018, down from 40.2% in 2011 (World Bank, 2019). Yet, despite agriculture’s prominence in the economy, Nigeria spends vast sums on food imports—especially, rice, wheat, fish, and milk. Between 2011 and 2018, these expenditures nearly doubled from US$3.2 billion to $6.1 billion annually. Along with rising food imports, the availability of calories per capita increased at the national level beginning in the late 1980s (FAO, 2019), although the share of calories obtained from nonstaple foods remained relatively constant. Moreover, despite the increase in calories, food insecurity remains prevalent today: Some 86.4 million people (44.1% of Nigeria’s population) were moderately or severely food-insecure during 2017–2019 (FAO, 2020).

In light of growing food import dependence and stagnant agricultural productivity, in 2011 the Federal Ministry of Agriculture and Rural Development (FMARD) initiated an agricultural structural reform process (FMARD, 2016). The ATA outlined a new national agricultural strategy based on the principle that agriculture should be a self-sustaining business, led by the private sector. Thus, the role of agricultural policy was to help the agriculture sector to become more productive, efficient, and effective (FMARD, 2011). Agricultural commercialization and intensification were seen as pathways to reducing spending on food imports through substitution with increased domestic production, generating foreign exchange through agricultural exports, and improving food security through increased food access across all segments of the population.

There had been an extended period of rising global oil prices and high economic growth in Nigeria in the years preceding the ATA. However, oil revenues began to decline in 2011 as a
result of stabilizing oil prices and lower crude oil production. GDP growth therefore slowed in 2011 and 2012 before rebounding to over 6% in 2013 and 2014. Oil revenues again dwindled in 2015 and 2016 because of a drop in global oil prices, which led to a sharp deterioration of the country's terms of trade (amplified by a strong depreciation of the Nigerian naira against the US dollar). Associated with these changing macroeconomic conditions were rising fiscal deficits beginning in 2013 (IMF, 2017).2

The ATA likely had the greatest impact on farm households' food production and consumption decisions through input-supply-related interventions clustered under the GES. The GES built on prior fertilizer industry reforms that reduced the public sector's role in procurement and distribution of inorganic fertilizer to catalyze private sector distribution channels (Liverpool-Tasie & Takeshima, 2013). Through the GES, the government provided farmers with e-vouchers to obtain subsidized NPK or urea fertilizer and improved seeds from input retailers (Wossen et al., 2017). This represented a dramatic shift from previous farm input-support programs, in which government authorities physically distributed subsidized fertilizer (Takeshima & Liverpool-Tasie, 2015). Internal FMARD estimates suggest that 12–14 million farmers received e-vouchers during 2011–2014 (FMARD, 2016). Wossen et al. (2017) found that, on average, farmers who received e-vouchers had higher maize yields, maize revenues, and welfare outcomes than nonrecipients. By strengthening private agricultural input markets, improved access to inputs extended beyond e-voucher recipients (FMARD, 2016). Despite some evidence of the ATA's success, policy coordination between the federal government and the states was challenging (FMARD, 2016); hence, input market improvement was stronger in some states than in others. Toward the end of the ATA, FMARD’s ability to implement policies began to diminish as macroeconomic conditions worsened and government funds declined. The GES was then scaled down considerably under the APP (FMARD, 2016).

DATA AND INDICATORS

Household panel survey data

Data for this study's empirical analysis come from the Nigeria General Household Survey–Panel Component (GHS-Panel) (NBS and World Bank, 2018). The survey period corresponds to the lifetime of the ATA. Households were surveyed six times in three waves: Wave 1 (W1) in 2010–11, Wave 2 (W2) in 2012–13, and Wave 3 (W3) in 2015–16. Each wave included two survey rounds to capture crop planting and harvest information within a given agricultural year. Data were collected between August and October for the PP rounds and between February and April for the PH rounds. The analysis includes all survey waves and uses data on household food consumption and household characteristics from the PH rounds and agricultural production data from the preceding PP rounds. Household food and non-food expenditures reported in both rounds were used to approximate the annual average income. The construction of expenditure aggregates follows the approach by Deaton and Zaidi (2002).

Given this study’s focus, the analysis includes only farm households. The GHS-Panel defined farm households as those engaged in crop production, livestock rearing, and other agriculture-related activities (NBS and World Bank, 2016a). For the purposes of this analysis, that larger sample was trimmed to include only those households that reported farmland area and cultivation of agricultural crops (and at-home food consumption) in all three waves. This excludes households that only reared livestock or did not farm during all survey years. The result is a
balanced panel sample of 2342 farm households, equivalent to 56.2% of the full balanced panel sample.³

Dietary indicators

This analysis uses two dietary diversity indicators and complements them with two calorie consumption indicators. The rationale for the indicator selection is based on Bennett's Law, which states that as economies grow and per capita incomes rise, the share of (cheap) calories from staple foods declines (Bennett, 1941). This reflects consumers' general desire for a high-quality, diversified diet. During economic crises, poor households generally reduce their consumption of high-value, nutritious foods before sacrificing the calories needed for productive activities such as farming (Headey & Ecker, 2013). To minimize adverse effects on caloric intake, poor households tend to shift from more expensive staple foods to cheaper, less desired ones. Such dietary shifts may result in consumption of more types of staple foods (Headey et al., 2014). Household diets strongly determine individuals' nutritional and health status. A high-quality diet provides the required nutrients in adequate amounts for health and well-being. Dietary diversity is generally a good predictor of diet quality and measure of food security in developing countries (Ruel, 2003; Ruel et al., 2013).

All four dietary indicators were drawn from the food consumption modules that used a 7-day recall questionnaire to survey household-level consumption of food eaten at home.⁴ The two dietary diversity indicators are the simple counts of the different food items and food groups consumed. The first indicator is the food variety score (FVS), which has a maximum of 60 food items.⁵ The second is the dietary diversity score (DDS), with a maximum of 12 food groups.⁶ The third indicator is the share of calorie consumption from nonstaple foods,⁷ and the fourth is the total calorie consumption amount per capita.

Food production diversity indicators

Two sets of food production diversity indicators are used here. The first set includes two indicators: the number of planted food crops, with a maximum of 41 (the number of food crop categories in the agricultural modules); and the number of food crop groups, with a maximum of seven (which correspond to the groupings of unprocessed or minimally processed plant-based foods for the DDS).⁸ The second set is based on the Simpson production diversity index (SPDI), which accounts for both the variety of crops or crop groups planted and the relative land allocation to the different crops or crop groups (Simpson, 1949). The food crop and crop group categories are identical to those used in the first set. The range of values of the SPDI is 0 to 1, such that 0 indicates monoculture and 1 signifies infinite production diversity.

DESCRIPTIVE ANALYSIS

Table 1 shows the summary statistics for the dietary and food production diversity indicators, the income measure, and the characteristics of the sampled farm households, as well as their mean changes between survey waves. Dietary diversity, on average, increased across all survey
## TABLE 1  Descriptive statistics

| Variables | 2010–11 (W1) | 2012–13 (W2) | 2015–16 (W3) | Percent and percentage point change |
|-----------|--------------|--------------|--------------|-------------------------------------|
|           | Mean   | SD     | Mean   | SD     | Mean   | SD     | W2–W1 | W3–W2 | W3–W1 |
| Dietary indicators |           |          |          |          |          |          |        |        |        |
| Food variety score (FVS; max. = 60) | 12.5 | 4.2 | 13.0 | 4.6 | 14.1 | 4.4 | 4.0%*** | 8.5%*** | 12.8%*** |
| Dietary diversity score (DDS; max. = 12) | 7.50 | 1.91 | 7.78 | 1.94 | 8.09 | 1.83 | 3.8%*** | 3.9%*** | 7.8%*** |
| Calorie consumption share from nonstaple foods (%)^a | 33.6 | 20.1 | 29.6 | 14.5 | 28.6 | 12.9 | −4.0*** | −0.9** | −4.9*** |
| Calorie consumption per capita (kcal/day; log)^a | 7.65 | 0.62 | 7.30 | 0.59 | 7.59 | 0.54 | −4.5%*** | 3.9%*** | −0.8%*** |
| Household income |           |          |          |          |          |          |        |        |        |
| Total expenditure per capita (NGN/day; log) | 5.07 | 0.65 | 4.92 | 0.59 | 4.97 | 0.62 | −3.0%*** | 1.1%*** | −1.9%*** |
| Food production diversity indicators |           |          |          |          |          |          |        |        |        |
| Number of planted food crops (max. = 41) | 3.17 | 1.47 | 3.33 | 1.54 | 3.32 | 1.51 | 5.1%*** | −0.3% | 4.8%*** |
| Simpson production diversity index (SPDI) for food crops | 0.73 | 0.34 | 0.75 | 0.33 | 0.76 | 0.31 | 3.1%** | 1.0% | 4.1%*** |
| Number of planted food crop groups (max. = 7) | 2.02 | 0.89 | 2.12 | 0.93 | 2.06 | 0.88 | 5.1%*** | −2.9%** | 2.0% |
| Simpson production diversity index (SPDI) for food crop groups | 0.67 | 0.35 | 0.69 | 0.35 | 0.69 | 0.33 | 3.9%** | −0.3% | 3.6%** |
| Farm household characteristics |           |          |          |          |          |          |        |        |        |
| Non-agricultural employment (0 = no, 1 = yes) | 0.55 | 0.50 | 0.59 | 0.49 | 0.57 | 0.50 | 3.8%*** | −2.6* | 1.2 |
| Farm size (acres) | 5.88 | 8.92 | 5.72 | 8.17 | 5.90 | 8.58 | −2.8% | 3.2% | 0.3% |
| Cash crop production (0 = no, 1 = yes) | 0.05 | 0.21 | 0.06 | 0.23 | 0.05 | 0.22 | 0.9 | −0.7 | 0.2 |
| Livestock ownership: |           |          |          |          |          |          |        |        |        |
| Poultry (0 = no, 1 = yes) | 0.50 | 0.50 | 0.48 | 0.50 | 0.50 | 0.50 | −2.3 | 2.5* | 0.2 |
| Cattle (0 = no, 1 = yes) | 0.21 | 0.41 | 0.19 | 0.39 | 0.19 | 0.39 | −2.8** | −0.1 | −2.9** |
| Sheep or goats (0 = no, 1 = yes) | 0.50 | 0.50 | 0.49 | 0.50 | 0.50 | 0.50 | −1.8 | 1.8 | 0.0 |
| **N (households)** | 2342 | 2342 | 2342 |          |          |          |        |        |        |

*Note:***, **, * Per a two-sided t-test, the mean difference is statistically significant at the 1%, 5%, and 10% level, respectively.

^aThe number of observations for the calorie consumption indicators is 2114 households per wave because of the exclusion of implausible calorie consumption amounts.
waves according to both FVS and DDS. The means of both calorie consumption indicators decreased over the entire analysis period. The mean decreases of the share of calorie consumption from nonstaple foods and the total calorie consumption per capita from W1 to W2 came with a reduction in the mean household income. The income reduction coincided with the slowdown of GDP growth in 2012 and 2013. Following the return to economic growth, average household income and calorie consumption increased again from W2 to W3, but each stayed below the 2011 level. The mean share of calorie consumption from nonstaple foods declined across all waves, though at progressively smaller margins, while the mean FVS rose across all waves, with an increase from W2 to W3 which was more than twice the increase from W1 to W2. The mean DDS increased at similar margins over the two waves.

Based on these trends, the dietary diversification observed over the entire analysis period likely reflected household consumption smoothing to cope with the perceived food security risk amid the unfolding economic crisis. The higher number of consumed foods and food groups resulted mainly from a shift away from more expensive and desired foods to cheaper and less desired ones—that is, substituting animal proteins (meat and fish) with plant proteins (pulses). Additionally, there was diversification of consumed staple foods toward a greater variety of cheap, calorie-dense cereals (including local rice, maize, and sorghum) and starchy roots and tubers (such as cassava and yams). The stronger increase of FVS relative to DDS, especially between W2 and W3, suggests that farm households diversified their diets primarily within their consumed food groups and largely toward a greater variety of cereals. This contributed to a partial compensation of the loss in total calorie consumption between W1 and W2, but did not translate into a more nutritionally balanced diet (according to the calorie consumption share from nonstaple foods).

Mean food production diversity increased from W1 to W2 and from W1 to W3, according to all four indicators. Given the loss in household income and calorie consumption from W1 and W2, production risk-mitigation practices may have been the dominant driver of the observed increase in food production diversity. This notion is supported by an increased dependence of food consumption on own production in the 2013 PH season compared with the 2011 and 2016 PH seasons: The mean share of own-produced food in total food consumption increased from 33.2% in W1 to 37.0% in W2 and then declined to 31.4% in W3. The decrease between W2 and W3 may be partly explained by implementation of the GES. Enhanced input access likely helped farmers to separate production and consumption decisions, thereby reducing the average reliance on own production for food consumption between W2 and W3. This issue is further explored in the section evaluating GES effects.

A key takeaway from this descriptive analysis is that the common food production patterns indicative of greater agricultural commercialization, as intended by the ATA, were not found. There was also no change in the mean share of farmers engaged in (non-food) cash crop production. Thus, farm households likely prioritized food production risk (and consumption risk) mitigation over agricultural commercialization. The deteriorating economic conditions over the observation period likely exacerbated risk-aversion preferences. The increase in the share of households with non-agricultural employment and the decrease in the share with cattle (often held for insurance purposes) between W1 and W2 point to additional risk-coping strategies for short-term income smoothing. However, the summary statistics in Table 1 do not reflect differences between states where the GES was better implemented and those where it was not. Such cross-state heterogeneity is examined below in the GES evaluation section.
EMPIRICAL STRATEGY

Estimation models

The first step in the econometric analysis was to estimate sets of fixed effects (FE) panel models, using dietary diversity indicators as dependent variables and the corresponding food production diversity indicators and household income as principle explanatory factors. To examine the stability of the estimated effects, these model sets were expanded by including controls for farm household characteristics and by implementing the model estimation with different intercepts that account for time-constant, unobserved heterogeneity that may occur at three levels of the FE entity—the state, the local government area (LGA), and the household. A term that captures the interaction between changes in food production diversity and household income was incorporated in the models to test for the hypothesized mitigation effect. To allow for direct comparison of the income and production diversity effects, the fully specified household FE models were then re-estimated with the dependent and independent variables transformed into standardized values (with means equal to 0 and standard deviations equal to 1 in the study sample).

The FE models have the following principal form:

\[ y_{has} = \alpha_{h|a|s} + \beta_1 x_{has} + \beta_2 d_{has} \times x_{has} + F_{has}' \gamma + Z_{has}' \delta + \phi_t + \epsilon_{has}, \]

where \( h \) is a farm household, and \( a \) and \( s \) are the LGA and state, respectively, where the farm household is located. \( y_{has} \) is the dietary indicator, \( x_{has} \) is the household income measure, and \( d_{has} \) is the food production diversity indicator.\(^{10}\) \( F_{has} \) is a vector of farm household characteristic variables, and \( Z_{has} \) is a vector of standard household demographic variables (including household size and the age, sex, and formal education level of the household head).\(^{11}\) Household, LGA, or state FE enter the models through the intercept \( \alpha_{h|a|s} \) and \( \phi_t \) controls for time-varying factors by survey wave. The coefficient \( \beta_3 \) allows testing the hypothesized interaction between food production diversity and income changes on farm household diets. A negative coefficient estimate indicates a mitigation effect if the estimated associations of food production diversity and household income with the dietary indicator, as expected, are positive. Standard errors were clustered for each FE entity, relaxing the usual requirement of observation independence at the entity level.

Differential effects

The next question to answer was whether the extent of GES implementation, which varied across states, influenced the strength of the consumption–production relationship. Since the GES included multiple interventions, which together aimed at improving farmers’ access to modern agricultural inputs, this analysis focused on wider, indirect program effects rather than on direct outcomes among e-voucher recipients and nonrecipients (as was done by Wossen et al., 2017). Based on the varying degrees of e-voucher distribution from state to state, differential effects were expected. The farm household sample was split into “adopter states” and “non-adopter states.” Adopter states were defined as those where farm households reported receipt of e-vouchers in W3.\(^ {12}\) Crowding out of commercial input purchases—found across SSA (Ricker-Gilbert et al., 2013)—was not expected, because the input procurement and distribution system was facilitated by private sector entities.

In the GES evaluation, the household FE models with the dietary diversity indicators and respective SPDIs were estimated separately for farm households in adopter states and non-
adopter states, followed by a comparison of the results. On Nigerian farms, inorganic fertilizer is applied mostly to plots planted with marketable cereals, especially maize (Liverpool-Tasie et al., 2017). This study therefore hypothesized that farmers in adopter states would have shifted a larger share of their farmland (than farmers in non-adopter states) from food production reserved for home consumption to commercial food production, and that such a shift would have led to a more even distribution of the cultivated area among all planted food crops, but especially staple crops. Thus, the direct association between food production diversity and dietary diversity was expected to be weaker—and the effect of the interaction of food production diversification and income increase stronger—for farm households in adopter states. To investigate this hypothesis, the household FE models were restricted to include only the dietary diversity indicators related to food consumption from own production, and the SPDI for food crops was segmented by staples and nonstaples in an additional model set.

MAIN ESTIMATION RESULTS

Estimated effects on dietary diversity indicators

Table 2 shows the main estimation results of the household FE models with FVS and DDS as the dependent variables. The results of the estimated models for these two dietary diversity indicators and across all specifications of the state, LGA, and household FE models are substantively similar. As expected, there is a strong positive association between food production diversity and dietary diversity. This implies that Nigerian farm households that planted a more diverse food crop portfolio were consuming a wider variety of foods. For example, the estimates of the household FE models that control for farm household characteristics suggest that one additional food crop planted increased the average number of food items consumed by 0.11 (model 2) and the number of food groups consumed by 0.09 (model 5), on average. The estimated relationship between household income and dietary diversity is also positive and statistically significant at the 1% level across all model specifications, as expected. The results imply that a 10% increase or decrease in income corresponded to an increase or decrease of 0.24 food items consumed and 0.09 food groups consumed. However, the association between the term representing the interaction between food production diversity and household income and dietary diversity was negative. This result implies that any positive effect of food production diversification on dietary diversity was mitigated by any associated change in income. Additionally, a strong, positive relationship was found between non-agricultural employment and dietary diversity across all models. A possible explanation for this is that farm households whose members engaged in off-farm work activities had better access to markets because they could buy food for their households on their way to and from work. Ownership of cattle and, especially, poultry was also positively associated with dietary diversity. This points to the importance of small-scale livestock husbandry for diversifying farm household diets.

Estimated effects on calorie consumption indicators

Table 3 shows the estimation results of the household FE models that include calorie consumption from nonstaple foods and total calorie consumption per capita as the dependent variables. The results are robust to any choice of the three FE entities. There is no statistically significant
relationship between food production diversification and improved diet quality with respect to the diversification into nonstaple calorie sources. This is despite the previously observed positive association between production diversification and the variety of foods and food groups consumed. This result might be explained by farm households’ response to worsening economic conditions. Farm households likely diversified their diets to maintain current calorie consumption levels—rather than for the purpose of achieving a more balanced diet—and adjust their production patterns to meet these goals. Consistent with this logic, a statistically significant and positive association between total calorie consumption per capita and the SPDI was observed. However, there was no significant association with the number of planted food crops. Accordingly, farmers appear to have allocated land more evenly among the different food crops within their existing production portfolio to lower the risk of reduced calorie consumption. The association between household income and both the share of calorie consumption from nonstaple

### Table 2
Main estimation results of the household fixed effects model for the dietary diversity indicators

| Model specification | Food variety score (FVS) | Dietary diversity score (DDS) |
|---------------------|-------------------------|-----------------------------|
|                     | [1]         | [2]    | [3]    | [4]    | [5]    | [6]    |
| Panel A             |             |        |       |       |       |       |
| Expenditure per capita (log) | 2.424*** (0.137) | 2.363*** (0.137) | 2.830*** (0.253) | 0.961*** (0.060) | 0.934*** (0.059) | 1.175*** (0.111) |
| Number of planted food crops | 0.145*** (0.042) | 0.113*** (0.044) | 0.855*** (0.327) | 0.118*** (0.030) | 0.095*** (0.031) | 0.694*** (0.231) |
| Food crops × crop groups × expenditure | −0.147** (0.065) |                     | −0.118*** (0.045) |             |       |       |
| F-test              | 51.7        | 32.3   | 30.4   | 43.0   | 26.6   | 25.2   |
| Overall $R^2$      | 0.638       | 0.641  | 0.642  | 0.605  | 0.608  | 0.609  |
| Within $R^2$       | 0.100       | 0.107  | 0.109  | 0.083  | 0.090  | 0.092  |
| Panel B             |             |        |       |       |       |       |
| Expenditure per capita (log) | 2.443*** (0.137) | 2.372*** (0.137) | 2.915*** (0.249) | 0.965*** (0.060) | 0.935*** (0.059) | 1.178*** (0.091) |
| SPDI for food crops | 0.337* (0.178) | 0.299* (0.178) | 4.109*** (1.378) | 0.214*** (0.075) | 0.188*** (0.076) | 2.053*** (0.559) |
| SPDI × expenditure | −0.757*** (0.274) |                     | −0.371*** (0.110) |             |       |       |
| F-test              | 49.5        | 31.6   | 29.8   | 40.6   | 25.7   | 25.6   |
| Overall $R^2$      | 0.638       | 0.641  | 0.642  | 0.604  | 0.608  | 0.609  |
| Within $R^2$       | 0.099       | 0.107  | 0.108  | 0.082  | 0.090  | 0.092  |

Farm household characteristics: No/Yes

Note: The sample has 7026 observations with 2342 households per survey wave. All estimations control for household demographics and household and time fixed effects (FE). Standard errors (in parentheses) are clustered at the household level. ***, **, * Coefficient is statistically significant at the 1%, 5%, and 10% level, respectively.

Tables A1-A4 in the supplementary appendix present the complete estimation results of these household FE models and the state and Local Government Area FE models.

Abbreviations: SPDI, Simpson production diversity index.
foods and total calorie consumption per capita was positive and statistically significant across all model specifications, as expected. For the model that controls for farm household characteristics, the estimates indicate that a 10% income increase (reduction) was associated with an increase (decrease) of approximately 0.13 percentage points in the nonstaple calorie consumption share (model 2) and of 5.4% in calorie consumption per capita (model 5).

It is important to note that the estimation results of the models for the calorie consumption indicators should be treated with some caution. Data checks and consultations with National Bureau of Statistics analysts suggest that food consumption quantities in the Nigeria GHS-Panel, and hence the derived calorie consumption amounts, suffer from measurement errors. Such errors likely resulted to a large extent from food quantities being reported in

## Table 3
Main estimation results of the household fixed effects model for the calorie consumption indicators

| Model specification | Calorie consumption share from nonstaple foods (%) | Calorie consumption per capita (log) |
|---------------------|-----------------------------------------------|-------------------------------------|
|                     | [1]   | [2]   | [3]   | [4]   | [5]   | [6]   |
| Panel A             |       |       |       |       |       |       |
| Expenditure per capita (log) | 1.363** | 1.333** | 2.088* | 0.536*** | 0.539*** | 0.497*** |
|                     | (0.615) | (0.617) | (1.174) | (0.020) | (0.020) | (0.035) |
| Number of planted food crops | 0.227 | 0.209 | 1.449 | −0.003 | −0.001 | −0.070 |
|                     | (0.201) | (0.208) | (1.707) | (0.006) | (0.006) | (0.047) |
| Food crops × expenditure | −0.245 |       |       |       | 0.014 |       |
|                     | (0.341) |       |       |       |       |       |
| F-test              | 3.9   | 2.3   | 2.2   | 143.7 | 79.0  | 73.5  |
| Overall $R^2$       | 0.457 | 0.457 | 0.458 | 0.664 | 0.665 | 0.665 |
| Within $R^2$        | 0.007 | 0.007 | 0.007 | 0.254 | 0.256 | 0.256 |
| Panel B             |       |       |       |       |       |       |
| Expenditure per capita (log) | 1.404** | 1.361** | 1.577 | 0.534*** | 0.539*** | 0.536*** |
|                     | (0.614) | (0.616) | (1.058) | (0.020) | (0.020) | (0.034) |
| SPDI for food crops | 0.440 | 0.371 | 1.912 | 0.056** | 0.060** | 0.040 |
|                     | (0.822) | (0.828) | (6.140) | (0.024) | (0.024) | (0.202) |
| SPDI × expenditure  | −0.306 |       |       |       | 0.004 |       |
|                     | (1.232) |       |       |       |       |       |
| F-test              | 3.8   | 2.3   | 2.1   | 145.3 | 80.0  | 74.6  |
| Overall $R^2$       | 0.457 | 0.457 | 0.457 | 0.664 | 0.665 | 0.665 |
| Within $R^2$        | 0.007 | 0.007 | 0.007 | 0.255 | 0.257 | 0.257 |
| Farm household characteristics | No | Yes | Yes | No | Yes | Yes |

Note: The sample has 6342 observations with 2114 households per survey wave. All estimations control for household demographics and household and time fixed effects (FE). Standard errors (in parentheses) are clustered at the household level. ***, **, * Coefficient is statistically significant at the 1%, 5%, and 10% level, respectively.

Tables A5–A8 in the supplementary appendix present the complete estimation results of these household FE models and the state and Local Government Area FE models.

Abbreviations: SPDI, Simpson production diversity index.
nonstandard units such as (small, medium, and large) piece, bunch, heap, and bowl. While this is common in such surveys, the recording of these units (and subunits) was done inconsistently across the three survey waves in terms of both the range of possible unit categories in the questionnaire and the level of precision applied to determine food quantities during survey implementation (NBS and World Bank, 2016b). The low goodness-of-fit statistics for the nonstaple calorie consumption share model estimations can be attributed mainly to these measurement errors in the dependent variable.

**Standardized effect estimates**

Since the dependent and independent variables in the FE models have different units of measurement, the coefficient estimates presented so far cannot be directly compared; the variables were therefore standardized. Table 4 shows the estimation results for the fully specified household FE models with standardized variables. The estimates of the first two model sets show that the food production diversity effect on dietary diversity was slightly smaller in the models with the number of planted food crops and the FVS than in those with DDS. The marginal income effect was somewhat larger for the FVS than the DDS. These results can be explained by differences in the construction of these dietary diversity indicators: Expansion of the variety of foods belonging to the same food group within the DDS will lead to a higher FVS and will not show up as an increase in the DDS. Across all model specifications, the estimated marginal income effect was more than 6 times larger than the estimated food production diversity effect at the margin. This implies that income changes explain a much greater degree of dietary diversity adjustments among Nigerian farm households than do shifts in production patterns. Moreover, the interaction term coefficient was negative and similar in magnitude to the positive production diversity coefficient. The net marginal effect was positive for the number of planted food crops or crop groups and negative for the SPDIs. A main takeaway from these results is that, once the joint effect is considered, gains in dietary diversity from production diversification were small at best.

The estimates of the second model set in Table 4 also show that the marginal income effect on calorie consumption per capita was many times larger than the effect on the calorie consumption share from nonstaple foods. Thus, as incomes rose, farm households first increased their staple food consumption but only marginally increased nonstaple food consumption.

**GES EVALUATION**

Table 5 presents descriptive statistics for the main indicators in the GES evaluation, showing changes from W1 to W3. The statistics indicate that, over the ATA’s lifetime, the share of farm households that used inorganic fertilizer increased in adopter states but stayed constant in non-adopter states. This differential is attributable to the robust implementation of the GES in adopter states, which resulted in improved agricultural input access through strengthened commercial retail channels. The statistics also suggest that farmers in adopter states increased their total food production diversity by shifting to a more even distribution of planted crops and crop groups within their food production area. This increase was largely driven by adjustments in the land area devoted to staple crop production. Differences in farm households’ distribution of the total food production area to staple versus nonstaple crops in adopter and non-adopter
| Model specification | Food variety score (FVS) | Dietary diversity score (DDS) | Calorie consumption share from nonstaple foods (%) | Calorie consumption per capita (log) |
|---------------------|------------------------|------------------------------|-----------------------------------------------|-----------------------------------|
|                     | [1]        | [2]        | [3]        | [4]        | [5]        | [6]        | [7]        | [8]        |
| Panel A             |           |           |           |           |           |           |           |           |
| Expenditure per capita (log) | 0.329*** | 0.327*** | 0.306*** | 0.305*** | 0.051**  | 0.049**  | 0.558*** | 0.561*** |
|                     | (0.019)   | (0.019)   | (0.019)   | (0.019)   | (0.024)   | (0.024)   | (0.021)   | (0.021)   |
| Number of planted food crops | 0.038**  | 0.040*** | 0.045*** | 0.049*** | 0.019    | 0.021    | −0.002   | −0.005   |
|                     | (0.015)   | (0.015)   | (0.015)   | (0.015)   | (0.019)   | (0.019)   | (0.015)   | (0.015)   |
| Food crops | crop groups × expenditure | −0.031** | −0.035*** | −0.014    | 0.021    |           |           |           |
|                     | (0.014)   | (0.013)   | (0.013)   | (0.020)   | (0.015)   |           |           |           |
| Panel B             |           |           |           |           |           |           |           |           |
| Expenditure per capita (log) | 0.330*** | 0.327*** | 0.306*** | 0.302*** | 0.052**  | 0.052**  | 0.558*** | 0.558*** |
|                     | (0.019)   | (0.019)   | (0.019)   | (0.020)   | (0.024)   | (0.024)   | (0.021)   | (0.021)   |
| SPDI for food crops | crop groups | 0.022*  | 0.025*  | 0.034**  | 0.036*** | 0.008    | 0.008    | 0.033**  | 0.032**  |
|                     | (0.013)   | (0.013)   | (0.014)   | (0.014)   | (0.017)   | (0.017)   | (0.013)   | (0.013)   |
| SPDI × expenditure | −0.035*** | −0.042*** | −0.004    | 0.001    |           |           |           |           |
|                     | (0.013)   | (0.012)   | (0.016)   | (0.014)   |           |           |           |           |

Note: See Tables 2 and 3 for model fit statistics and their table notes for sample sizes. All estimations control for household demographics, household farm characteristics, and household and time fixed effects. Standard errors (in parentheses) are clustered at the household level. ***, **, * Coefficient is statistically significant at the 1%, 5%, and 10% level, respectively. Abbreviations: SPDI, Simpson production diversity index.
**TABLE 5** Descriptive statistics for the main indicators in the GES evaluation by adopter and non-adopter states

| Variables                                      | Adopter states | Non-adopter states |
|------------------------------------------------|----------------|--------------------|
|                                                | Wave 1 (2010–11) | Wave 3 (2015–16) | Percent and percentage point difference | Wave 1 (2010–11) | Wave 3 (2015–16) | Percent and percentage point difference |
|                                                | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Dietary indicators                             |      |    |      |    |      |    |      |    |
| Food variety score (FVS)                       | 12.2 | 4.2 | 13.7 | 4.1 | 12.3%*** | 12.8 | 4.3 | 14.4 | 4.6 | 13.2%*** |
| FVS for own production                         | 2.58 | 1.95 | 2.58 | 1.54 | −0.3% | 2.36 | 1.88 | 2.82 | 1.95 | 19.6%*** |
| Dietary diversity score (DDS)                  | 7.23 | 1.89 | 7.88 | 1.74 | 9.0%*** | 7.69 | 1.90 | 8.23 | 1.87 | 7.1%*** |
| DDS for own production                         | 1.64 | 1.18 | 1.72 | 0.98 | 5.0%* | 1.57 | 1.26 | 1.85 | 1.23 | 17.9%*** |
| Food crop production diversity indicators      |      |    |      |    |      |    |      |    |
| Simpson production diversity index (SPDI) for food crops | 0.74 | 0.34 | 0.79 | 0.29 | 6.2%*** | 0.71 | 0.34 | 0.73 | 0.32 | 2.5% |
| staple crops                                   | 0.71 | 0.33 | 0.76 | 0.29 | 6.9%*** | 0.68 | 0.35 | 0.68 | 0.34 | −0.6% |
| nonstaple food crops                           | 0.49 | 0.45 | 0.55 | 0.44 | 11.7%*** | 0.40 | 0.44 | 0.45 | 0.45 | 14.4%*** |
| food crop groups                               | 0.68 | 0.35 | 0.73 | 0.31 | 6.8%*** | 0.66 | 0.35 | 0.67 | 0.34 | 1.4% |
| Household income                               |      |    |      |    |      |    |      |    |
| Total expenditure per capita (NGN/d, const. 2010; log) | 4.95 | 0.67 | 4.84 | 0.58 | −2.2%*** | 5.15 | 0.63 | 5.07 | 0.62 | −1.7%*** |
| GES incentives                                 |      |    |      |    |      |    |      |    |
| Use of inorganic fertilizer (0 = no, 1 = yes)  | 0.55 | 0.50 | 0.59 | 0.49 | 4.1%* | 0.34 | 0.47 | 0.34 | 0.47 | −0.1% |
| Share of staple crops on total food production area (%)   | 79.0 | 22.6 | 77.1 | 22.6 | −1.9%* | 82.6 | 24.0 | 80.7 | 26.2 | −1.9%* |
| N (households)                                 | 959  |    | 1383 |    |      |    |      |    |

**Note:** ***, **, * Per a two-sided t-test, the mean difference is statistically significant at the 1%, 5%, and 10% level, respectively. Descriptive statistics for additional variables used in the GES evaluation are shown in Table A9 in the supplementary appendix.
**TABLE 6** Estimation results of the household fixed effects models for the dietary diversity indicators considering all food sources by adopter and non-adopter states

| Model specification                  | Food variety score (FVS) | Dietary diversity score (DDS) |
|-------------------------------------|--------------------------|------------------------------|
|                                     | Adopter [1] [2]          | Adopter [5] [6]              |
| Expenditure per capita (log)        | 1.987***                 | 0.875***                    |
|                                     | (0.229)                  | (0.104)                     |
| SPDI for food crops | crop groups | 0.103                     | 0.135                        |
|                                     | (0.277)                  | (0.116)                     |
| SPDI × expenditure                  | −1.563***                | −0.379                      |
|                                     | (0.462)                  | (0.344)                     |
| F-test                              | 9.4                      | 8.6                         |
| Overall $R^2$                       | 0.615                    | 0.603                       |
| Within $R^2$                        | 0.079                    | 0.080                       |

|                                     | Non-adopter [3] [4]      | Non-adopter [7] [8]         |
| Expenditure per capita (log)        | 3.194***                 | 1.321***                    |
|                                     | (0.429)                  | (0.163)                     |
| SPDI for food crops | crop groups | 7.824***                  | 3.242***                    |
|                                     | (2.279)                  | (0.955)                     |
| SPDI × expenditure                  | 0.443*                   | 0.202**                     |
|                                     | (0.235)                  | (0.101)                     |
| F-test                              | 9.5                      | 9.3                         |
| Overall $R^2$                       | 0.618                    | 0.605                       |
| Within $R^2$                        | 0.085                    | 0.086                       |

Note: The samples for adopter and non-adopter states have 2877 observations (with 959 households per survey wave) and 4149 observations (with 1383 households per survey wave), respectively. All estimations control for household demographics, household farm characteristics, and household and time fixed effects (FE). Standard errors (in parentheses) are clustered at the household level.

***, **, * Coefficient is statistically significant at the 1%, 5%, and 10% level, respectively.

Abbreviations: SPDI, Simpson production diversity index.
states were not observed. Moreover, increases in the mean numbers of food crops and crop groups planted by farmers were similar in adopter and non-adopter states.\textsuperscript{17} Regarding dietary diversity, increases in the mean FVS and DDS were similar for the two groups when consumed foods from all sources are included. However, when considering foods from own production alone, only the non-adopter states showed sizable increases in the means of both dietary diversity indicators; in adopter states, there was no change in mean FVS and a small increase in mean DDS.

Table 6 presents the estimation results of the household FE models with the dietary diversity indicators and corresponding SPDIs. The significance of the coefficient estimates indicates that the food consumption–production linkage was stronger in non-adopter states than in adopter states: The simple associations between the SPDIs and the dietary diversity indicators are statistically significant and positive only for non-adopter states. Additionally, the estimated mitigation effects represented by the interaction term coefficients in the expanded model set are statistically significant and larger for adopter states.

Table 7 provides more detailed information on the plausible mechanism through which the GES affected the food consumption–production linkage. The difference in the significance of the simple associations between the SPDIs and the dietary diversity indicators shown in Table 6 becomes stronger when limiting the analysis to the consumption of foods from own production. This result provides evidence supportive of the hypothesis that the differential effects of GES

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
\textbf{Model specification} & \multicolumn{2}{c|}{\textbf{Food variety score (FVS)}} & \multicolumn{2}{c|}{\textbf{Dietary diversity score (DDS)}} \\
 & Adopter & Non-adopter & Adopter & Non-adopter \\
\hline
Expenditure per capita (log) & \textsuperscript{1}0.312\textsuperscript{***} & \textsuperscript{1}0.310\textsuperscript{***} & \textsuperscript{1}0.602\textsuperscript{***} & \textsuperscript{1}0.605\textsuperscript{***} \\
& (0.093) & (0.093) & (0.069) & (0.068) \\
SPDI for food crops | crop groups & 0.126 & 0.288\textsuperscript{*} & 0.063 & 0.205\textsuperscript{***} \\
& (0.138) & (0.112) & (0.078) & (0.071) \\
SPDI for staple crops & 0.149 & 0.448\textsuperscript{***} & & \\
& (0.161) & (0.123) & & \\
SPDI for nonstaple food crops & 0.025 & 0.242\textsuperscript{***} & & \\
& (0.111) & (0.085) & & \\
\hline
\textit{F}-test & 3.4 & 3.2 & 9.4 & 10.6 \\
Overall \textit{R}^2 & 0.496 & 0.496 & 0.499 & 0.503 \\
Within \textit{R}^2 & 0.022 & 0.022 & 0.042 & 0.050 \\
\textit{N} (households) & 959 & 1383 & 959 & 1383 \\
\hline
\end{tabular}
\caption{Estimation results of the household fixed effects models for the dietary diversity indicators considering only own-produced foods by adopter and non-adopter states}
\end{table}

Note: The samples for adopter and non-adopter states have 2877 observations (with 959 households per survey wave) and 4149 observations (with 1383 households per survey wave), respectively. All estimations control for household demographics, household farm characteristics, and household and time fixed effects (FE). Standard errors (in parentheses) are clustered at the household level.

\(**, **, *\) Coefficient is statistically significant at the 1%, 5%, and 10% level, respectively.

Abbreviations: SPDI, Simpson production diversity index.
implementation on dietary diversity indeed occurred primarily through changes in the direct link between food consumption and own production. This finding holds for production diversity within both staple and nonstaple food crops as the estimates of the model with the respectively segmented SPDIs suggest.

The composite implication of the summary statistics and model estimates in this GES evaluation is that there was greater separation of production and consumption decisions among farm households in adopter states than in non-adopter states. Overall, the results suggest that ATA policy initiatives to improve access to modern farm inputs helped in easing farmers’ (perceived) dependence on self-sufficiency for protecting their families’ food security from adverse economic shocks.

CONCLUSIONS

Using the case of Nigeria’s ATA, this study sheds new light on the ways in which farm households adjust their consumption and production patterns in response to changes in agricultural policy and macroeconomic conditions, as well as the effects that these adjustments have on household diets. The study has three main findings. First, during the ATA’s lifetime, food production diversity and dietary diversity of Nigerian farm households increased, while the share of calories from nonstaple food sources declined. This is likely because farm households prioritized production and consumption of staple foods to mitigate food security risks from the unfolding economic crisis. Such a production response to deteriorating macroeconomic conditions overshadowed the ATA’s initiatives to promote greater agricultural transformation. These results suggest that Nigerian farmers tend to adjust toward meeting at least some consumption needs via own production rather than full commercialization to protect their families from expected income loss and food security shocks. While it is natural for farm households to adopt risk-mitigation strategies, such strategies can have substantial dietary effects and may also impede progress toward commercialization by increasing reliance on own production for food consumption.

Second, the results of this study expand on those of Dillon et al. (2015) and Ayenew et al. (2018) by confirming that the observed positive relationship for dietary diversity with production diversity holds when analyzed over a longer timeframe. The key novel finding in this regard is that there are mitigating effects between production diversity and income, but that the income effects far outweigh those from production diversity. This suggests that food production diversification is generally ineffective at diversifying Nigerian farm household diets, and that the associated opportunity costs likely offset any potential dietary benefits.

Third, building on Wossen et al. (2017), which found positive farm income and welfare effects among GES e-voucher recipients, this study shows that households in states where the program was robustly implemented were less reliant on own production for food consumption than were households in states where it was not. This finding emphasizes the wider, indirect effects of such farm input-support programs and implies that the GES was not only successful in lessening the income constraint for input purchases but also allowed farmers to remain positioned for commercialization even when macroeconomic conditions deteriorated.

This study has several important policy implications. The results underscore the importance of income growth for increasing farm households’ dietary diversity. This is consistent with the principal strategic direction of Nigeria’s current agricultural policy—and that of many other African countries—toward greater farm commercialization. Additionally, the results imply that agricultural policymakers must take into account farm households’ response patterns to policy
and macroeconomic factors if policies are to achieve commercialization goals and not lose momentum during periods of deteriorating macroeconomic conditions. Promoting food production diversification for home consumption in order to increase farm households’ dietary diversity does not appear sufficient to make up for shock-induced income losses, nor does it complement agricultural commercialization efforts. However, food production diversification remains a common response for coping with income shocks.

Based on these findings, there is a policy need for interventions to help farmers mitigate production risks, especially for crops associated with greater agricultural commercialization. Such interventions could be designed to promote income effects similar to those of Nigeria’s GES under the ATA. The GES was abandoned under the following 5-year agricultural strategy in large part due to its high costs amid declining government revenues. However, designing similar but more efficient mechanisms, such as a system of low-interest loans for modern inputs, would reduce the likelihood of farmer reversion to reliance on own production for food consumption in response to economic downturns. More broadly, the study findings imply that, particularly in resource-dependent developing economies vulnerable to export market volatility, agricultural policy continuity is critical for achieving sustainable progress toward agricultural transformation and food security.

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ENDNOTES
1 Average agricultural labor productivity is higher in Nigeria than Ghana. In 2010–2015, agriculture value added per worker (in constant 2010 US dollars) averaged $4809 in Nigeria and $2092 in Ghana (World Bank, 2019).
2 Figure A1 in the supplementary appendix shows annual estimates of selected macroeconomic and financial indicators for Nigeria.
3 This study focuses on household farms that farm mostly very small areas of land. Large-scale agricultural operations are not represented in the balanced panel sample. Less than a third of farm households in the study sample (32.6%) cultivated more than 10 acres in any survey wave, of which only 13.7% and 1.6% of all farm households cultivated more than 20 acres and 50 acres, respectively, across all survey waves.
4 Consumption of meals and drinks taken outside the home (such as in restaurants and at street vendors) was surveyed only as expenditure aggregates; consumed food items (and quantities) were not reported. Therefore, incorporation of consumption of food away from home cannot be accommodated in the construction of the dietary indicators. In the study sample, expenditure for away-from-home food consumption accounts for an average of 9.2% of total (at-home and away-from-home) food expenditure (including beverage expenditure).
To avoid double-counting of the same food reported for different stages of processing or different product forms, several of the 116 food product categories of the food consumption modules were aggregated into the 60 food item categories of the FVS. For example, “unshelled maize on the cob,” “shelled maize on the cob,” “shelled maize off the cob,” and “maize flour” were combined into the single set “maize.”

Following the classification by Swindale and Bilinsky (2006), the food groups are cereals; starchy roots/tubers and plantains; vegetables; fruits; meat and poultry; fish and seafood; eggs; pulses, nuts, and seeds; milk and dairy products; edible oils and fats; sugars and sweets; and miscellaneous.

Staple foods include all food items in the DDS food groups of cereals and starchy roots/tubers and plantains.

The food crop groups are cereals; starchy roots/tubers and plantains; vegetables; fruits; legumes and tree nuts; oil crops; and herbs and spices.

Per two-sided t-tests, the reported mean differences are statistically significant at the 1% level.

Total expenditure per capita and calorie consumption per capita were transformed into logarithms because of highly skewed distributions. The transformed variables have a nearly normal distribution.

Estimates for the household demographic variables are not reported because they served only as controls in the estimations and were not of primary interest for this study.

The corresponding survey question was not included in the agricultural questionnaire of W2 (or W1).

The full estimation results of the state, LGA, and household FE models for FVS and DDS are shown in Tables A1–A4 in the supplementary appendix.

Across all FE models, the found relationship between food production diversity and dietary diversity is robust to omitting household income from the model equations (Tables A1–A4 in the supplementary appendix). This result provides suggestive evidence that food production diversification translates into increased dietary diversity predominantly through the assumed direct effect of improved access to a diverse diet from own production rather than an indirect income effect (Ecker, 2018). Such an indirect income effect may occur if, for example, adding food crops to the existing portfolio or shifting toward a more even land allocation to the different food crops planted improves soil fertility or pest management that results in higher farm incomes, allowing households to afford a more diverse diet from market purchases.

The estimated effect of the number of planted food crop groups is similar to and, in relative terms, slightly lower than the respective estimate by Ecker (2018) for Ghana (which makes sense considering that agricultural transformation is somewhat less advanced in Ghana than Nigeria). Ecker (2018) used a cross-sectional farm household dataset that pools data from the 2005–06 and 2012–13 Ghana Living Standard Surveys and a district FE regression to estimate the effect of the number of planted crop groups on household dietary diversity, measured by the DDS, and found a coefficient estimate of 0.11. At the sample mean, a 10% increase in production diversity was associated with a DDS increase of 0.35% in Ghana, compared with an increase of 0.30% at the sample mean of the Nigeria farm household dataset in this study. These effect estimates are considerably smaller than the estimates found in Dillon et al. (2015), which used an instrumental variable regression with state FE and cross-sectional data from W1 of the Nigeria GHS-Panel, and estimated that a 10% increase in the number of planted crop groups increased the DDS by 2.4%.

The full estimation results of the state, LGA, and household FE models for the share of calorie consumption from nonstaple foods and total calorie consumption per capita are shown in Tables A5–A8 in the supplementary appendix.

See Table A9 in the supplementary appendix.

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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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