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# Women's empowerment boosts the gains in dietary diversity from agricultural technology adoption in rural Kenya

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ABSTRACT

Using new survey data from rural Kenya, this paper assesses the moderating effect of women's empowerment on the relationship between agricultural technology adoption and women's dietary diversity. We use a multiple treatment endogenous switching regression framework to control for potential endogeneity of women's empowerment and technology adoption. We find that women's empowerment has a positive and significant effect on the women's dietary diversity score regardless of technology adoption status. We further show that women's empowerment enhances the positive effects of technology adoption on women's dietary diversity. Although technology adoption has a positive impact on women's dietary diversity regardless of empowerment status, its effect is stronger for households with empowered vs. disempowered women. Study results suggest that individual and household welfare could be enhanced to a greater degree through interventions that promote women's empowerment and technology adoption simultaneously rather than separately.

## 1. Introduction

Nutrition-specific interventions, such as supplementation, fortification, and nutrition education programs, have been instrumental in reducing global malnutrition (Bhutta et al., 2013; Ruel et al., 2018). These interventions are, however, insufficient on their own to meet global targets for improving nutrition, and agriculture is increasingly viewed as a key sector with important contributions to make (Ruel et al., 2018; Fiorella et al., 2016). Research points to six main pathways through which agriculture influences nutrition: (1) consumption of own food production, (2) income from the sale of agricultural commodities produced by farmers and wages earned by agricultural workers, (3) changes in food prices owing to supply and demand factors, and three pathways linked to gender (Ruel and Alderman, 2013). The three gender-linked pathways include women's (4) involvement in agriculture, which can influence their say in the intrahousehold allocation of food, health, and care; (5) balance of time between income-generating activities and household maintenance and caregiving; and (6) own health (e.g., through exposure to agricultural chemicals) and nutritional status (e.g., through energy expenditure).

The importance of integrating women's empowerment into nutrition-sensitive agricultural programs is evident, and considerable research has investigated the role of women's empowerment in child nutrition and growth, although reviews reveal mixed evidence thus far (Carlson et al., 2015; Cunningham et al., 2015; Santoso et al., 2019). For instance, Santoso et al. (2019) concluded from 62 studies that the role of women's empowerment has an indeterminate influence on child nutrition since most of the 1316 tested associations were insignificant. The authors recommended that future studies use context-appropriate empowerment indicators and appropriate methods for causal analysis to enable the hypothesized underlying relationships to be revealed. Encouraging is the study of Heckert et al. (2019) that used context-relevant empowerment measures, experimental data, and simultaneous equation modeling and found women's empowerment was a pathway by which a nutrition-sensitive intervention reduced child wasting.

In contrast to the large literature on women's empowerment and child nutrition, research on how women's empowerment influences their own nutrition is sparse: our literature search identified only four studies. Malapit and Quisumbing (2015) found the overall score of the women's empowerment in agriculture index (WEAI) and empowerment in credit decisions were positively associated with women's dietary diversity in Ghana. For Nepal, Malapit et al. (2015) showed that mother's dietary diversity increased with community engagement, control over income, reduced workload, and overall empowerment. Sinharoy et al. (2018) showed that Bangladeshi women with higher levels of schooling had more diverse diets, a relationship that was mediated by agency, as measured by women's voice with their husbands. Finally, Jones et al.'s (2020) study in five East African countries found three key

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domains of women's empowerment positively associated to women's body mass index (BMI), namely women's human/social assets, intrinsic agency to reject violence, and instrumental agency in household decisions.

The present study uses gender-disaggregated data collected in 2016 from a sample of western Kenya farm households to assess the impact on women's dietary diversity of women's empowerment individually and in combination with agricultural technology adoption. The focal technology is the push-pull organic pest control system introduced in the study areas in 1998 by the International Centre of Insect Physiology and Ecology (*icipe*) and its partners using model farmers and field days as main dissemination approaches. Push-pull technology (PPT) is a cropping system in which cereals such as maize are intercropped with a perennial fodder legume (*Desmodium*) that repels (pushes) stemborers and suppresses *Striga* weed species. A border of perennial (e.g., *Brachiaria* species) fodder grass also surrounds the cereal crops that attract (pulls) stemborers away from cereal plants (Khan et al., 2014). PPT is an attractive technology to women and men farmers alike. In a recent survey, the percentages of women and men farmers that favorably evaluated PPT were 98.6% and 96.7%, respectively, and women farmers rated PPT higher than men on several attributes, such as *Striga* control, soil fertility management, and cereal production (Murage et al., 2015). A recent study found that, in net, the technology is labor-saving for both men and women. The labor savings for women result from the PPT-induced reduction in labor for weeding, a laborious activity is largely done by women in the study areas (Diiro et al., 2020). PPT further serves as a quality source of fodder for livestock production, which can enhance farm income and animal protein sources of farm households (Kassie et al., 2018).

We estimate the impact of women's empowerment on the women's dietary diversity score (WDDS) using the Abbreviated Women's Empowerment in Agriculture Index (A-WEAI) (Malapit et al., 2017); these are standardized measures that can be easily adapted to different contexts, allowing for meaningful comparisons across countries and regions. The A-WEAI, like its predecessor, the WEAI, is a survey-based index that measures women's empowerment, agency and inclusion in agriculture, based on their achievement adequacy scores in five agricultural domains, namely production, resources, income, leadership, and time (Alkire et al., 2013; Malapit et al., 2017). Each domain indicator measures whether an individual respondent has achieved adequacy, with each domain receiving equal weight when the indicators are aggregated (Table 1). Table 1 also captures the variables used to calculate the empowerment index.

This study contributes to existing research in three main ways. First, as highlighted above, very few studies have systematically examined how women's empowerment affects the status of their own dietary diversity. And these studies did not control for potential endogeneity, i.e., the same factors that affect dietary diversity may also affect women's empowerment and technology adoption. We address potential endogeneity issues using an endogenous switching regression approach. Sraboni et al. (2014) controlled for endogeneity in their study of how women's empowerment impacts household dietary diversity and concluded that failure to control for endogeneity might underestimate the impact of increasing women's empowerment on food and nutrition security outcomes.

Second, we are aware of only one previous study that examined whether women's empowerment has a moderating effect on agriculture, changing the relationship between agricultural interventions and nutrition outcomes. Malapit et al. (2015) found that women's empowerment mitigates the effect of low production diversity on maternal dietary diversity. Research demonstrates the importance of understanding the balance of power within households to explain technology adoption and determine its impact. Fisher and Carr (2015) found that husbands in Uganda were less likely to adopt new maize varieties on plots they managed if their wives were more empowered, as measured by women's asset ownership and women being older and more

**Table 1**
Domains, indicators, variables, and adequacy definition for the A-WEAI.

| Domains | Indicators | Variables from the survey tool | Definition of adequacy | Weights |
|---|---|---|---|---|
| Production | Input in productive decisions | Decisions on food crop farming, cash crop farming, livestock raising, and fishing. | Sole or joint participation in at least one decision related to food and cash-crop farming, livestock farming, and fishery production. | 1/5 |
| Resources | Asset ownership | Assets: agricultural land; large livestock; small livestock; poultry; non-mechanized farm equipment; mechanized farm equipment; large consumer durables; small consumer durables; cellphone; transport equipment. | Sole or joint ownership of at least one major household asset. | 1/10 |
| | Access to and decisions on credit | Credit sources: NGO, formal lender, informal lender, friends or relatives, group-based microfinance or lending, informal credit/savings groups. | Sole or joint control or participation in decision-making on credit from at least one source. | 1/10 |
| Income | Control over the use of income | Income sources: food crop farming, cash crop farming, livestock, non-farm activities, wage and salary, fishing income, major and minor household expenditures | Sole or joint control over income for at least one of food and cash-crop farming, livestock farming, and fishery production. | 1/5 |
| Leadership | Group membership | Groups: Saving and credit associations, mutual help or insurance, input supply, farmer cooperative union, trade and business, water users association, crop and livestock marketing, women's association, civic or charitable, religious association, development group. | Active member in at least one formal or informal group. | 1/5 |
| Time | Workload | Time spent on a comprehensive list of productive activities, domestic tasks, and leisure activities in the last 24 h. | Spent less than or equal to 10.5 h on paid and unpaid work during the previous day. | 1/5 |

Source: Malapit et al. (2015).

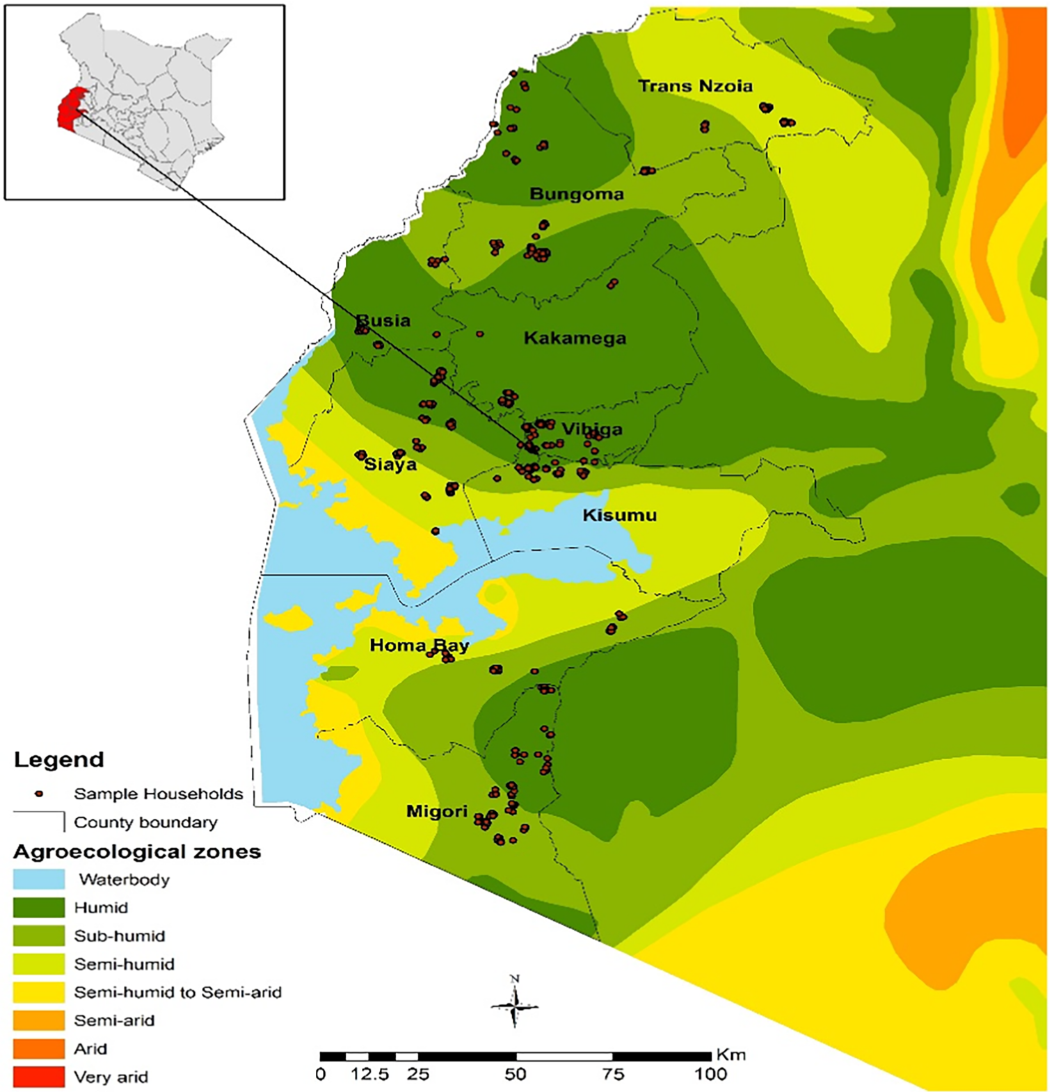


**Fig. 1.** Study area and sample distribution.

educated relative to the husband. Similarly, a study in Mali revealed that women with greater bargaining power were able to negotiate for financial compensation from their husbands for the increase in their workload accompanying adoption of a labor-increasing agricultural technology (Lilja et al., 1996).

Considerable research in low-income settings indicates that agricultural technology adoption can improve nutritional outcomes at the household level (Kabunga et al., 2017; Kidoido and Korir, 2015; Larochelle and Alwang, 2014). But to ensure equity in the distribution within households of the nutrition benefits from technology adoption, observers argue that pairing agricultural development programs with related programs on women's empowerment is key (Kidoido and Korir, 2015; Larochelle and Alwang, 2014). However, none of these studies empirically tests this proposition, i.e., it is a maintained hypothesis.

A third key contribution is our focus on PPT, whose potential to improve nutritional outcomes warrants further investigation. Previous research on links between agricultural technology and nutrition outcomes has mostly concerned bio-fortified crops (see Bouis and Saltzman, 2017 for a review), with a few recent studies on high-yielding crop varieties (Zeng et al., 2017; Larochelle and Alwang, 2014) and dairy innovations (Kabunga et al., 2017; Kidoido and Korir, 2015). We add another empirical point to this expanding literature with evidence on a unique technology known to increase both crop yields and livestock production (Kassie et al., 2018). Importantly, the results of our study can help guide development interventions, suggesting whether technology adoption and women's empowerment should be treated as separate or complementary approaches to promote dietary diversity and other nutrition outcomes.

## 2. Study context and data

### 2.1. Gender disparities in rural Kenya

Available evidence shows that women form a sizable proportion of Kenya's agricultural labor force. For instance, rural women in eastern and western Kenya constitute 49–60% of the agricultural labor force, depending on the agricultural activity involved (Kassie et al., 2014). Despite this, they have less access and control over many productive resources (land, labor, education, information, and financial resources). As little as 0.5% of women in Kenya have access to financial services (ERH, 2016). And only about 6% of Kenyan women own land (FIDA, 2009), largely due to cultural norms and traditions that restrict women from inheriting land (Kameri-Mbote, 2005; Manda and Mwakubo, 2013). Women have limited access to labor and agricultural markets (Farnworth and Colverson, 2015; Kameri-Mbote, 2005; Wekwete, 2014) and tend to have less control over revenue from agricultural production than men (Fischer and Qaim, 2012).

Since women spend more time in caregiving and domestic work than men (Wekwete, 2014), they are less able to participate in income-generating activities (Wekwete, 2014) and have less access to productive resources such as extension and advisory services (Farnworth and Colverson, 2015; Meinzen-Dick et al., 2010). Moreover, extension workers have traditionally tended to favor male adults over female adults (Blumberg, 1992; FAO, 1998). For a more detailed discussion on gender differences in rural Kenya, see Kassie et al. (2014).

In terms of micronutrient deficiencies, which are highly prevalent in Kenya, women are at greater risk than men, with pregnant women being extremely vulnerable: up to 60% may suffer from iron deficiency, while 39% may suffer from Vitamin A deficiency; both these conditions have adverse effects on their health and that of their children (Government of Kenya, 2011). Women have a higher biological need than men for several micronutrients, such as iron, vitamin A, and folate; this is particularly the case during certain parts of the lifecycle, notably pregnancy and lactation (Bartley et al., 2005).

### 2.2. Study area and data collection

Data for this study were collected in 2016 in western Kenya. The data collection process was carried out in several stages. In the first stage, nine out of 11 counties in western Kenya were purposively selected. The selected counties were Bungoma, Busia, Homa Bay, Kakamega, Kisumu, Migori, Siaya, Trans-Nzoia, and Vihiga (Fig. 1). Next, between three and 11 villages were randomly selected in each county using probability proportional to size (PPS) sampling. This was followed by the random selection of between two and 21 households in each village, also via PPS sampling, using the list obtained from extension officers in charge of promoting the technology. In total, 60 villages and 711 farm households were surveyed, comprising 361 adopters and 350 non-adopters of PPT. Out of the 711 households sampled, 688 female respondents were successfully interviewed to provide data on women's dietary diversity as well as gender-disaggregated data for computation of the A-WEAI (Alkire et al., 2013).

Separate questionnaires were designed for households and individuals and administered using semi-structured interviews by trained enumerators who spoke and understood local languages. While the household questionnaire was administered jointly to the male and female adult decision-makers in the household, the A-WEAI questionnaire was administered to women only, including both wives in spousal couple households and female heads of households. Adult male decision-makers in a household were not interviewed on the A-WEAI questionnaire due to budget constraints.

The household questionnaire elicited information on, among other things, household and individual demographic characteristics, crop and livestock production and utilization (e.g., consumption and marketing), access to development services (extension, credit, and markets), social capital and network variables (e.g., membership in rural institutions), and non-agricultural income-generating activities.

A special module of the questionnaire elicited data on seven days' food consumption via recall to capture the dietary patterns of mothers. Similarly, a production module was designed within the household questionnaire to capture households' PPT-adoption status. Tables 2 and 3 offer definitions and summary statistics of treatment variables and covariates used in the regression models.

## 3. Methodology

### 3.1. Conceptual framework and research questions and hypotheses

Fig. 2 proposes a framework for understanding direct and indirect links between agricultural technology adoption, women's empowerment, and women's dietary diversity. This framework presents three testable hypotheses (H) related to the study's research questions (RQ).

- RQ1 and H1: How does women's empowerment influence their dietary diversity? We hypothesize a positive association.
- RQ2 and H2: What is the effect of PPT adoption on women's dietary diversity? A positive association is hypothesized.
- RQ3 and H3*:* What is the moderating effect of women's empowerment on the relationship between PPT adoption and women's dietary diversity? We posit that women's empowerment boosts the gains in dietary diversity from PPT adoption.

The first hypothesis (pathway H1 in Fig. 2) is that a woman's empowerment in agriculture has a direct effect on her dietary diversity. This reflects that women as the traditional family caregivers in many societies play essential roles in their family's nutrition through selection, acquisition, preparation, and allocation of food among family members (Reiheld, 2014). Empowered women are expected to have better knowledge of nutrition and health (e.g., through greater resource access and control, and group membership) and the decision-making power, income control, and time to apply that knowledge in their self-care and caregiving practices. Thus, women's empowerment can lead to improved nutrition outcomes, such as dietary diversity, for women and their family members.

The second hypothesis relates to the effect of technology adoption on women's dietary diversity, which we posit operates through production, income, and labor allocation pathways. Kassie et al. (2018) show that the adoption of PPT could increase maize yields and net income in western Kenya by 62% and 39%, respectively. Increased yields from PPT adoption can increase household food availability from own production (pathway H2a) and farm incomes from marketable surplus (pathway H2b). The latter can be used to increase the quantity and quality of food purchases. PPT provides additional benefits such as high-quality livestock forage, which increases animal health and milk production and, in turn, household income and dietary intake of animal source foods (Kassie et al., 2018). The third pathway from PPT adoption to improved dietary diversity reflects the technology's potential for labor savings, largely because of reduced plowing frequency and the suppression of weed infestation through intercropping (Diiro et al., 2020). The labor freed up because of PPT adoption could be re-allocated to increase productivity and income from other crop enterprises (other than maize) and off-farm activities, potentially increasing the quantity and quality of food available at the household level (pathway H2c).

Hypothesis 3 concerns the role of women's empowerment in moderating the effects of technology adoption on dietary diversity. Substantial evidence from rural households in low-income areas suggests that husbands and wives differ in their preferences for and patterns of resource allocation and spending on food and non-food items, with women, generally having more significant concern with diet quality and nutrition (Hoddinott and Haddad, 1995; Haddad et al., 1997; Quisumbing, 2003; Duflo and Udry, 2004; Doss, 2006). Women with greater say in household production decisions, and better resource access are more able to ensure that the PPT-induced increase in food availability at household level trickles across to family members, including women (pathway H3a). Where women are empowered in the domain of income control, increased income resulting from PPT adoption is more likely to be equitably distributed within the household and lead to an increase in the quantity and quality of food consumed (pathway H3b). Pathway H3c reflects our contention that the current workload and decision-making power of women influence whether the reduced labor requirements under the PPT system leads women to re-allocate their time to production of other crops and engagement in income-generating activities, or if women instead devote more time to domestic tasks and leisure. Finally, pathway H3d represents the interaction of women's empowerment (income control and say in production decisions) in determining whether any increased income or other-crop production translates to an improvement in women's dietary diversity.

**Table 2**
Outcome and treatment variables definition and descriptive statistics.

| Variables | Description | Mean | Std dev. |
|---|---|---|---|
| *Outcome variables* | | | |
| Women's dietary diversity score | Number of food groups consumed by women in the last 7 days | 7.19 | 1.28 |
| *Treatment variables* | | | |
| Overall empowerment score | Women's overall empowerment score | 0.65 | 0.17 |
| Disempowered women and non-PPT-adoption (1/0) | Disempowered women belonging in non-PPT-adopting households | 0.32 | – |
| Empowered women and non-PPT-adoption (1/0) | Empowered women belong to in non-PPT-adopting households | 0.17 | – |
| Empowered women in PPT-adopting households (1/0) | Empowered women belong to PPT-adopting households | 0.18 | – |
| Disempowered women in PPT-adopting households (1/0) | Disempowered women belong to PPT-adopting households | 0.33 | – |
| Women's production decision | Number of production decisions in which the woman participates | 1.97 | 0.83 |
| Women's ownership of assets | Number of assets over which the woman has control | 2.59 | 1.49 |
| Women's decision making on income | Number of income decisions in which the woman participates | 4.73 | 1.99 |
| Women's decision making on credit | Number of credit-related decisions in which the woman participates | 2.98 | 2.59 |
| Women's group membership | Number of formal and informal groups to which the woman belongs | 1.27 | 2.18 |
| Workload | Time adequacy (1/0) | 0.28 | – |
| Observations | | 688 | |

### 3.2. Econometric approach

Assessing the impact on the women's dietary diversity score (WDDS) of women's empowerment individually and in conjunction with PPT requires constructing the counterfactual: What would the WDDS have been if an empowered woman had instead been disempowered, or if a disempowered woman had been empowered? What would the WDDS outcome have been for a (dis)empowered woman belonging to a PPT adopting household had it not taken up PPT? The construction of accurate counterfactual outcomes is challenged by the potential presence of sample selection: empowered and disempowered women (and PPT adopting and non-adopting households) may vary systematically in terms of observed factors (e.g., education; age; available physical resources; and access to development services, credit, input and output markets, and extension services) and unobserved attributes (e.g., motivation, risk preference, and managerial ability), which simultaneously affect women's empowerment and households' PPT adoption status (hereafter called the *treatment variables*) and women's dietary diversity score (hereafter called the *outcome variable*). Unless corrective measures are taken to account for such systematic differences, a comparison between empowered and disempowered women (and among adopting and non-adopting households) is likely to result in inconsistent outcome estimates.

We use two strategies to address the selection bias problem. First, we include many explanatory variables that influence both treatment and outcome variables. Second, we use an endogenous switching regression (ESR) framework, which is a variant of the instrumental variable approach also adopted in studies by Carter and Milon (2005), Di Falco et al. (2011), Abdulai and Huffman (2014), and Kassie et al. (2017).

**Table 3**
Definition and descriptive statistics of variables used in the regression models.

| Variables | Description | Mean | Std dev. |
|---|---|---|---|
| *Socio-economic characteristics* | | | |
| Occupation | Household head main occupation (1 = Farming; 0 = Other) | 0.75 | – |
| Family size | Household size (adult equivalent) | 5.58 | 2.42 |
| Credit constrained | Household credit constrained (1 = Yes; 0 = No) | 0.62 | – |
| Food crop groups grown | Number of food crop groups grown by household | 2.31 | 0.84 |
| Land owned | Per capita land owned (ha/adult equivalent) | 0.20 | 0.26 |
| Dairy cow ownership | Household owns dairy cow (1 = Yes; 0 = No) | 0.75 | 0.43 |
| Number of Livestock | Total livestock ownership (TLU) | 2.18 | 1.88 |
| Off-farm income | Income from non-farm activities ('000 Kenya shilling) | 160.24 | 207.01 |
| *Access to development services and social network* | | | |
| Distance to market | Distance to main market (walking minutes) | 60.61 | 41.07 |
| Distance to extension office | Distance to nearest extension office (walking minutes) | 69.07 | 52.50 |
| Confident in extension staff | Respondent has confidence in the skill of extension staff (1 = Yes; 0 = No) | 0.74 | – |
| Rely on government support | Can rely on government support during crop failure (1 = Yes; 0 = No) | 0.40 | – |
| Number of relatives | Number of relatives respondent can rely on in critical times in a village | 6.66 | 25.17 |
| *Instrumental variables* | | | |
| Education difference | Education difference between adult male and female (male–female) | 0.094 | 4.10 |
| Woman brought assets into marriage (1/0) | Woman brought assets into marriage | 0.14 | – |
| Children below 10 years (1/0) | Proportion of children below 10 years | 0.69 | – |
| Field day | Number of push–pull fields attended | 1.47 | 2.15 |
| Number of push–pull adopters known | Number of push–pull adopters respondents know in a village | 3.30 | 3.27 |
| County fixed effects | | | |
| Migori | Migori County (1/0) | 0.18 | – |
| Hoam Bay | Homa Bay County (/0) | 0.17 | – |
| Kisumu | Kisumu County (1/0) | 0.09 | – |
| Siaya | Siaya County (1/0) | 0.18 | – |
| Busia | Busia County (1/0) | 0.04 | – |
| Vihiga | Vihiga County (1/0) | 0.13 | – |
| Kakamega | Kakamega County (1/0) | 0.07 | – |
| Bungoma | Bungoma County (1/0) | 0.10 | – |
| Trans-Nzoia | Trans-Nzoia County (1/0) | 0.10 | – |
| Observations | | 688 | |

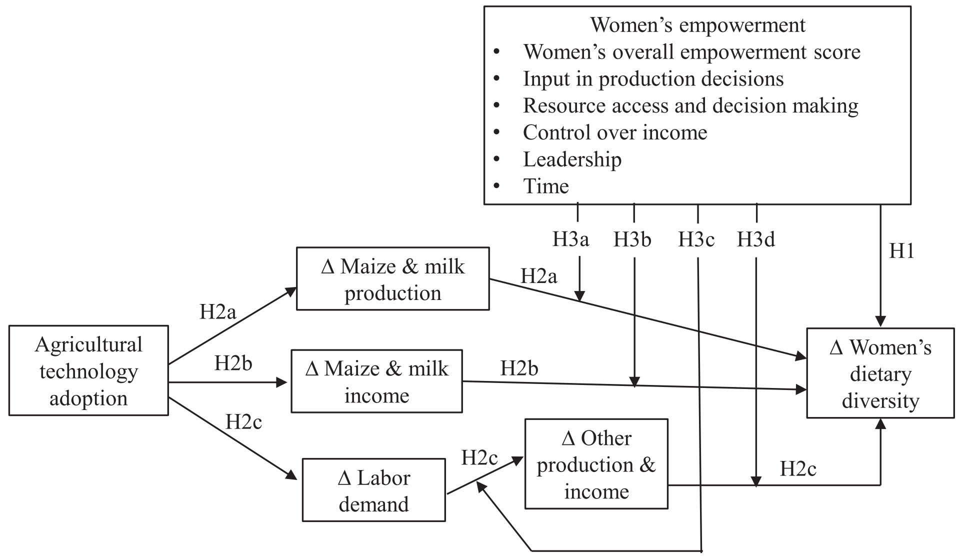


**Fig. 2.** Conceptual framework of the links between agricultural technology adoption, women's empowerment, and women's dietary diversity.

The ESR framework is a two-stage estimation procedure aimed at correcting potential selection bias. The first stage involves modelling treatment variables using choice models to generate selection correction parameters, which are then included in the second-stage model to purge potential selection bias. The second stage involves employing an outcomes model to estimate the effects of empowerment and adoption status on outcomes, using the inverse Mills ratios as additional regressors.

### 3.2.1. The first stage: Modelling women's empowerment status

Four categories of treatments ($W_{it}$) were established, based on women's overall empowerment and households' PPT-adoption status. These treatments *(t)* are as follows: (i) Treatment *0* $(t = 0)$ – Disempowered women belonging to households that did not adopt PPT; (ii) Treatment 1 $(t = 1)$ – Empowered women belonging to households that did not adopt PPT; (iii) Treatment 2 $(t = 2)$ – Empowered women belonging to households that adopted PPT; and (iv) Treatment 3 $(t = 3)$ – Disempowered women belonging to households that adopted PPT. These multiple treatments lead to the formulation of the following multinomial choice models:

$$W_{it} = \varphi X_{it} + \delta Z_{it} + u_{it},\ t = 0, 1, 2, 3 \tag{1}$$

The symbol $i$ indexes individual women in a household, while $t$ indexes their treatment status. The vector $W_{it}$ represents the empowerment status of the $i^{th}$woman in a household, $X$ denotes the vector of individual- and household-level characteristics as well as location dummies that influence empowerment, $Z$represents a vector of variables that influence women's empowerment and adoption status but not outcome variables, $u$ is the error term, and $\varphi$ and $\delta$ are parameters to be estimated. Equation (1) is estimated using the multinomial logit model, given the multinomial nature of the treatment variables. It has become common to use the multinomial logit model as a selection rule in the impact literature (Bourguignon et al., 2007; Dimova and Gang, 2007; Kassie et al., 2017).

In addition to the binary women's empowerment treatment variable, we considered the continuous version of the overall empowerment score and different domains of empowerment (see Tables 2 and 5). On the estimation procedure, see Section 3.2.3 below.

In our study, vector $Z$ used for the overall women's empowerment regression models includes the difference in education level between the adult male and female decision makers in the household and binary variables for whether the wife brought assets into the marriage and whether the household has children under the age of 10 years (for studies using these as instrumental variables, see Smith et al., 2003; Quisumbing and Maluccio, 2003; Sraboni et al., 2014; Diiro et al., 2018). The difference in education between male and female adult decision makers and whether the woman brought assets into her marriage are used as instruments for the A-WEAI indicators of production, resources, income, credit, and leadership. The instruments used for the workload indicator are the difference in education between adults male and female decision makers and whether the household has children under the age of 10 years.

The difference in the education variable may reflect the difference in human capital and has been used to proxy women's relative bargaining position in the household (Quisumbing and Maluccio, 2003; Smith et al., 2003; Sinharoy et al., 2018). Likewise, women's bringing of assets to their new household upon marriage, a common practice in the study area (Diiro et al., 2018), may also be a good proxy for a woman's bargaining power (Quisumbing and Maluccio, 2003; Doss, 1996). The proportion of household members below ten years is used as an instrument to indicate a woman's workload and time available for leisure.

The identifying variables for PPT adoption include the number of adopters in their village known by the respondents and the number of PPT field days they attended, both are proxies for farmer exposure to PPT (Kassie et al., 2018). These instruments are used in the regression models where treatments 1 and 2 are specified.

### 3.2.2. The second stage: Modelling impacts of women's empowerment status on outcomes

The second stage of the econometric model establishes the relationship between the outcome variable (WDDS and a set of explanatory variables that include selection correction terms (the Mills ratios) in addition to individual, household, and location characteristics ($X$). The four treatment categories mentioned in Section 3.2.1 result in four outcome equations, which are defined as follows for treatment $t$:

$$\begin{cases} Regime\ \ 0\text{: } Y_{i0} = \beta_0 X_{i0} + \sigma_0 \widehat{\lambda}_{i0} + \varepsilon_{i0},\ if\ \ W_{it} = 0 \\ \vdots \\ Regime\ \ t\text{: } Y_{it} = \beta_t X_{it} + \sigma_t \widehat{\lambda}_{it} + \varepsilon_{it}, if\ \ W_{it} = t\ \ for\ \ t = 1, 2, 3 \end{cases} \tag{2}$$

As in Equation (1), $i$ indexes individual women and households and $t$ indexes treatment status. The vector $Y$ denotes the outcome variable (WDDS); $X$ is a vector of observable regressors that influence treatment and outcome variables; $\widehat{\lambda}$ is a vector of the inverse Mills ratio for each treatment status obtained from the estimation of Equation (1) to

**Table 4**
Impact of women's empowerment interaction with technology adoption on WDDS, multiple treatment results.

| | Treatment | Actual outcome | Counterfactual outcome | ATT |
|---|---|---|---|---|
| 1 | Women's empowerment for non-PPT adopting households (actual = t1 and counterfactual = t0) | 7.087 | 6.758 | 0.329(0.107)*** |
| 2 | Women's empowerment for PPT adopting households (actual = t2 and counterfactual = t3) | 7.532 | 7.338 | 0.194(0.070)*** |
| 3 | PPT adoption for households with disempowered women (actual = t3 and counterfactual = t0) | 7.335 | 6.969 | 0.366(0.073)*** |
| 4 | PPT adoption for households with empowered women (actual = t2 and counterfactual = t1) | 7.532 | 6.902 | 0.630(0.084)*** |

Notes: Treatments are Disempowered women belonging to households that did not adopt PPT (t0), empowered women belonging to households that did not adopt PPT (t1), Empowered women belonging to households that adopted PPT (t2), and disempowered women belonging to households that adopted PPT (t3). Standard errors in parentheses; ** and *** denote significance levels at < 5% and < 1%, respectively.

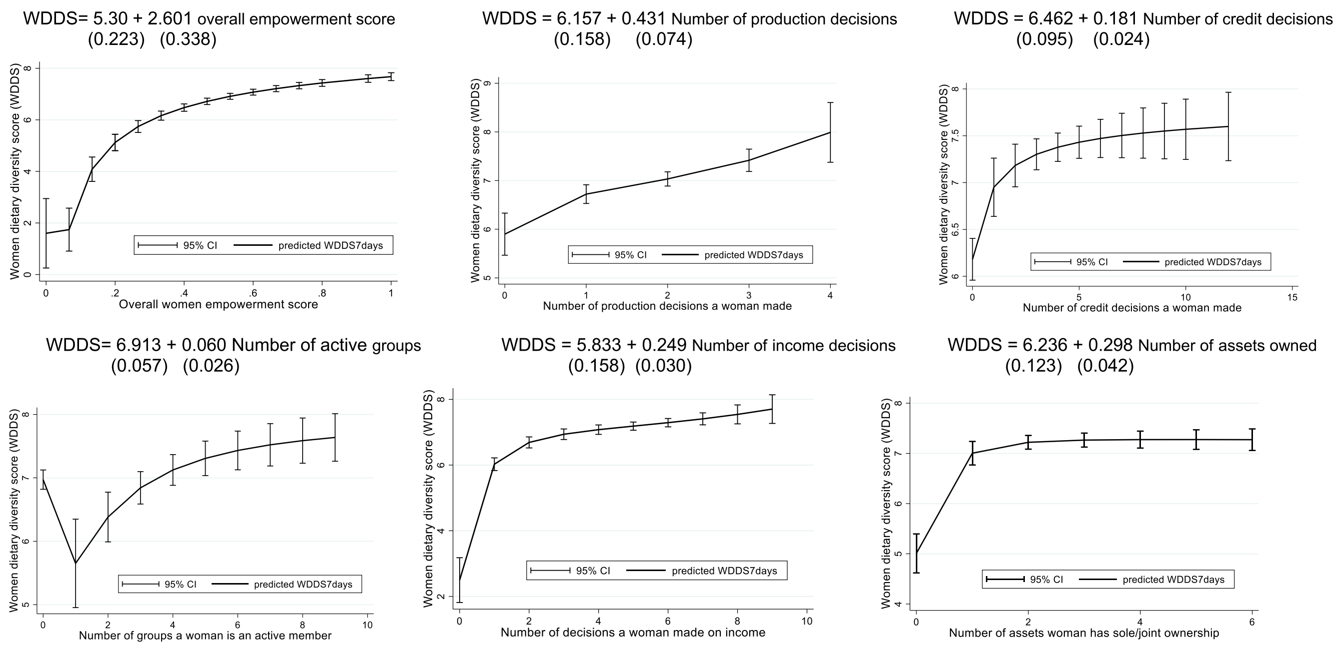


**Fig. 3.** Women's Dietary Diversity Score (WDDS) and overall empowerment score and individual A-WEAI indicator. Notes: 1) Standard errors in parentheses; 2) Coefficient estimates for the overall empowerment score, number of production decisions in which the woman participates solely or jointly, number of credit decisions that a woman made solely or jointly, number of groups in which a woman is an active member, number of income decisions in which the woman participates, and number of assets for which a woman has sole or joint ownership; and 3) Continuous indicators were used because there was minimal variation when dummy indicator variables were used.

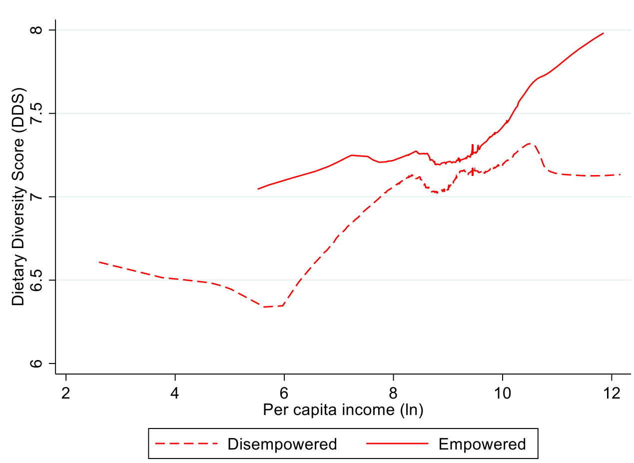


**Fig. 4.** Per capita income and WDDS, by women's empowerment status.

capture unobservable regressors; $\sigma$ denotes the covariance between the error terms in Equations (1) and (2); $\varepsilon$ are regression error terms; and $\beta_1$ and $\varphi$ are vectors of parameters to be estimated.

Equation (2) is used to generate the expected actual and counterfactual outcomes, which are then used to estimate the average treatment effects (ATT). For instance, the counterfactual outcome for treatment 1 is defined as the expected counterfactual outcomes of empowered women (belonging to non-PPT-adopting households) if the returns on their observed ($X_{it}$) and unobserved ($\hat{\lambda}_{it}$) characteristics had the same effect as the current returns ($\beta_0$and$\sigma_0$)of disempowered women's belonging to non-PPT-adopting households (treatment 0) observed ($X_{i0}$)and unobserved ($\hat{\lambda}_{i0}$)characteristics. The counterfactual for other treatments can be generated in a similar way, depending on which treatment is used as counterfactual (Table 4).

Using treatment 1 and treatment 0, we show the computation of the expected actual and counterfactual outcomes and ATT. A similar procedure can be followed to generate the same information for other treatments. The actual outcome for treatment 1 (equation (3a)) and treatment 0 (equation (3b)) are observed from the data; these are defined below for each treatment:

$$E(Y_{i1}\ |W_{i1}=1; X_{i1}, \hat{\lambda}_{i1}) = \beta_1 X_{i1} + \sigma_1 \hat{\lambda}_{i1} \tag{3a}$$

$$E(Y_{i0}\ |W_{i0}=0; X_{i0}, \hat{\lambda}_{i0}) = \beta_0 X_{i0} + \sigma_0 \hat{\lambda}_{i0} \tag{3b}$$

The counterfactual outcome for treatment 1 to estimate the effect of women's empowerment on dietary diversity is measured as follows:

$$E(Y_{i0}\ |W_{i1}=1; X_{i1}, \hat{\lambda}_{i1}) = \beta_0 X_{i1} + \sigma_0 \hat{\lambda}_{i1} \tag{3c}$$

In Equation (3c), $\beta_0$ and $\sigma_0$ are the regression coefficients obtained from the outcome equation for the regime *t=0* or treatment 0 (see

**Table 5**
Effects of overall empowerment score and individual indicators of women's empowerment on WDDS.

| Variables | Overall Empowerment score | Women's production decision | Women's ownership of assets | Women's decision making on income | Women's decision making on credit | Women's group membership | Workload |
|---|---|---|---|---|---|---|---|
| Women's overall empowerment score | 0.05** | | | | | | |
| | (0.024) | | | | | | |
| Number of production decisions in which the woman participates | | 0.04<br>(0.041) | | | | | |
| Number of assets over which the woman has control | | | 0.03**<br>(0.014) | | | | |
| Number of income decisions in which the woman participates | | | | 0.05*<br>(0.029) | | | |
| Number of credit-related decisions in which the woman participates | | | | | 0.02***<br>(0.008) | | |
| Number of formal and informal groups to which the woman belongs | | | | | | 0.08**<br>(0.030) | |
| Time adequacy | | | | | | | −0.02<br>(0.033) |
| Other control variables | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| County fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | 1.94***<br>(0.063) | 1.88***<br>(0.099) | 1.90***<br>(0.064) | 1.74***<br>(0.132) | 1.92***<br>(0.060) | 1.87***<br>(0.067) | 1.96***<br>(0.065) |
| Observations | 688 | 688 | 688 | 688 | 688 | 688 | 688 |

Notes: Bootstrapped standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Equation (3b)). We bootstrapped Equations 3a-3c to account for generated regressors, i.e., the inverse Mills ratios.[1] The inclusion of variables in the treatment and outcome equations are drawn from existing women's empowerment and nutrition impact analysis literature (Babatunde and Qaim, 2010; Larochelle and Alwang, 2014; Sraboni et al., 2014; Malapit and Quisumbing, 2015; Malapit et al., 2015; Sibhatu et al., 2015; Koppmair et al., 2016; Diiro et al., 2018, Kassie et al., 2018).

Equations 3a-3c are used to compute the average treatment effects ($ATT$), which is derived as the difference between Equations (3a) and (3c), as specified in Equation (4):

$$ATT = E(Y_{i1} | W_{i1} = 1; X_{i1}, \hat{\lambda}_{i1}) - E(Y_{i0} | W_{i1} = 1; X_{i1}, \hat{\lambda}_{i1}) = (\beta_1 - \beta_0)X_{i1} + (\sigma_1 - \sigma_0)\hat{\lambda}_{i1} \quad (4)$$

In Equation (4), the terms $(\beta_1 - \beta_0)X_{i1}$ and $(\sigma_1 - \sigma_0)\hat{\lambda}_{i1}$ respectively denote the impact of observed and unobserved characteristics on outcomes.

### 3.2.3. Estimation procedure

We estimate three WDDS equations. In the first specification, we assess the impact of multinomial treatments (the interaction of empowerment with technology adoption) as specified in Sections 3.2.1 and 3.2.2 in the ESR framework. The first stage is estimated using the multinomial logit model because of their binary nature. The WDDS is a count variable, and we thus employ a Poisson regression model.

In the second model specification, we estimate the impact of the continuous version of the overall empowerment score, and the different domains of empowerment on WDDS using the control function (CF) approach. The CF method is suitable for nonlinear models with endogenous variables (Wooldridge, 2002), such as those in our case. It involves a two-stage estimation procedure as in the ESR approach but has the advantage of estimating nonlinear models with an endogenous treatment variable (Diiro et al., 2018). Therefore, in the first stage, the women's empowerment score is predicted using instruments outlined in Section 3.2.2, and the predicted values are included as an additional regressor in the second stage regression model of WDDS. The first stage is estimated using a fractional response probit model (FRPM) because the empowerment score values lie between zero and one (Papke and Wooldridge, 1996).

In the third specification, the impact of individual indicators of empowerment on WDDS is estimated to assess the individual effect on WDDS. The five empowerment indicators enter the WDDS equation as count variables (the number of groups in which a woman is an active member, the number of decisions a woman makes about credit, the number of decisions a woman makes about production, the number of assets over which a woman has control, and the number of decisions a woman makes about household income). For workload, we created a dummy variable, which takes a value of 1 if the woman spent 10.5 h or less working on the day before the survey interview, and 0 otherwise. A similar CF approach as the overall empowerment score is used because of the nonlinear nature of the models used to estimate these indicators. The Poisson regression model is used to estimate input in productive decisions, asset ownership, and control over the use of income indicators. The group membership indicator is estimated using a zero-inflated Poisson because of numerous zeros. A negative binomial model is applied for the number of decisions a woman makes about credit due to over-dispersion, and we use a probit model to estimate the workload indicator.

### 3.2.4. Measurement of treatment variables

As mentioned in the Introduction section, the women's empowerment variable is measured using the A-WEAI following Malapit et al. (2017) (see Table 1). Due to budget constraints, the A-WEAI was administered to women only, i.e., male adult decision-makers in a household were not interviewed. We classified each woman as empowered or disempowered using the 80% cut-off proposed by Alkire et al. (2013), namely that women with overall adequacy scores not less than 80% were considered empowered and women with scores less than this were regarded as disempowered. By this measure, about 65% of women in our study were disempowered, which is close to the

[1] We are not aware of an estimation command that simultaneously estimates the first and second stages in the framework of multiple treatment variables when the outcome variable is estimated using count models. However, we implemented the Stata selmlog command (Bourguignon et al., 2007) that simultaneously estimates the two stages. In the selmlog, the first stage is estimated using a multinomial logit model and a linear regression model is used to estimate the second stage. The results are qualitatively close to the ESR model results.

baseline WEAI results reported by Malapit et al. (2014) for northern Kenya, which revealed that 68.4% of women in the area were disempowered. The disempowerment of the women in our study arose largely because of a lack of time (high workloads) and a lack of leadership opportunities in the community (group membership).

The household was considered as an adopter of PPT if household members had been using the technology for more than a year at the time of the survey. The proportion of PPT adopters in the sample was 50.8%. Regarding the distribution of the sample with respect to the different combinations of adoption and women's empowerment (i.e., treatments), 18% of the women in our sample were empowered and resided in PPT adopting households, 17% were empowered, but from non-adopting households, 33% were disempowered from adopting households, and 32% were disempowered and from non-adopting households.

#### 3.2.5. Measurement of outcome variables

In the nutrition literature, it is common to use the individual dietary diversity score (DDS) as an indicator of nutrient adequacy and access to a variety of foods. For example, the DDS has been found to be positively correlated with macronutrient and micronutrient adequacy of diets for adults (Ogle et al., 2001; Foote et al., 2004; Arimond et al., 2010). Savy et al. (2005) report a positive relationship between DDS for the nutritional status of adult women in rural Burkina Faso. Other studies (Haddad et al., 1994; Arimond et al., 2010) have shown that a low DDS may present risks of micronutrient deficiencies, such as iron deficiency leading to anemia. Concerning women, such deficiencies may not only affect their ability to provide adequate care for their families but may also lower their income-generating potential.

A measure of DDS was developed by previous studies using either seven-day food consumption data (Kennedy et al., 2010; Jones et al., 2014; Sraboni et al., 2014; Snapp and Fisher, 2015; Sibhatu et al., 2015) or 24-hour recall food consumption data (Olney et al., 2009; Herforth, 2010; Kennedy et al., 2010; Malapit and Quisumbing, 2015; Koppmair et al., 2016). In our survey, the individual dietary diversity questionnaire elicits information on mothers' (hereafter women's) food consumption from nine food groups over the reference period of seven days before the survey. We use 7-day recall data (rather than a single 24-hour recall period) as we believe this provides a better measure of an individual's habitual diet in the study context. In rural areas of low-income countries, access to and affordability of healthy foods are highly problematic, and food consumption can, therefore, differ enormously from one day to the next. While repeated 24-hour recall offers a way to overcome some of the limitations of 24-hour recall data for collecting accurate information on dietary habits, this was not possible in our study for budgetary reasons. The food groups indicated in our questionnaire followed those developed by Kennedy et al. (2011).[2] These nine food groups were (i) starchy staples; (ii) dark green leafy vegetables; (iii) other vitamin-A-rich fruits and vegetables; (iv) other fruits and vegetables; (v) organ meat; (vi) meat and fish; (vii) eggs; (viii) legumes, nuts and seeds; and (ix) milk and milk products. The women's dietary diversity score (WDDS) is computed as the sum of the nine food groups consumed by the woman in the household during this seven-day reference period.

## 4. Results

### 4.1. Descriptive statistics

Descriptive results support a positive relationship between the WDDS and the overall women's empowerment score and individual A-WEAI indicator (Fig. 3). The data also show that the unconditional number of food groups consumed by empowered women belonging to non-adopting households (7.09) is higher than for disempowered women in non-adopting households (6.92) (Table 2). Similarly, the number of food groups consumed by empowered women in PPT adopting household is 7.54 and is 7.33 for disempowered women in adopting households. Fig. 4 indicates a positive association between per capita income, empowerment, and WDDS.

### 4.2. Econometric results

#### 4.2.1. Multiple treatment effects

This section presents findings based on multinomial binary treatments. The discussion of results focuses mainly on treatment effects. Detailed first and second stage regression results are reported in the Appendix (Tables A1 and A3).

Table 4 reports results for the multiple treatment effects of how women's empowerment moderates the impact of PPT adoption on WDDS using the ESR approach. The average treatment effects results show that women's empowerment in agriculture has a positive and significant effect on WDDS for both PPT adopting and non-adopting households (see the first two rows of Table 4).[3] These findings are in support of Hypothesis 1. For instance, the ATT of 0.329 represents a 5% increase in WDDS as a result of women's empowerment for those households that did not adopt PPT (row 1 of Table 4). Previous studies (Malapit and Quisumbing, 2015; Malapit et al., 2015) have similarly found a positive association between women's empowerment and the WDDS. Furthermore, Gupta et al. (2019) reported a positive association between women's empowerment and their iron status in India. While Jones et al. (2020) found women's empowerment positively associates with women's BMI in five East African countries.

Turning to the impact of PPT adoption on dietary diversity (Hypothesis 2), results show a positive and significant impact regardless of women's empowerment status and the measure of dietary diversity used. For households with disempowered women, the third row of Table 4 indicates that PPT adoption increases WDDS by 5%. For households with empowered women, the fourth row of the tables shows that PPT adoption increases WDDS by 10%. In short, we find evidence in favor of the hypothesis that PPT adoption increases dietary diversity. We expect this effect to operate through production, income, and labor allocation pathways (Fig. 2), but we leave the testing of these mechanisms for future research. Importantly, our results add to literature showing that adoption of improved crop and livestock technologies can improve nutrition outcomes in low-income settings (Zeng et al., 2017; Larochelle and Alwang, 2014; Kabunga et al., 2017; Kidoido and Korir, 2015).

Our results indicate that women's empowerment boosts the WDDS impact of PPT adoption (Hypothesis 3). Two sets of findings support this hypothesis of a moderating effect of women's empowerment. First, as row 3 of Table 4 shows, disempowered women can achieve higher dietary diversity if their households adopt PPT, but the magnitude of the impact vis-à-vis nutrition benefits is lower than that which empowered women can achieve (see row 4 of Table 4). As revealed by Table 4, the WDDS for disempowered women from non-adopting households would increase from 6.969 to 7.335 (5%) if their households were to adopt PPT. The corresponding increase in WDDS for empowered women is 10%, suggesting that the impact of PPT adoption on WDDS is five percentage points higher for households with empowered vs. disempowered women. These findings are consistent with evidence indicating that income and production increase the

[2] We use the WDDS instead of the minimum dietary diversity for women (MDD-W), because during data collection we combined pulses with nuts and seeds, which precludes calculation of the MDD-W.

[3] To assess robustness of results, we jointly estimate the selection and outcome equations using the Stata selmlog command and we find qualitatively similar results for both specifications: all treatments have a positive and significant effect on the WDDS.

household's food budget share to a greater degree when women vs. men control the income (Hoddinott and Haddad, 1995; Haddad et al., 1997; Quisumbing, 2003; Duflo and Udry, 2004; Doss, 2006).

#### 4.2.2. Overall empowerment score and dimensions of women's empowerment

Table 5 displays the results of the impact of women's overall empowerment score on WDDS derived using the control function fractional response probit model and assuming exogeneous empowerment. We report bootstrapped standard errors given the use of predicted (vs. observed) values of the empowerment score in the WDDS equation. Table 5 reports results from the selection correction and outcome equations. Our results indicate that empowering women increases the dietary diversity score.

Moving to the individual indicators, except for the production decision and time adequacy domain, we find a significant and positive association between WDDS and women's group membership, income control, ownership of assets, and decision making on credit (Table 5). The results are in line with Fig. 3 and previous literature (Sraboni et al., 2014; Malapit et al. 2015; Malapit and Quisumbing, 2015).[4]

The second result in support of Hypothesis 3 is shown in row 2 of Table 4, which indicates that by pairing women's empowerment and technology dissemination efforts, the dietary diversity gain increases by three percentage points compared to matching disempowered women with technology adoption. Furthermore, the comparison of results in rows 1 and 2 suggests that technology adoption can contribute to closing the dietary diversity gap of women regardless of their empowerment status. In summary, our results indicate that women's empowerment boosts the dietary diversity gains from agricultural technology adoption, for the case of PPT adoption in Kenya.

## 5. Discussion and policy implications

Empowerment is widely recognized as an important indicator of progress towards achieving gender equity objectives as well as having the potential to advance broader welfare outcomes, such as improved food and nutrition security and reduced poverty (Ruel and Alderman, 2013; Malapit and Quisumbing, 2015). While researchers, practitioners, and policymakers agree that women can shape family nutritional outcomes through their own nutritional status and self-care and caregiving practices (e.g., breastfeeding, food purchasing, and cooking), there remains a need for additional research before strong conclusions can be reached on the instrumental value of women's empowerment (Santoso et al., 2019). This paper contributes to the literature by examining for the case of western Kenya how women's empowerment and agricultural technology adoption influence women's dietary diversity both individually and in tandem. The role of women's empowerment in moderating the impact of technology adoption on nutrition outcomes had not previously been assessed to our knowledge. We adopted a treatment effects model to allow for causal analysis of the empowerment-technology-nutrition linkage, whereas most studies in the women's empowerment and nutrition literature have identified correlations rather than causal effects (e.g., Malapit and Quisumbing, 2015; Sinharoy et al., 2018).

Our results suggest that women's empowerment is an important determinant of women's dietary diversity, which is unsurprising. As women's empowerment levels increase, they have greater knowledge of nutrition and health and the decision-making power, income control, and time to exercise that knowledge in their self-care and caregiving practices. The positive impact of women's empowerment on the WDDS is not only relevant to women themselves but can also impact the health of their family and the development of the next generation.

We also find evidence that the interaction of women's empowerment with technology adoption further increases dietary diversity scores. The adoption of PPT, the technology of focus in the study, has a positive nutrition effect regardless of empowerment status, but its effect is stronger for households with empowered women than households with disempowered women. This result has two policy implications. First, policies aimed at achieving higher women's dietary diversity should consider pairing technology dissemination efforts with women's empowerment interventions. Second, development partners and policymakers can also enhance disempowered women's dietary diversity through the diffusion of economic and nutrition enhancing technologies such as PPT.

As a first assessment of the impact on dietary diversity that women's empowerment has in combination with technology adoption, our study has certain limitations. The cross-sectional nature of our data does not support a rigorous examination of the underlying mechanisms through which women's empowerment and technology adoption interact in determining women's dietary diversity. We proposed several plausible pathways (Fig. 2) but were unable to rigorously test them in the absence of longitudinal data. Another limitation is that the data are not nationally representative and, thus, may not reflect women's empowerment status across Kenya. Thus, we recommend future research uses nationally-representative panel data to assess better the extent to which women's empowerment and its interaction with technology adoption positively impact women's dietary diversity and understand the underlying mechanisms of these effects.

## CRediT authorship contribution statement

**Menale Kassie:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Funding acquisition. **Monica Fisher:** Conceptualization, Methodology, Resources, Visualization, Writing - review & editing. **Geoffrey Muricho:** Investigation, Writing - review & editing. **Gracious Diiro:** Writing - review & editing.

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[4] Although results are not reported, we obtained similar findings when WDDS was estimated assuming the overall empowerment score and individual indicators are not endogenous (i.e., exogeneity assumed). Except for the time domain, other indicators are significantly and positively correlated with WDDS.

Economic Cooperation and Development (BMZ), and the Federal Democratic Republic of Ethiopia and the Kenyan Government. We also thank Jackson Kimani of *icipe* for generating the map of the study area, the enumerators and supervisors for their dedication in conducting the fieldwork, the farmers for their time, and *icipe* Nairobi support staff for facilitating the filed survey logistic. The views expressed here are those of the authors and do not necessarily reflect the views of the donors or the authors' institutions. The usual disclaimers apply.

## Appendix A

Tables A1–A3.

**Table A1**
First stage results of the multiple treatments – Multinomial logit model results.

| | Regression models for treatments-women empowered and disempowered belong to non-adopting households | | | Regression models for treatments-women empowered and disempowered belong to adopting households | | |
|---|---|---|---|---|---|---|
| | Empowered women in non-PPT-adopting households | Empowered women in PPT-adopting households | Disempowered women in PPT-adopting households | Empowered women in non-PPT-adopting households | Empowered women in PPT-adopting households | Disempowered women in PPT-adopting households |
| Education difference | −0.39*** | −0.36*** | −0.03 | −0.41*** | −0.42*** | −0.10** |
| | (0.041) | (0.044) | (0.036) | (0.046) | (0.052) | (0.052) |
| Woman brought assets into marriage | 0.63 | 0.53 | 0.50 | 0.66 | 0.80* | 0.70* |
| | (0.407) | (0.387) | (0.317) | (0.433) | (0.449) | (0.387) |
| Children below 10 years | −0.37 | −0.66** | −0.15 | −0.34 | −0.54 | −0.03 |
| | (0.305) | (0.308) | (0.258) | (0.326) | (0.337) | (0.309) |
| Field day | NA | NA | NA | −0.23 | 0.65*** | 0.66*** |
| | | | | (0.217) | (0.172) | (0.168) |
| Number of push-pull adopters known | NA | NA | NA | −0.06 | 0.51*** | 0.49*** |
| | | | | (0.090) | (0.086) | (0.085) |
| Ln(Food crop groups grown) | 0.07 | 1.76*** | 2.12*** | 0.21 | 1.51*** | 1.98*** |
| | (0.357) | (0.374) | (0.331) | (0.382) | (0.398) | (0.386) |
| Ln(off-farm income) | −0.05 | −0.01 | 0.14 | −0.04 | −0.24 | −0.10 |
| | (0.126) | (0.137) | (0.111) | (0.135) | (0.149) | (0.133) |
| Family size | 0.01 | 0.04 | 0.00 | 0.02 | −0.03 | −0.05 |
| | (0.065) | (0.063) | (0.054) | (0.064) | (0.068) | (0.062) |
| Occupation | 0.61** | 1.39*** | 0.70*** | 0.62* | 0.98** | 0.30 |
| | (0.306) | (0.364) | (0.249) | (0.323) | (0.416) | (0.306) |
| Credit constrained | −0.63** | −0.64** | −0.25 | −0.77** | −0.70* | −0.28 |
| | (0.301) | (0.317) | (0.255) | (0.344) | (0.374) | (0.334) |
| Ln(Land owned) | −0.74 | 0.70 | −0.16 | −0.69 | 0.96** | 0.13 |
| | (0.567) | (0.468) | (0.627) | (0.581) | (0.479) | (0.641) |
| Dairy cow ownership | 0.39 | 0.65 | 0.28 | 0.66 | 1.24** | 0.99** |
| | (0.471) | (0.441) | (0.359) | (0.532) | (0.495) | (0.433) |
| Ln (Number of livestock) | −0.08 | −0.14 | 0.09 | −0.12 | −0.30* | −0.06 |
| | (0.166) | (0.154) | (0.137) | (0.172) | (0.180) | (0.168) |
| Ln(Distance to market) | −0.03 | −0.08 | 0.05 | 0.03 | 0.09 | 0.28 |
| | (0.198) | (0.204) | (0.168) | (0.212) | (0.227) | (0.215) |
| Confident in extension staff | −0.36 | 1.12*** | 0.63** | −0.36 | 0.70* | 0.21 |
| | (0.280) | (0.361) | (0.264) | (0.289) | (0.393) | (0.317) |
| Ln(Distance to extension office) | −0.04 | −0.09 | 0.02 | −0.12 | −0.12 | −0.05 |
| | (0.178) | (0.175) | (0.134) | (0.176) | (0.195) | (0.163) |
| Rely on government support | −0.15 | −0.05 | 0.06 | −0.04 | −0.17 | −0.14 |
| | (0.265) | (0.284) | (0.234) | (0.272) | (0.315) | (0.278) |
| Number of relatives | −0.00 | −0.01 | −0.00 | −0.00 | −0.01 | 0.00 |
| | (0.006) | (0.005) | (0.003) | (0.005) | (0.008) | (0.004) |
| Ln (fertilizer use) | −0.04 | 0.10** | 0.13*** | −0.03 | 0.10* | 0.15*** |
| | (0.037) | (0.051) | (0.040) | (0.041) | (0.056) | (0.045) |
| County fixed effects | Yes | yes | Yes | Yes | Yes | Yes |
| Constant | 1.02 | −4.17*** | −4.01*** | 0.79 | −4.89*** | −5.01*** |
| | (1.551) | (1.609) | (1.482) | (1.584) | (1.793) | (1.748) |
| Observations | 688 | 688 | 688 | 688 | 688 | 688 |

Notes: Robust standard errors in parentheses ; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; In respect of the reference treatment, disempowered women have lived in non-PPT-adopting households.

**Table A2**
First stage results for overall women's empowerment and individual indicators of women's empowerment.

| Variables | Overall empowerment | Women's production decision | Women's ownership of assets | Women's decision making on income | Women's decision making on credit | Women's group membership | Workload |
|---|---|---|---|---|---|---|---|
| Education difference | −0.05*** | −0.01*** | −0.03*** | −0.01** | −0.04*** | −0.03*** | 0.01 |
| | (0.004) | (0.003) | (0.004) | (0.004) | (0.008) | (0.012) | (0.014) |
| Woman brought assets into marriage | 0.12** | 0.14*** | 0.13** | 0.04 | 0.08 | 0.16 | |
| | (0.049) | (0.042) | (0.058) | (0.045) | (0.105) | (0.114) | |
| Children below 10 years | −0.06 | | | | | | −0.38*** |
| | (0.039) | | | | | | (0.128) |
| Ln(Food crop groups grown) | −0.05 | −0.01 | −0.14*** | −0.02 | 0.02 | −0.04 | −0.22 |
| | (0.045) | (0.043) | (0.051) | (0.043) | (0.092) | (0.105) | (0.150) |
| Ln(off-farm income) | −0.02 | 0.00 | 0.05** | 0.05*** | 0.10*** | 0.02 | −0.13** |
| | (0.015) | (0.016) | (0.020) | (0.016) | (0.034) | (0.036) | (0.055) |
| Family size | −0.00 | 0.01* | 0.02** | 0.01 | 0.02 | 0.03* | −0.01 |
| | (0.007) | (0.007) | (0.008) | (0.007) | (0.016) | (0.017) | (0.026) |
| Occupation | 0.11*** | 0.08** | 0.06 | 0.05 | 0.18** | 0.18 | 0.10 |
| | (0.038) | (0.039) | (0.048) | (0.038) | (0.080) | (0.144) | (0.131) |
| Credit constrained | −0.04 | −0.02 | 0.06 | −0.01 | −0.02 | −0.14 | 0.01 |
| | (0.036) | (0.036) | (0.047) | (0.034) | (0.071) | (0.089) | (0.122) |
| Ln(Land owned) | 0.04 | 0.02 | 0.05 | −0.01 | −0.23 | −0.17 | 0.04 |
| | (0.082) | (0.063) | (0.079) | (0.065) | (0.197) | (0.208) | (0.209) |
| Dairy cow ownership | 0.07 | 0.12** | 0.08 | 0.06 | −0.03 | 0.03 | −0.09 |
| | (0.051) | (0.054) | (0.069) | (0.050) | (0.118) | (0.126) | (0.170) |
| Ln (Number of livestock) | −0.01 | −0.00 | 0.06** | 0.01 | 0.03 | 0.07 | −0.02 |
| | (0.018) | (0.018) | (0.027) | (0.020) | (0.041) | (0.046) | (0.063) |
| Ln(Distance to market) | −0.00 | −0.05** | −0.10*** | −0.01 | −0.03 | −0.10** | 0.03 |
| | (0.024) | (0.024) | (0.028) | (0.022) | (0.051) | (0.049) | (0.082) |
| Confident in extension staff | −0.01 | −0.06 | −0.11** | −0.00 | −0.30*** | 0.17 | 0.08 |
| | (0.035) | (0.037) | (0.043) | (0.038) | (0.071) | (0.112) | (0.128) |
| Ln(Distance to extension office) | 0.00 | 0.01 | 0.02 | −0.04** | 0.05 | −0.01 | 0.11 |
| | (0.023) | (0.020) | (0.026) | (0.019) | (0.045) | (0.046) | (0.072) |
| Rely on government support | −0.08** | 0.04 | −0.04 | 0.12*** | 0.16** | 0.16** | −0.58*** |
| | (0.033) | (0.032) | (0.042) | (0.031) | (0.072) | (0.081) | (0.119) |
| Number of relatives | −0.00 | −0.00 | −0.00** | 0.00 | −0.00* | −0.01* | 0.00 |
| | (0.000) | (0.001) | (0.001) | (0.000) | (0.002) | (0.004) | (0.002) |
| Ln (fertilizer use) | −0.01 | 0.00 | −0.01* | 0.01* | 0.00 | −0.01 | −0.03 |
| | (0.006) | (0.006) | (0.006) | (0.006) | (0.011) | (0.014) | (0.018) |
| Push-pull adoption | 0.02 | 0.03 | 0.11** | 0.04 | 0.26*** | 0.14 | 0.00 |
| | (0.035) | (0.035) | (0.044) | (0.034) | (0.077) | (0.089) | (0.124) |
| Count fixed effects | Yes | Yes | Yes | Yes | −0.20 | −0.01 | −0.53*** |
| Constant | 0.52** | 0.66*** | 0.64*** | 1.48*** | 0.68 | 1.36*** | 0.42 |
| | (0.213) | (0.190) | (0.223) | (0.165) | (0.436) | (0.452) | (0.622) |
| Observations | 688 | 688 | 688 | 688 | 688 | 688 | 688 |

Notes: Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

**Table A3**
Second stage regression results of the determinants of WDDS - Multiple treatment endogenous switching regression.

| Variables | Disempowered women in non-PPT-adopting households | Empowered women in non-PPT-adopting households | Empowered women in PPT-adopting households | Disempowered women in PPT-adopting households |
|---|---|---|---|---|
| Ln(off-farm income) | 0.07*** | 0.05 | −0.00 | 0.05** |
| | (0.020) | (0.037) | (0.020) | (0.020) |
| Family size | −0.01 | 0.00 | 0.00 | −0.00 |
| | (0.006) | (0.010) | (0.007) | (0.006) |
| Occupation | 0.05 | −0.05 | −0.09 | 0.04 |
| | (0.090) | (0.132) | (0.092) | (0.078) |
| Credit constrained | −0.00 | −0.02 | −0.05 | −0.05** |
| | (0.034) | (0.049) | (0.036) | (0.023) |
| Ln(Food crop groups grown) | 0.00 | 0.18 | −0.15 | 0.14 |
| | (0.211) | (0.286) | (0.205) | (0.196) |
| Ln(Land owned) | 0.01 | 0.09 | −0.07 | −0.06 |
| | (0.173) | (0.279) | (0.140) | (0.125) |
| Dairy cow ownership | −0.03 | 0.01 | −0.02 | 0.05 |
| | (0.056) | (0.065) | (0.058) | (0.046) |
| Ln (Number of livestock) | 0.04** | 0.03 | 0.01 | 0.01 |
| | (0.018) | (0.030) | (0.019) | (0.016) |
| Ln(Distance to market) | −0.04** | 0.02 | −0.00 | −0.03 |
| | (0.021) | (0.028) | (0.023) | (0.020) |
| Confident in extension staff | −0.07 | 0.03 | −0.14 | −0.03 |
| | (0.148) | (0.200) | (0.120) | (0.113) |
| Ln(Distance to extension office) | −0.02 | 0.01 | −0.03 | −0.01 |
| | (0.019) | (0.031) | (0.018) | (0.014) |
| Rely on government support | 0.01 | 0.00 | 0.04 | 0.01 |
| | (0.028) | (0.045) | (0.035) | (0.022) |
| Number of relatives | 0.00 | −0.00 | 0.00 | 0.00 |
| | (0.001) | (0.005) | (0.002) | (0.001) |
| Ln (fertilizer use) | 0.01 | 0.01 | −0.02 | 0.01 |
| | (0.015) | (0.023) | (0.014) | (0.014) |
| County fixed effects | 0.02 | −0.02 | −0.08 | 0.03 |
| Mills ratio | Yes | Yes | Yes | Yes |
| Constant | 1.94*** | 1.42* | 2.58*** | 1.88*** |
| | (0.642) | (0.832) | (0.488) | (0.514) |
| Observations | 223 | 115 | 126 | 224 |

Notes: Bootstrapped standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

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