Food security mediates the decrease in depressive symptoms among smallholder women farmers in a participatory nutrition-sensitive agroecology intervention in rural Tanzania

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Abstract

Objective: To investigate if food security mediated the impact of a nutrition-sensitive agroecology intervention on women's depressive symptoms.

Design: We used annual longitudinal data (4 time points) from a cluster-randomized effectiveness trial of a nutrition-sensitive agroecology intervention, the Singida Nutrition and Agroecology Project. Structural equation modeling estimation of total, natural direct, and natural indirect effects was used to investigate food security's role in the intervention's impact on women's probable depression (CES-D $\geq$ 17) over three years.

Setting: Rural Singida, Tanzania.

Participants: 548 food insecure, married, smallholder women farmers with children < 1-year-old at baseline.

Results: At baseline, one third of the women in each group had probable depression (Control: 32.0%, Intervention: 31.9%, p-difference=0.97). The intervention lowered odds of probable depression by 43% (OR=0.57, 95% CI: 0.43-0.70). The effect of the intervention on probable depression that was due to differences in food security was approximately 10% (OR = 0.90, 95% CI: 0.83-0.95).

Conclusions: Nutrition-sensitive agricultural interventions can have broader impacts than previously demonstrated, i.e., on mental health, and food security plays an important causal role in this pathway. These data suggest nutrition-sensitive agriculture interventions have the potential to reduce the loss of quality life years for women in farming communities. Future agricultural and nutrition projects should include mental health evaluations to determine generalizability.

Introduction

Depression is a leading cause of disability(1), especially amongst women in low- and middle-income countries(2,3). In 2017, depressive disorders ranked as the third leading cause of disability and led to over 40 million years lived with disability (Y.L.D.s) lost in low- and middle-income countries(4). Additionally, economic consequences of depression due to early onset and productivity loss are astronomical: the global economy is estimated to loss over US$16 trillion between 2010-2030 from mental disorders(5,6). Depression is associated with poor quality of life, negative physical health outcomes such as cognitive impairment, cardio- and cerebrovascular diseases, and higher levels of mortality(5,7,8), and is a point of concern for individuals with substance abuse disorders and dementia(5). Moreover, parental depression could also impede their capacity to provide quality childcare(9), therefore casting negative downstream effects to children(10,11). Unfortunately, the burden of depressive disorders, measured by disability-adjusted life years (D.A.L.Ys), continues to rise globally(5,12). As such, the 2030 Sustainable Development Goals emphasized the importance of understanding the causes of depression for better prevention and promotion of mental health(5).

Previous work has demonstrated food insecurity to be a significant driver of depression, especially in low-resource settings. Food insecurity, defined as inadequate access to both quality and quantity of food for an active and healthy life(13), is an important and often overlooked social determinant of health in low-income countries(13). The link between food security and mental health has been found to be bidirectional(14) and may operate through biological(15) and psychosocial pathways(16,17). Suggested biological pathways include inadequate access to nutritious foods that lead to nutritional deficiencies associated with poor mental health status(15,18) and physical morbidities associated with food insecurity, such as

stomachaches and headaches that can in turn impact mental health status(18,19). Potential psychosocial pathways include inadequate access to sufficient preferred food creating stress(16,17,20–23) and experiences of stigma from not being able to fulfill social expectations of providing food for the household (24).

Empirical findings support the proposed mechanisms linking food insecurity and women's mental health. The link between food security and mental health has been found to be bidirectional(14) and operates through biological(15) and psychosocial pathways(16,17). Specifically, biological pathways include inadequate access to nutritious foods that lead to nutritional deficiencies associated with poor mental health status(15,18) and physical morbidities associated with food insecurity that can impact mental health status(18,19) while psychosocial pathways include inadequate access to sufficient preferred food creating stress(16,17,20–23) and experiences of stigma from not being able to fulfill social expectations of providing food for the household (24). Empirical findings support these proposed mechanisms demonstrating the influence of food insecurity on women's depression. From Weaver and Hadley's systemic review(16), significant associations include: cumulative life exposure to hunger and higher frequency of women's depression(25); number of meals missed by respondents or their children due to lack of resources and higher frequency of depression in adults(26); household food insecurity with mothers' reports of increased anxiety and depressive symptoms(17); and women who had trouble meeting daily needs and/or who had gone hungry in the past month and higher rates of postnatal depression(27). Furthermore, inadequate nutrition has also been associated with depression among women of childbearing age(28) and is a risk factor for perinatal depression(29,30). For example, previous work in Uganda and South Africa has found that food insecurity was associated with depression among seropositive women(21,31,32). Additionally, Jones' analysis of 2014 Gallup World Poll data

found that food security was associated with depression throughout low-income countries across 149 countries(33). From Tribble and colleagues' meta-analysis, food insecure individuals were at two-times greater risk of depressive symptoms than food secure individuals (OR=2.35)(34). In a high-income country, the United States, Huddleston-Casas and colleagues found through structural equation modeling that food insecurity caused depression within rural, low-income women over a three year observational study(14), demonstrating the directionality of food security's impact on depression.

However, most of the evidence connecting food security and depression has been observational, especially in low-income countries. Multiple studies have called for the need to further explore directionality between the two in order to establish causality(16,34). The relationship between food insecurity and mental health is especially important in these settings, considering the high rates of poverty and food insecurity there. Additionally, food security's impact on depression at a community level has yet to be studied.

Nutrition-sensitive agriculture programs have been found to improve food security. Nutrition-sensitive agriculture programs are agricultural interventions aimed to improve underlying determinants of nutrition(35,36) and therefore expected to impact food security by improving diversity of household agricultural production, increasing household resilience in times of climatic shock, and improving women's nutritional knowledge, input to, and control over household and agricultural decisions(35,37). Existing work supports these suggested mechanisms: in Zambia, a nutrition-sensitive agriculture program improved food access, a facet of food security, over four years of interventions(37). Additionally, a participatory nutrition-sensitive agriculture program in Malawi, which incorporated lessons on gender equity, nutrition, and agriculture, increased food security over two years(38).

Due to the aforementioned relationships between nutrition-sensitive agriculture programs, food security, and women's depression, nutrition-sensitive agriculture programs are posited to impact women's depression. However, to date, there is only sparse empirical evidence to support this relationship. A recent study, the Singida Nutrition and Agroecology Project (SNAP-Tz) (39), found through longitudinal analyses that smallholder women farmers participating in a participatory, nutrition-sensitive, agroecological intervention experienced an 11.4 percentage point reduction in prevalence of depressive symptoms compared to those not receiving interventions. This impact bears unpacking since it is the first ever reported nutrition-sensitive agriculture program to positively impact prevalence of depressive symptoms.

The Lancet Commission on global mental health and sustainable development has recommended the need for using unique approaches to address mental health by targeting environmental and social determinants(5), therefore highlighting the potential of this unprecedented application of nutrition-sensitive agriculture programs. Proponents of nutrition-sensitive agriculture programs also have specifically emphasized improving mental health as a way to enhance nutrition-sensitive programs(35). As such, nutrition-sensitive agriculture interventions have the ability to reduce the loss of quality life years, i.e years with substantial health-related impairment(40), for women in farming communities.

Therefore, we investigated the role of food security in the intervention's impact on decreasing the prevalence of probable risk of depression among women smallholder farmers. Notably, this is the first analysis to consider linking nutrition-sensitive agriculture programs, food security, and depressive symptoms, demonstrating the causal role of food security's impact on women's depressive symptoms within a randomized trial.

Methods

Study Design & Setting

This study took place in the Singida rural district of Tanzania's semi-arid central region. Smallholder farming is the primary source of livelihood, as households cultivate an average 2.15 ha of fields(41). In Tanzania, depressive disorders have increased 35% between 2007 and 2017 and are ranked as the third leading cause of disability(42). Food security is also a persistent issue for the majority of smallholder households in rural Tanzania(43,44). In 2012, 49% of households in the Singida region had poor household dietary diversity, another indicator of food insecurity(41).

Intervention

The Singida Nutrition and Agroecology Project (SNAP-Tz; NCT02761876)(39) was a cluster-randomized effectiveness trial which investigated the effects of a participatory, nutrition-sensitive, agroecological intervention on improving child's diet through improvements in sustainable agriculture, gender equity, and food security(39,45). The project used the Farming for Change curriculum(45), an integrated smallholder farmer education program linking agroecology with climate change, nutrition, gender, and social equity teachings. These lessons were disseminated using participatory learning mechanisms, such as experiential-based learning and theatre. One male and one female 'mentor farmer' from each village led peers on learning exchanges regarding the curriculum topics during monthly community meetings and

household visits. Additionally, each participating household received a mix of legume seeds at the beginning of farming season during the first two years of the project.

The project enrolled 598 households: 25-30 households from each of twenty villages, with ten villages randomized to receive interventions. Village selection criteria included leadership's willingness to participate in the study, having enough children <1-year-old, not participating in other interventions, and having socio-demographic and infrastructural characteristics similar to another village, for randomization of pairs. Household eligibility criteria included: [1] being food insecure, [2] having a child <1 years old at baseline, [3] having access to land and planning to farm in the coming year, [4] intending to reside in that village for the next 3 years, and [5] being interested in experimenting with new farming techniques. From amongst these households, the two mentor farmers were elected by participating households. For this analysis, we only included married women (n=548) from the study because the relationship of food insecurity and depression would likely greatly differ from single and widowed populations(46,47).

Data Collection

Four annual household surveys were conducted between 2016 – 2019 through enumerator-facilitated questionnaires at the participant's residence or public village meeting place. The data collection team consisted of twenty local enumerators, and each survey took about one hour to administer. Survey pre-testing was performed to ensure participant comprehension and accurate outcome measurement within the questionnaire.

Key Outcomes:

The primary outcome, depressive symptoms, was evaluated through local enumerator-administered surveys using the Center for Epidemiologic Studies Depression Scale (CES-D, range: 0-60)(48). The CES-D scale is comprised of 20 items that query the frequency with which participants have experienced depressive symptoms, such as sadness and trouble sleeping in the past week. The CES-D can be used to quantify depressive symptoms and to predict probable depression but is not a clinical diagnostic tool. Probable depression was defined as a score of 17 or greater, the appropriate cutoff value which has been evaluated for use among similar populations in East Africa(49).

The CES-D scale was also locally qualitatively validated through cognitive interviews with eight project enumerators who had participated as enumerators in at least three of the annual surveys. For each of the 20 CES-D questions, the following were asked whether: 1) enumerators understood the question, 2) mothers could understand the question when asked, and 3) mothers could be honest in answering the question. Themes for each of the 20 items were assessed in Excel. Each item where 5/8 of the enumerators indicated any of the three aforementioned problems was then excluded from an adapted scale. Three items were removed due to the enumerator misunderstanding of the item: “bothered by normal things”, “everything was an effort”, and “people were unfriendly”; while two items were removed due to participant misunderstanding of the item: “loss of appetite” and “talked less than usual” (Table 0). No items were removed for participant dishonesty, since the majority of enumerators relayed that *women* were honest in answering these questions about their emotions and behaviors (Table 0). The adapted 15-tem scale predicted similarly to the original 20-item CES-D

score and concluded that CES-D was an adequate measure of risk of depression in Singida in this situation for women (Figure 1).

Food security was measured using the Household Food Insecurity Access Scale (HFIAS, range: 0-27, with higher values indicating greater insecurity(50)). Women and men were jointly asked to report their household access to food in the prior month. HFIAS has previously been used to assess food security impact in rural settings in Sub-Saharan Africa(51,52).

Sociodemographic Characteristics:

Sociodemographic information was collected across all timepoints (2016-2019). Covariates assessed for confounding include: marital status (monogamous or polygamous), farming as main occupation, ethnic group (Nyaturu or other ethnic group), religion (Muslim or other religion), years of education, years lived in village before 2016, and dependency ratio, calculated as number of children ($\leq$14) and elders (>65)/number of household members between the ages of 15 and 64(53). Household wealth (low, medium, high) was derived from a principal component analysis of self-reported household asset ownership of twenty-twenty items in January 2016 and made into tertiles.

Gender Equity Indicators:

Gender equity has previously been found to be associated with food security and depressive symptoms(27,54–62), so multiple indicators of gender equity were assessed as potential confounders of the relationship between food security and depressive symptoms. Domestic violence experience was measured by asking if participants had experiences with any emotional, financial, sexual, or physical violence with any family members living inside or

outside of the household (dichotomous). Attitude towards domestic violence was then measured by asking participants if physical violence was justified in seven scenarios (range: 0-7)(63). Additionally, women were asked if and to what extent they had decision-making power within agricultural and income allocation activities (mean score: no/little=0, some=0.5, final say=1) using the Women's Empowerment in Agriculture Index (WEAI) questions(64). Since we expected the risk of probable depression to change between groups of women with lower income allocation decision-making power and levels of joint- and higher income-allocation decision-making power(65,66), linear splines were used to split income allocation decision-making scores between groups of (0-0.4) and (0.41-1) to analyze its true relationship with probable depression. (Figure 2). Two indicators of women's burden of household work were included: men's involvement with household work, measured by averaging the number activities women reported husband help with over seven household tasks commonly perceived as "women's work", such as fetching water, within the past month (range: 0–1) (67) and leisure time during the previous 24 hours(64). Finally, social support was indicated using an adapted version of Duke's Perceived Social Support Scale(68) (range: 0-40), where women were asked to what extent they liked the amount of help they received during various life instances, such as when they are sick or during household work. Low social support was classified as a score<30, adequate social support $\geq$30, based on Antelman and colleagues' previous use of the scale in urban Tanzania(68).

Data analysis

Evaluating Predictors

We first described baseline characteristics between study arms using t-tests and Pearson chi-squared tests as appropriate. Standard errors were adjusted for village-level clustering in all

cases. We found that randomization balanced all predictors except: women in the intervention group were more likely to be Muslim (C: 69.1%, I: 77.7%, p difference=0.02) and had lower income allocation decision-making power (C: 0.38, I: 0.33, p difference=0.04) (Table 1).

To assess covariate associations with baseline probable depression (CES-D $\geq$ 17), we first calculated risk ratios for all covariates, including demographics, gender equity, social support, and physical health variables, using log-binomial regression models (Table 2). We then used a Poisson approximation to a log-binomial multivariable regression model due to convergence issues, including all significant variables from the bivariate risk ratio estimates (Table 2). Finally, backwards stepwise model selection(69) was used until all variables remaining in the model were significant ($p < 0.05$). We chose to keep maternal social support in the final model due to epidemiologic reasoning, later described in the discussion(24,70). Adjusted risk ratios were calculated from this parsimonious model (Table 2). Standard errors for all models accounted for clustering at the village level. All above analyses were performed using Stata 16(71).

Mediation analysis

To understand food security's role in the intervention's impact on women's depressive symptoms between 2016 and 2019, we carried out mediation analyses using structural equation modeling estimation of total, natural direct, and natural indirect effects(72). We followed the mediation method outlined by Peterson and colleagues(73) and used Valeri & Vanderweele's SAS mediation macro (74). Specifically, the natural direct effect is an estimate of the effect of the intervention on probable depression as if the intervention had no impact on food security. The calculation of the natural direct effect contrasts the intervention group with the control group, assuming that food security values are those that participants would have

had in absence of the intervention regardless of their intervention assignment. The natural indirect effect represents the effect of the intervention that is due to the effect of the intervention on food security(75) (i.e, the proportion of the intervention effect that is mediated by food security), contrasting the food security values that participants would have had under the intervention versus control, if all participants had undergone the intervention.

Probable depression was modeled as a binary outcome (CES-D $\geq$ 17) and food insecurity as a continuous mediator (assuming a normal kernel). Income allocation decision-making power, men's involvement with household work, domestic violence experience, social support, and probable depression were *a priori* identified as time-varying confounders of the mediator-outcome relationship (Figure 3), and subsequently controlled for in mediation analyses. Mediation analyses were performed via the 'mediation' macro in SAS 9.4(76,77).

Missing data

Baseline missingness ranged from 0-6% for all variables (Table 3), while the number of missing values on probable depression, food security, and covariates ranged from 0-13% during follow-up (from 2017-2019) (Table 4). Study attrition differed by participant age, ethnic group, and length of time living in the village before study baseline, so were included in imputation models, along with all confounders, mediators, and outcomes discussed above (Table 5). Imputation with chained equations(78) with 20 iterations was used to impute missing probable depression, food security, and covariate data at each time point. For imputed values below zero or outside of score ranges, post-estimate rounding was used to adjust values into range. Imputation was performed using Stata 16(71).

Results

Population characteristics at baseline

At baseline, one third of the married women in each group had probable depression (Control: 32.0%, intervention: 31.9%, p difference=0.97, Table 1). The majority were married monogamously, of the Nyaturu ethnic group, and reported farming as their main occupation. On average, they were about 30 years old (C: 29.7±7.2, I: 29.8±7.8, p difference=0.87) and lived in households with a food insecurity score of ~14 (C: 13.6, I: 13.9, p difference=0.63). In both groups, more than 60% of participants reported moderate to severe food insecurity (Table 1).

Baseline Covariate Associations with Probable Depression

At baseline, probable risk of depression was associated with food insecurity, domestic violence experience, men's involvement with household work, and income-allocation decision-making power (Table 2). Women who had higher food insecurity (aRR= 1.06, 95% CI: 1.03, 1.08) were at a higher risk of baseline probable risk of depression. Measures of gender equity were also correlated with increased risk of probable risk of depression: married women who experienced domestic violence (aRR= 1.47, 95% CI: 1.15, 1.89) and reported a lack of men's involvement with household work (aRR= 0.60, 95% CI: 0.40, 0.90) were at higher risk of baseline probable risk of depression (Table 2). Income allocation decision-making power scores >0.4 were associated with an increased risk of probable risk of depression (RR= 6.42, 95% CI: 3.31, 12.45; aRR=2.90, 95% CI: 1.79, 4.69) while lower scores did not have any significant association with probable risk of depression (RR=0.60, 95% CI: 0.14, 2.53) (Table 2). Notably, there were no

significant associations between probable risk of depression and social support, dependency ratio, wealth tertiles, occupation, age, marital status, leisure time, and education. Sensitivity analyses modeling depression as a continuous variable demonstrated similar results (Table 6).

Mediation analysis

The intervention lowered the odds of probable depression by 43% (total effect OR=0.57, 95% CI: 0.43-0.70) (Figure3A). The effect of the intervention on probable depression that was due to differences in food security was approximately 10% (natural indirect effect OR = 0.90, 95% CI: 0.83-0.95) (Figure 3B). The total effect of the intervention on probable depression was partially attenuated after accounting for differences in food security (natural direct effect OR=0.63, 95% CI: 0.47-0.80) (Figure 3B). When depression was modeled as a continuous variable, or when income-allocation decision-making power was removed as a confounder, similar results were found (Table 7).

Discussion

Food security plays a mediating role in the impact of a nutrition-sensitive agroecology intervention on decreasing the prevalence of depressive symptoms amongst women in rural Tanzania. The intervention lowered the odds of probable depression by 43% (OR=0.57, 95% CI: 0.43-0.70), and the effect of the intervention on probable depression mediated by food security was approximately 10% (OR = 0.90, 95% CI: 0.83-0.95) (Figure 3). To our knowledge, this is the first demonstrated evidence of the strong, positive, and unexpected impact of a nutrition-sensitive agriculture program on women's depressive symptoms.

This finding highlights an opportunity for interdisciplinary work between mental health, nutrition, and agriculture fields to improve quality of life for women in low-resource areas. Specifically, nutrition-sensitive agriculture programs should consider targeting and measuring

mental health outcomes(35) to capture a previously under-appreciated role of women's mental health in such interventions. Inversely, those concerned with public mental health should consider livelihood interventions in addition to promoting traditional cognitive therapies(79) as discussed by the Lancet commission on global mental health(5). Although there are known and effective treatments for mental disorders, fewer than 25% of people affected by depression in low- and middle-income countries receive such treatments(40). Livelihood interventions have the potential to be a more accessible method of reducing depressive symptoms in low-resource settings.

Food insecurity, domestic violence experience, lack of men's involvement with household work, and high-income allocation decision-making power scores were identified as salient baseline predictors of women with probable depression (Table 2). These findings largely correspond with existing literature: a multitude of studies have observed significant relationships between food security and depressive symptoms(16,32,79,80), domestic violence experience and depressive symptoms(27,54–57), and social support and mental health(59–62) amongst women.

Curiously, we found that women with higher income allocation decision-making power scores were at higher risk for probable depression at baseline (Table 2). Subgroup analyses, however, revealed that this is true only for the 39% of women with decision-making scores above 0.4. Amongst women with lower scores (0-0.4), income allocation decision-making was not associated with probable depression. Since all participants within this analysis were married and scores of 0.5 indicated joint decision-making between a husband and wife(64), it is unclear what "having a majority" of income allocation decision-making power means for women whose partners simultaneously report their wives have no say in decision making(65). In a household that reported joint-decision making in the survey, the husband said in an interview that his

wife and him never have disagreements over decision-making because women don't have their own ideas(67).

Additional qualitative findings may explain the association between decision-making scores above 0.4 and higher risk for probable depression at baseline. In a discussion with participants about preliminary findings about depressive symptoms, women discussed the mental burden of the responsibility for child welfare without having the ability to act as highly depressing(67). Specifically, one woman said "husbands put all responsibilities on wives…you may have activities to do and children wants some food which you can't afford, you just wish you could provide…you are depressed because you have a lot to do all alone"(67). This dynamic was also reported amongst Irish women: having more say in decision-making without adequate resources was associated with dissatisfaction and social stress(66). This relationship between income allocation decision-making power and women's mental health bears further investigation.

While this study took an important first step in identifying food security as a mediator between nutrition-sensitive agriculture programs and depressive symptoms, further studies are needed to elucidate the role of other promising pathways between the two. This is evidenced by our findings: a proportion of the intervention's impact on depressive symptoms after eliminating the effect of food security (natural direct effect OR=0.63, 95% CI: 0.47-0.80) (Figure 3B), and therefore there is room for other modifiers of the pathway. First, gender equity and social support indicators have been previously linked to food security and women's depression and warrant further exploration in relation to nutrition-sensitive agriculture programs. In Uganda, Tsai et. al. found that food security and depressive symptom severity were linked, and that social support was an important buffer in this relationship(21). Hadley and colleagues have also observed a significant relationship between social support, maternal depression, and food

security in rural Tanzania(70). Uniquely, in this study, no significant relationship between social support and probable depression at baseline was found (Table 5). Piperata et. al. may explain our findings since they found in Nicaragua that spousal support and maternal social support networks were not important modifiers of the link between food insecurity and mental distress due to the fear of gossip and embarrassment surrounding food insecurity buffering the capacity of social support(24). We offer a different explanation though, since these women at baseline reported unusually high levels of social support (C: 82.5%, I: 76.9%, p difference=0.10, Table 1), and instead believe that a ceiling effect may have masked any associations between changes in social support and depressive symptoms over time. Since previous literature demonstrated relationships between social support, food insecurity, and depressive symptoms(21,31,70,81), social support was included as a confounder in the mediation analyses.

Additionally, gender equity indicators, such as domestic violence experience and decision-making power, have similarly been found to be associated with food security and depression. Hernandez and colleagues found that maternal depression mediated the relationship between intimate partner violence and food security(82). Furthermore, a study in South Africa found that woman-headed households, even with fewer resources, achieved better food security than households headed by men(83).

Understanding the impact of such interventions on men's mental health also warrants further investigation, given recent literature on gender transformative approaches which actively enlist men in addressing gender inequity(67,84–86). Insight into interactive and cumulative effects between men and women's mental health, food security improvements and gender relations may provide further recommendations for effective intervention strategies.

Furthermore, the participatory agroecology approach of this project may hold an important role in explaining the impact on depressive symptoms. Collective action between researchers and farmers, explicit efforts to draw on local knowledge and use culturally appropriate approaches to address them, as well as improved self-efficacy from a participatory project, are expected to improve social support and gender relations and therefore could impact women's and men's mental health. Enhanced social relations within the community, knowledge, and resource sharing can lead to overcoming structural constraints to improve nutrition-sensitive agriculture program outcomes(38), which are consequently tied to women's mental health. Other nutrition-sensitive agriculture programs may not see as large of an impact without this specific project approach.

Strengths, Limitations

Strengths of this study include randomization, large sample size, longitudinal analysis, and robust statistical techniques. Limitations include measurement error of sensitive topics which could have resulted in systematic underreporting of food insecurity, probable depression, domestic violence experience, and decision-making. Because these measurements were recorded for each participant at multiple time points, we believe that relative changes analyzed in the longitudinal mediation analyses will address that bias. Furthermore, it is important to note that a limitation of using depression screening tools in general is that information gets lost in dichotomized scoring groups (i.e what is the difference between a score of 17 vs 60)(88), and there is a need for evidencing the accuracy of discernment between groups (89). Because the analyses were modeled both dichotomously and continuously, we believe the study's interpretations remain valid (Table 7). Another possible limitation is the project's external

validity since these analyses only included food insecure, married women with a child <1-year-old at enrollment. Further studies on this relationship should be conducted in other populations.

Conclusions

These data highlight the important role of food security in the impact of a nutrition-sensitive agroecology project on women's depressive symptoms. Ultimately, these results demonstrate that mental health improvements could be a very important outcome of nutrition-sensitive agriculture programs. Indeed, it seems possible that nutrition-sensitive agriculture interventions have the ability to reduce the loss of quality life years for women in farming communities. Those concerned with public mental health should consider livelihood interventions, while future agriculture and nutrition projects should include mental health evaluations to assess if this impact can be generalized.

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660 Appendix

661 Table 0. *For each of the 20 CES-D items, three questions were asked (columns below) in cognitive*
662 *interviews. Five items were dropped from the CES-D scale since 5/8 of the enumerators indicated*
663 *any of the three problems (columns) and were therefore excluded from our adapted CES-D scale.*

664

CES-D Question	Enumerator Misunderstood	Participant Misunderstood	Participants Not Honest Answering
Bothered by normal things			
Loss of appetite			
Trouble keeping my mind on task			
Everything was an effort			
Restless sleep			
Talked less than usual			
Didn't have the energy			
Low spirits			
Sad and unhappy			
Thought life was failure			
Fearful			
Lonely			
Crying spells			
Sad			
Feel valuable†			
Hopeful about future			
Happy			
Enjoyed life			
People were unfriendly			
Felt people disliked me			

†Out of 7 enumerator responses. Lightest blue refers to 0-2 enumerator responses, middle blue 3-4, darkest blue 5-8.

Figure 1. *Adapted CES-D change predicts 96% of original CES-D scores (p <0.001), indicating that the two scales are comparable. Therefore, original CES-D scale will be used for SNAP-Tz impact analyses. Standardized scores were created by dividing scores by standard deviation.*

Table 1. *Comparison of baseline characteristics between intervention and delayed intervention groups shows that randomization held for most variables besides Muslim status and income allocation decision-making power: SNAP-Tz, 01/2016, n=548*

	Control N=275	Intervention N=273	p-value
Key Outcomes			
Probable Depression (CES-D[a] ≥17)	32.0% (88)	31.9% (87)	0.97
Household Food Insecurity Access Scale (0-27)	13.6 (7.8)	13.9 (8.1)	0.63
Household Food Insecurity			0.63
Low (HFIAS 0-9)	34.2% (80)	28.9% (74)	
Moderate (HFIAS 10-18)	33.8% (118)	41.0% (112)	
Severe (HFIAS 19-27)	28.0% (77)	30.0% (82)	
Sociodemographics			
Pregnant	0% (0)	0% (0)	--
Farming as main occupation (ref: any other)	98.5% (270)	97.8% (267)	0.52
Monogamous marital status (ref: polygamous)	91.3% (251)	91.9% (251)	0.78
Nyaturu ethnic group (ref: other)	96.7% (266)	95.6% (261)	0.49
Muslim (ref: Christian, Traditional African, none)	69.1% (190)	77.7% (212)	0.02*
Wealth Tertiles			0.45
Poorest	34.2% (94)	29.3% (80)	
Middle	33.8% (93)	35.2% (96)	
Wealthiest	32.0% (88)	35.5% (97)	
Dependency Ratio[b]	1.50 (0.75-2.00)	1.25 (0.75-2.00)	0.35
Age (years)	29.8 (7.2)	29.9 (7.8)	0.80
Years of education	7.9 (9.5)	6.8 (3.1)	0.09
Years lived in village	7.8 (7.5)	8.1 (8.3)	0.67
Gender equity			
Adequate social support (≥3 out of 4)	82.5% (227)	76.9% (210)	0.10
Experience any domestic violence (0,1)	25.1% (69)	28.6% (78)	0.42
Attitude towards domestic violence (0-7)	5.0 (2.0-7.0)	5 (2.0-7.0)	0.92
Men's involvement with household work (0-1)	0.4 (0.3)	0.4 (0.3)	0.50
Leisure time (hours)	2.0 (1.9)	1.8 (1.8)	0.25
Agricultural decision-making power (0-1)	0.33 (0.19-0.50)	0.31 (0.19-0.50)	0.89
Income allocation decision-making power (0-1)	0.38 (0.25-0.46)	0.33 (0.19-0.47)	0.04*
Low income allocation decision-making power (<0.4)[c]	58.6% (161)	64.5% (176)	0.15

Note: % (n) for categorical variables, mean + SD for normally distributed continuous variables, median (IQR) for non-normally distributed continuous variables. [a]CES-D: Center for Epidemiologic Studies Depression Scale; [b]dependency ratio calculated as number of children (≤14) and elders (>65)/number of household members between the ages of 15 and 64; [c]secondary analysis of income allocation decision-making power.

* p<0.05

Table 2. Food security, domestic violence experience, men's involvement with household work, and high income allocation decision-making power are significantly associated with probable risk of depression among smallholder farmers in Tanzania at baseline in log-binomial multivariable regressions: [SNAP-Tz, 01/16, n=548]

Variable	R.R.	95% CI	aRR	95% CI
Intervention	1.00	(0.75, 1.32)	--	--
Key outcome				
Household Food Insecurity Access Scale (0-27)	1.07**	(1.05, 1.10)	1.06**	(1.03, 1.08)
Demographics				
Farming as main occupation (ref: any other)	1.07	(0.36, 3.16)	--	--
Monogamous marital status (ref: polygamous)	1.57**	(1.16, 2.12)	--	--
Nyaturu ethnic group (ref: Nyiramba or other)	0.96	(0.49, 1.86)	--	--
Muslim (ref: Christian, Traditional African, none)	0.96	(0.69, 1.33)	--	--
Wealth Tertiles				
Poorest	Ref	--	--	--
Middle	0.83	(0.66, 1.04)	--	--
Wealthiest	0.91	(0.70, 1.19)	--	--
Dependency Ratio [a]	1.08	(0.92, 1.28)	--	--
Age (years)	1.02**	(1.01, 1.04)	--	--
Years of education	0.99	(0.96, 1.03)	--	--
Years lived in village	1.02**	(1.01, 1.03)	--	--
Gender equity				
Adequate social support (≥3 out of 4)	0.78	(0.56, 1.10)	0.76	(0.56, 1.04)
Experience any domestic violence	1.91**	(1.47, 2.47)	1.47**	(1.15, 1.89)
Attitude towards domestic violence (0-7)	1.08**	(1.02, 1.13)	--	--
Men's involvement with household work (0-1)	0.37**	(0.23, 0.60)	0.60*	(0.40, 0.90)
Leisure time (hours)	1.00	(0.92, 1.08)	--	--
Agricultural decision-making power (0-1)	1.84	(0.89, 3.79)	--	--
Income allocation decision-making power (0-1)	2.76**	(1.48, 5.15)	--	--
Low income allocation decision-making power (0-0.4)[b]	0.60	(0.14, 2.53)	--	--
High income allocation decision-making power (0.4-1)[b]	6.42**	(3.31, 12.45)	2.90**	(1.79, 4.69)

* p<0.05, **p<0.01; [a] Dependency ratio calculated as number of children (<14 y.o.) and elders (>65 y.o.) divided by number of adult household members (15-64 y.o.); [b] secondary analysis of income allocation decision-making power

694 Table 3. *Proportion of missing baseline information is low (0-5%): SNAP-Tz, 01/2016, n=548*

	Total	Missing	% Missing
Probable Depression	548	0	0
Household Food Insecurity Access Scale (0-27)	548	0	0
Demographics			
Pregnant	548	15	2.74
Farming as main occupation	548	1	0.18
Monogamous marital status	548	0	0
Nyaturu ethnic group	548	0	0
Muslim	548	0	0
Wealth Tertiles	548	0	0
Poorest		0	0
Middle		0	0
Wealthiest		0	0
Dependency Ratio[a]	548	0	0
Age (years)	548	1	0.18
Years of education	548	1	0.18
Years lived in village	548	10	1.82
Gender equity			
Adequate social support (≥3 out of 4)	548	4	0.73
Experience any domestic violence	548	0	0
Attitude towards domestic violence (0-7)	548	0	0
Men's involvement with household work (0-1)	548	0	0
Leisure time (hours)	548	7	1.28
Agricultural decision-making power (0-1)	548	0	0
Income allocation decision-making power (0-1)	548	30	5.47
Income allocation decision-making power (0-0.4][b]	548	0	0

695 [a]Dependency ratio calculated as number of children (≤14) and elders (>65)/number of household members between
696 the ages of 15 and 64; [b]secondary analysis of income allocation decision-making power.

Table 4. *Missingness of variables included in mediation analyses across 2016-2019 ranges from 0-20%, with more missing data in later years: SNAP-Tz, n=548*

	Total	Missing	% Missing
Probable Depression (CESD≥17)			
0*	548	61	5.16
1	548	31	11.13
2	548	70	12.77
Household Food Insecurity Access Scale (0-27)			
0	548	31	5.66
1	548	62	11.31
2	548	58	20.58
Muslim**	548	0	0
Wealth Tertiles**	548		
Poorest		0	0
Middle		0	0
Wealthiest		0	0
Adequate social support (≥3 out of 4)			
0	548	4	0.73
1	548	31	5.66
2	548	64	11.68
Experience any domestic violence			
0	548	0	0
1	548	31	5.66
2	548	61	11.13
Men's involvement with household work (0-1)			
0	548	0	0
1	548	31	5.66
2	548	66	11.68
Income allocation decision-making power (0-1)			
0	548	30	5.47
1	548	32	5.84
2	548	64	11.68

*0,1,2 refer to time points used for mediation analyses. For Men's involvement with household work, Income allocation decision-making power, domestic violence experience, and adequate social support 0=2016, 1=2017, 2=2018. For HFIAS and CES-D, 0=2017, 1=2018, 2=2019.**Time-invariant covariates, so only 2016 data used.

Table 5. *Attrition from 2017-2019 by Baseline Characteristics among SNAP-Tz participants (n=548). Attrition was significantly different by ethnic group, age, and years resident in village.*

	2017			2018			2019		
	Present N=517	**Missing N=31**	**p-value**	**Present N=489**	**Missing N=59**	**p-value**	**Present N=487**	**Missing N=69**	**p-value**
Intervention	49.7%	51.6%	0.84	49.3%	54.2%	0.47	48.5%	58.6%	0.12
Key Outcomes									
Probable Depression (CES-D[a] ≥17)	31.5%	38.7%	0.40	32.3%	28.8%	0.59	32.8%	25.7%	0.23
Household Food Insecurity Access Scale (0-27)	13.9 (7.9)	11.7 (8.6)	0.14	13.9 (7.8)	12.8 (8.6)	0.36	13.9 (7.9)	12.4 (8.0)	0.13
Sociodemographics									
Farming as main occupation (ref: any other)	98.3%	96.8%	0.55	98.4%	96.6%	0.34	98.3%	97.1%	0.49
Monogamous marital status (ref: polygamous)	91.1%	100.0%	0.08	91.8%	89.8%	0.60	91.6%	91.4%	0.95
Nyaturu ethnic group (ref: other)	96.7%	87.1%	<0.01*	96.9%	89.8%	<0.01*	96.9%	91.4%	0.03*
Muslim (ref: Christian, Traditional African, none)	73.9%	64.5%	0.25	73.6%	71.2%	0.69	73.2%	74.3%	0.85
Wealth Tertiles			0.02*			0.33			0.97
Poorest	31.7%	32.3%		31.5%	33.9%		31.6%	32.9%	
Middle	33.3%	54.8%		33.7%	40.7%		34.5%	34.3%	
Wealthiest	35.0%	12.9%		34.8%	25.4%		33.9%	32.9%	
Dependency Ratio[b]	1.33 (0.80-2.00)	1.00 (0.50-1.50)	0.12	1.50 (0.80-2.00)	1.00 (0.50-2.00)	0.25	1.50 (0.80-2.00)	1.00 (0.50-2.00)	0.14
Age (years)	30.1 (7.5)	25.6 (6.4)	<0.01*	30.1 (7.5)	27.8 (7.3)	0.03*	30.3 (7.5)	26.5 (6.8)	<0.01*
Years of education	7.4 (7.3)	6.1 (3.1)	0.32	7.4 (7.5)	6.5 (3.1)	0.33	7.4 (7.5)	6.6 (3.3)	0.36
Years lived in village	8.1 (8.0)	4.7 (5.2)	0.02*	8.2 (8.0)	5.6 (6.7)	0.02*	8.3 (8.1)	5.0 (5.6)	<0.01*
Gender Equity									
Adequate social support (≥3 out of 4)	79.1%	90.3%	0.13	78.3%	91.5%	0.02*	78.7%	87.1%	0.10
Experience any domestic violence (0,1)	27.1%	22.6%	0.58	27.2%	23.7%	0.57	26.6%	28.6%	0.72
Attitude towards domestic violence (0-7)	5.00 (2.00-7.00)	2.00 (0.00-7.00)	0.12	5.00 (2.00-7.00)	5.00 (1.00-6.00)	0.21	5.00 (2.00-7.00)	4.00 (1.00-6.00)	0.28
Men's involvement with household work (0-1)	0.4 (0.3)	0.3 (0.3)	0.36	0.4 (0.3)	0.3 (0.3)	0.08	0.4 (0.3)	0.4 (0.3)	0.84
Leisure time (hours/day)	1.9 (1.9)	2.1 (1.8)	0.60	1.9 (1.9)	2.1 (1.7)	0.35	1.9 (1.8)	2.1 (1.9)	0.34
Agricultural decision-making power (0-1)	0.33 (0.19-0.50)	0.31 (0.19-0.50)	0.75	0.31 (0.19-0.50)	0.31 (0.25-0.50)	0.45	0.31 (0.17-0.50)	0.32 (0.25-0.50)	0.35
Income allocation decision-making power (0-1)	0.36 (0.21-0.47)	0.31 (0.17-0.44)	0.30	0.36 (0.21-0.47)	0.34 (0.19-0.50)	0.76	0.36 (0.21-0.47)	0.35 (0.25-0.50)	0.91

*p<0.05; [a]CES-D: Center for Epidemiologic Studies Depression Scale; [b]dependency ratio calculated as number of children (≤14) and elders (>65)/number of household members between the ages of 15 and 64.

Table 6. Food security, domestic violence experience, men's involvement with household work, and high income allocation decision-making power are significantly associated with probable depression among smallholder farmers in Tanzania at baseline in log-binomial multivariable regressions: [SNAP-Tz, 01/16, n=548]

Variable	R.R	95% CI	aRR	95% CI
Intervention	1.00	(0.75, 1.32)	--	--
Household Food Insecurity Access Scale (0-27)	1.07**	(1.05, 1.10)	1.06**	(1.03, 1.08)
Demographics				
Farming as main occupation (ref: any other)	1.07	(0.36, 3.16)	--	--
Monogamous marital status (ref: polygamous)	1.57**	(1.16, 2.12)	--	--
Nyaturu ethnic group (ref: Nyiramba or other)	0.96	(0.49, 1.86)	--	--
Muslim (ref: Christian, Traditional African, none)	0.96	(0.69, 1.33)	--	--
Wealth Tertiles				
Poorest	Ref	--	--	--
Middle	0.83	(0.66, 1.04)	--	--
Wealthiest	0.91	(0.70, 1.19)	--	--
Dependency Ratio[a]	1.08	(0.92, 1.28)	--	--
Age (years)	1.02**	(1.01, 1.04)	--	--
Years of education	0.99	(0.96, 1.03)	--	--
Years lived in village	1.02**	(1.01, 1.03)	--	--
Gender equity				
Adequate social support (≥3 out of 4)	0.78	(0.56, 1.10)	0.76	(0.56, 1.04)
Experience any domestic violence	1.91**	(1.47, 2.47)	1.47**	(1.15, 1.89)
Attitude towards domestic violence (0-7)	1.08**	(1.02, 1.13)	--	--
Men's involvement with household work (0-1)	0.37**	(0.23, 0.60)	0.60*	(0.40, 0.90)
Leisure time (hours)	1.00	(0.92, 1.08)	--	--
Agricultural decision-making power (0-1)	1.84	(0.89, 3.79)	--	--
Income allocation decision-making power (0-1)	2.76**	(1.48, 5.15)	--	--
Income allocation decision-making power (0-0.4][b]	0.60	(0.14, 2.53)	--	--
Income allocation decision-making power (0.4-1)[b]	6.42**	(3.31, 12.45)	2.90**	(1.79, 4.69)

* p<0.05, **p<0.01; [a] Dependency ratio calculated as number of children (≤14 y.o.) and elders (>65 y.o.) divided by number of adult household members (15-64 y.o.); [b] secondary analysis of income allocation decision-making power

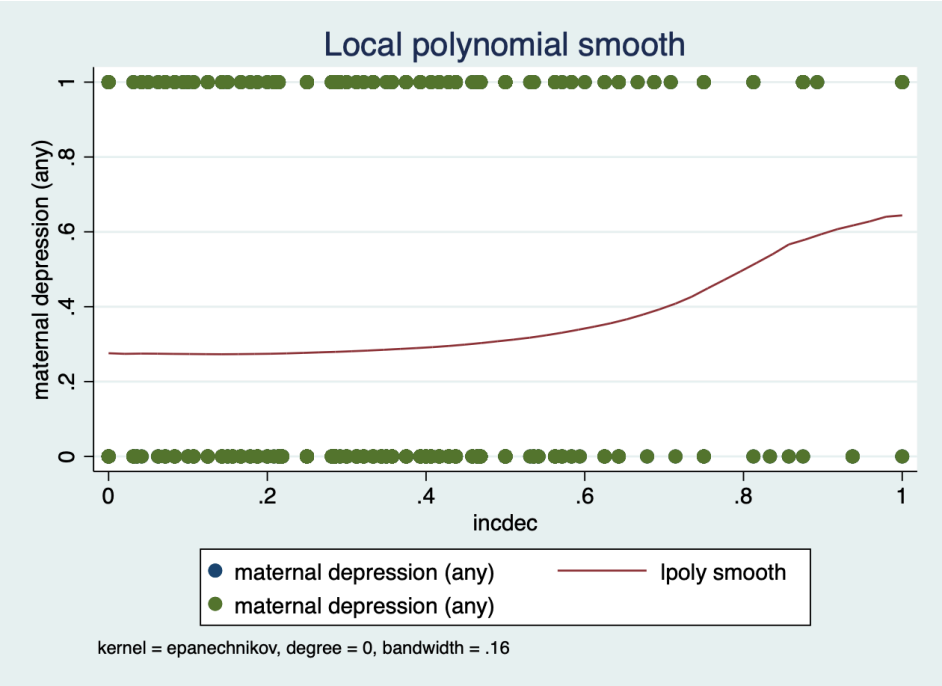
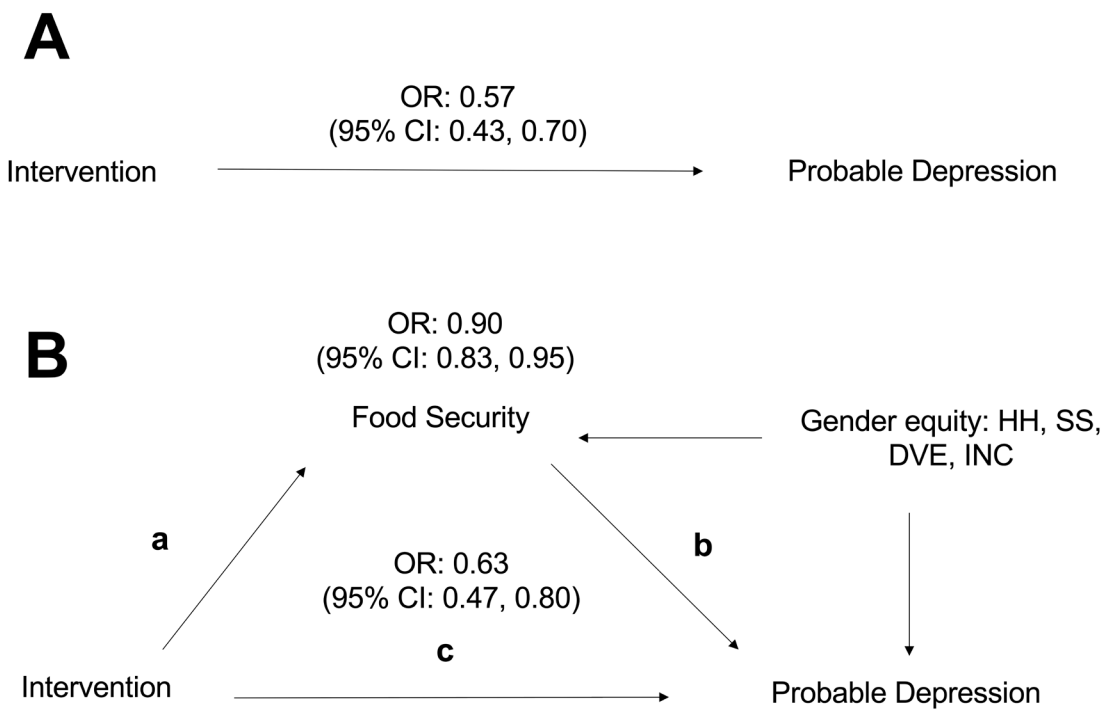


Figure 2. *Polynomial Smoothing graph shows linear association between women's probable risk of depression and low income allocation decision-making scores (0-0.4) at baseline:* SNAP-Tz, 01/2016, n=548.

Table 6. Food security, domestic violence experience, men's involvement with household work , and income allocation decision-making power are significant baseline covariate associations of depression when modeled as a continuous variable: SNAP-Tz, 01/16, n=548

Variable	*Univariable β*	95% CI	*Multivariable β*	95% CI
Intervention	0.58	(-1.48, 2.64)	--	--
Household Food Insecurity Access Scale (0-27)	0.61**	(0.46, 0.76)	0.54**	(0.40, 0.67)
Demographics				
Farming as main occupation (ref: any other)	-1.37	(-5.26, 2.53)	--	--
Monogamous marital status (ref: polygamous)	3.85*	(0.34, 7.36)	--	--
Nyaturu ethnic group (ref: Nyiramba or other)	-1.85	(-9.11, 5.42)	--	--
Muslim (ref: Christian, Traditional African, none)	-0.27	(-2.6, 2.05)	--	--
Wealth Tertiles				
Poorest	Ref	--	--	--
Middle	-1.81	(-4.07, 0.45)	--	--
Wealthiest	-1.16	(-3.94, 1.61)	--	--
Dependency Ratio[a]	0.03	(-0.03, 0.09)	--	--
Age (years)	0.17*	(0.03, 0.32)	--	--
Years of education	-0.01	(-0.15, 0.13)	--	--
Years lived in village	0.12	(-0.002, 0.24)	--	--
Gender equity				
Adequate social support (≥3 out of 4)	-1.42	(-4.03, 1.18)	-1.79	(-3.97, 0.58)
Experience any domestic violence	7.27**	(5.03, 9.50)	5.06**	(2.75, 7.36)
Attitude towards domestic violence (0-7)	0.57**	(0.18, 0.96)	--	--
Men's involvement with household work (0-1)	-7.02**	(-10.28, -3.76)	-3.42*	(-6.33, -0.51)
Leisure time (hours)	-0.12	(-0.82, 0.57)	--	--
Agricultural decision-making power (0-1)	5.49*	(0.30, 10.67)	--	--
Income allocation decision-making power (0-1)	4.91*	(0.06, 9.76)	--	--
Income allocation decision-making power (0-0.4][b]	-6.55	(-16.78, 3.67)	--	--
Income allocation decision-making power (0.4-1)[b]	17.67**	(8.71, 26.63)	7.78*	(0.25, 15.32)

* p<0.05, **p<0.01; [a] Dependency ratio calculated as number of children (≤14 y.o.) and elders (>65 y.o.) divided by number of adult household members (15-64 y.o.); [b] secondary analysis of income allocation decision-making power



<u>Figure 3:</u> Diagrams of estimates of total effect (Panel A), natural direct effect (Panel B, path c) and natural indirect effect (Panel B, path ab) estimates for mediation of food security in the intervention's impact on probable depression. OR with 95% CI shown correspond to each emboldened pathway. OR: odds ratio; CI: confidence intervals; H.H.: Men's involvement with household work; S.S.: social support; D.V.E.: Domestic Violence Experience; I.N.C.: income allocation decision-making power.

Table 7. Mediation coefficient comparisons between models. All models demonstrate similar effects of food security as a mediator of SNAP-Tz's impact on probable risk of depression: SNAP-Tz, 01/16-01/29, n=548

	Outcome = probable depression (CES-D ≥ 17)		***Outcome = CES-D***	
	1	*2*	*1*	*2*
Natural Indirect Effect Estimate[a]	0.90 (0.83, 0.95)	0.89 (0.85, 0.94)	-0.52 (-0.75, -0.27)	-0.53 (-0.72, -0.28)
Natural Direct Effect Estimate[a]	0.63 (0.47, 0.80)	0.65 (0.51, 0.81)	-1.92 (-2.52, -1.22)	-1.81 (-2.66, -1.30)
Total Effect Estimate[a]	0.57 (0.43, 0.70)	0.58 (0.46, 0.76)	-2.50 (-2.98, -1.76)	-2.39 (-3.15, -1.94)
Controlled for:				
Social Support	yes	yes	yes	yes
Men's involvement with household work	yes	yes	yes	yes
Domestic Violence Experience	yes	yes	yes	yes
Income allocation decision-making power[b]	yes	no	yes	no

[a]*β* or odds ratio estimate, with 95% confidence intervals; [b]Modeled as with spline at knot=0.4.