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Peri-urban agriculture and household food and nutrition security around Eldoret, Kenya

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Abstract

Rapid urbanisation in low- and middle-income countries, which has encroached on agricultural lands but has not been consistently accompanied by corresponding improvements in water and sanitation services, has raised questions about its impact on the food and nutrition security of households living in transitional, peri-urban areas. Through an analysis of survey data collected from 518 households living around the town of Eldoret, Kenya, we investigate the existing links between peri-urban households' engagement in agriculture, their dietary behaviour, and their children's nutrition outcomes. We find that peri-urban households engaged in agriculture, particularly in crop growing and in the sales of their agricultural produce, have more diverse and nutritious diets than agriculturally non-engaged households, all other things being equal. However, a significant improvement in children's health outcomes is observed in these households only when coupled with improved water, sanitation, and hygiene conditions.

Keywords Peri-urban agriculture · Kenya · Eldoret · Food security · Nutrition · WASH

1 Introduction

Low- and middle-income countries (LMICs) have experienced rapid urbanisation in the past several decades, with the proportion of population living in cities increasing from

35 percent in 1990 to 52 percent in 2022 (World Development Indicators, 2023). This urbanisation trend has created new income-generating opportunities but has generally lagged in provisioning of essential public services, including water, sanitation, and hygiene (WASH). It has also led to widespread losses of agricultural lands. In the peri-urban spaces surrounding African cities, many households have tried to resist the encroaching spread of urban construction and infrastructure and have continued growing crops and raising livestock, even if those activities no longer necessarily constitute their main income stream (e.g., Bundala et al., 2020; Mortoja et al., 2020; Petrikova et al., 2020). However, whether engagement in peri-urban agriculture helps households in LMICs achieve better food and nutrition security¹,

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¹ The Food and Agriculture Organisation (FAO) defines food security as a situation 'when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life' (FAO, 2002). The term 'nutrition security' has been increasingly used in recent years to emphasise the importance of good access to nutritious and healthy food – rather than any food – for people's health and wellbeing. In this article, we mostly use the terms dietary quality, dietary diversity, and good nutrition outcomes as our outcomes of interest; however, good performance in these translates more broadly also into improvements in households' food and nutrition security.

as they intend, remains a matter of investigation as does the extent to which this is influenced by households' access to WASH services.

Existing research, with a few exceptions (e.g., Frayne et al., 2014), has found urban and peri-urban households engaged in crop and livestock production to have 'better' diets than comparable households not engaged in agriculture, with the dietary quality measured through dietary diversity or, in the case of livestock ownership, often through the frequency of consumption of animal-sourced food (ASF) (Bellon et al., 2020; Chagomoka et al., 2018; Choudhury & Headey, 2018; Kim et al., 2019; Pimkina et al., 2013; Rammohan et al., 2019)². The positive relationship appears stronger in lower-income countries, including Kenya (Badami & Ramankutty, 2015; Omondi et al., 2017; Zezza & Tasciotti, 2010), and during times of high food-price inflation, when home-produced food is relatively more shielded from price increases (Armar-Klemesu, 2000; Crush & Frayne, 2011; de Zeeuw & Dubbeling, 2009). Because household members involved in (peri)urban agriculture are predominantly women, such agriculture has also been found to contribute to women's social and economic advancement (Poulsen et al., 2015).

A related debate concerns the decision of agriculturally engaged households to consume or sell their produce. One study from Uganda suggested that households' consumption of home-grown crops was linked with monotonous, low-protein diets (Kirk et al., 2018) but most studies discovered the opposite effect, particularly in households growing a variety of crops and/or raising a variety of livestock (Dillon et al., 2015; Hirvonen & Hoddinott, 2017; Murendo et al., 2019). However, even households selling rather than consuming their produce or livestock have frequently been found, *ceteris paribus*, to have better diets than agriculturally unengaged households, due to higher or more diverse, and thus more resilient, incomes (e.g., Bellon et al., 2020; Bundala et al., 2020; Covarrubias et al., 2012). The research framing that positions domestic consumption of households' agricultural products in contrast to their sales might, however, be somewhat misleading since it has been estimated that about 90 percent of smallholder African farmers both consume and sell some of their produce (Carletto et al., 2017).

Do the 'better' diets among agriculturally engaged households translate into better nutrition security, as measured by children's nutrition outcomes? Research suggests that this is not always the case (e.g., Pickering et al., 2012; Warren et al., 2015). Studies that explored the link between growing crops and nutrition outcomes have yielded mixed findings,

with some showing a positive link (Chagomoka et al., 2018; Warren et al., 2015) but others no significant link (e.g., Chegere & Stage, 2020; Warren et al., 2015). Many studies interrogating the effects of livestock ownership similarly concluded that while it increased ASF consumption, that consumption did not necessarily lead to better nourished children (Azzarri et al., 2015; Christian et al., 2019; Dumas et al., 2018; Headey et al., 2018; Kaur et al., 2017).

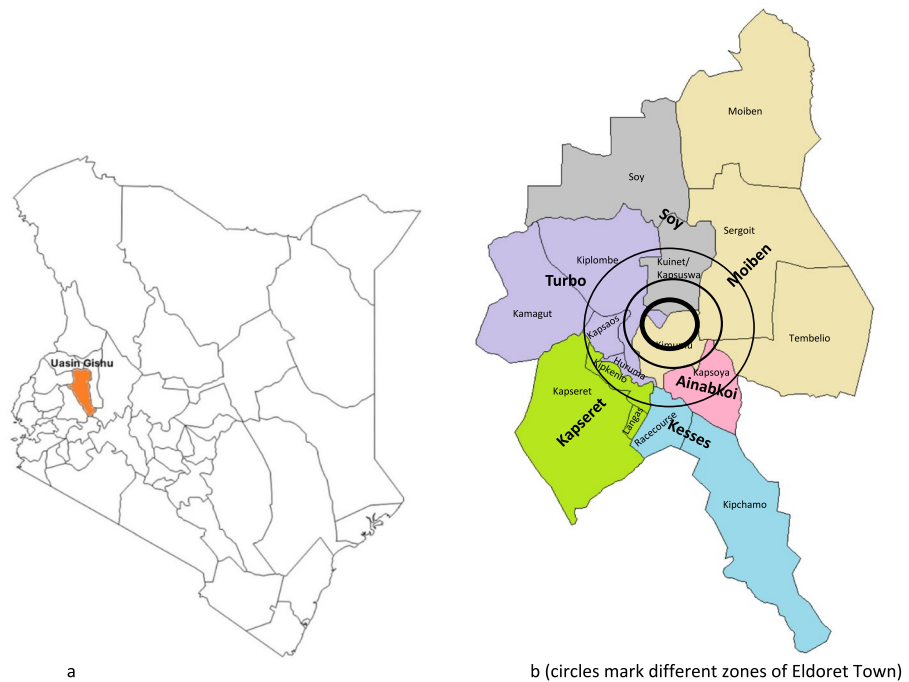
The quality of WASH has been identified as a key intervening factor in children's nutrition outcomes. Poor WASH conditions have a detrimental effect on children's growth and nutritional status due to sustained exposure to enteric pathogens (Choudhary et al., 2021; Cumming & Cairncross, 2016; Meshram et al., 2019; Pickering et al., 2012; Spears, 2013). Inadequate access to hygienic sanitation and good-quality water leads to extended and repeated instances of diarrhoea and to environmental enteric dysfunction (EED), a chronic condition that reduces intestinal nutrient absorption. Both diarrhoea and EED are conditions that are particularly harmful for children (Humphrey et al., 2015; Jacob Arriola et al., 2020).

The incidence of enteric pathogens might be higher in agriculturally engaged households; a conjecture explored particularly when it comes to livestock ownership. Livestock-keeping is associated with more animal faeces in the household environment, which, particularly in the absence of good WASH conditions, can undermine the positive effect that more diverse and protein-rich diets in livestock-keeping households could have on households' nutrition outcomes (Gelli et al., 2019; Ngure et al., 2019). Growing crops in peri-urban areas might also be linked with higher hygiene risks, due to significant contamination of peri-urban soils and water sources with heavy metals, enteric pathogens, and parasites (Graefe et al., 2019). This relationship has, however, not been explored to our knowledge in detail thus far.

Our study draws on original survey data gathered from 518 households in peri-urban areas of Eldoret, Kenya and examines the complex interplay between households' agricultural practices, access to water and sanitation, and their food and nutrition security. We hypothesise that: (H1) agriculturally engaged households in the peri-urban area have, *ceteris paribus*, better diets than other households but that (H2) the positive link between agricultural engagement – crop growing and livestock raising – and dietary behaviour as well as its positive link with better nutrition outcomes are mediated by access to adequate WASH. In a partial confirmation of H1, we find that some household engagement in agriculture is correlated with more diverse diets. However, in line with H2, this engagement tends to translate into improved nutrition outcomes most when accompanied by improved water, sanitation, and hygiene (WASH). Our study's main novel contributions lie in exploring links between the three concepts – agricultural engagement, WASH, and food and nutrition security – in peri-urban

² Studies on livestock ownership and diets focused specifically on urban and peri-urban areas less frequently than studies on crop growing and diets.

Fig. 1 Map of Kenya with Uasin Gishu county (a) and a map of surveyed sub-counties and wards in Uasin Gishu county with Eldoret at the centre (b)



rather than more commonly investigated urban or rural areas and in assessing the conditional effects of WASH on nutrition outcomes also among crop-growing and mixed-farming, rather than only livestock-raising households.

The rest of the article proceeds as follows. Section 2 describes the data and methodology used. Section 3 presents the results. The implications of the results and related policy recommendations are discussed in Sect. 4.

2 Methodology

2.1 Study area and data collection

The study was conducted around the town of Eldoret, Uasin Gishu County, Kenya. Uasin Gishu County is located in high plateau, between 1500 to 2700 m above sea level, with a relatively cool annual mean temperature of 21 °C. The area receives about 1000 to 1250 mm of rainfall per year (MoALF, 2017) and lies within the agriculturally productive highlands of Western Kenya, predominantly inhabited by farmers (Lomurut, 2014). Eldoret is a mid-size town of approximately 500,000 inhabitants. It is the fifth most populous town in Kenya, after Nairobi, Mombasa, Nakuru, and Ruiru, and is the largest town in Kenya's Rift Valley region. Like other towns in Kenya, it has grown rapidly in recent years, increasing in population size by 64 percent between 2009 and 2019 (Macrotrends, 2023).

The survey data were collected from 518 households in peri-urban areas of Eldoret between July and October 2021. Peri-urban areas were defined as spaces where some city

construction has already spread but remains interspersed with rural landscapes (Mortoja et al., 2020). Data collection was organised in all six sub-counties in the Uasin Gishu County – Ainabkoi, Kapsabet, Kesses, Moiben, Soy, and Turbo (see Fig. 1). In each sub-county, a random point in a pre-agreed peri-urban area was selected through the Map.Me® software application. From the point, enumerators walked in different directions and randomly chose the first household to survey, with the key selection criteria being that the household had at least one child between 6 months and 5 years old³. From that household, the enumerators asked for directions to the next nearest household with children of appropriate age and continued this process until reaching a desired number of households or running out of time. Pre-survey, an approximate target of 80 households to survey was set for each sub-county⁴. In the end, as Table 1 later shows, 644 child samples were collected (as some households had more than one child between 6 months

³ Enumerators in the field chose to collect data also on several children, who had already passed their 5th – but not their 6th—birthday, and we chose to keep those data as part of the sample. However, these slightly older children constitute only 2 percent of the final sample (14 out of 644 children were between 61 and 68 months old at the time of the survey).

⁴ When applying for Kenya's Government ethics approval of the survey, given the population size of Uasin Gishu County and using the sample size calculator at <http://www.qualtrics.com>, it was estimated that at least 380 household surveys were needed to ensure representation. As the budget allowed for more surveys to be collected, an approximate target of 480–500 households to be surveyed was set – and was eventually slightly exceeded.

Table 1 Summary statistics of the variables used

<i>Dietary behaviour</i>	<i>N</i>	<i>Mean</i>	<i>Std. Dev</i>	<i>Min</i>	<i>Max</i>
FCS—full	518	88.46	20.74	14	112
FCS—levels	518	3.44	1.76	0	6
DDS—full	518	5.47	1.71	1	9
DDS—levels	518	1.18	0.62	0	2
Food insecurity index	460	2.60	3.80	0	10
<i>Nutrition outcomes</i>					
Height for age (Z score)	593	-1.10	-1.50	-4.95	3.89
Weight for age (Z score)	618	-0.34	-1.25	-4.67	3.32
Weight for height (Z score)	582	0.30	-1.40	-4.58	4.47
Undernourished	582	0.30	0.46	0	1
Anaemia	495				
None	270	54.55			
Mild	102	20.61			
Moderate	120	24.24			
Severe	3	0.61			
<i>Agricultural engagement</i>					
Any agricultural land (owned or leased)	518	0.43	0.50	0	1
Owned	518	0.36	0.48	0	1
Leased	518	0.07	0.25	0	1
Owned land size					
< 0.25 ha	90	0.50			
0.25–1 ha	55	0.30			
> 1 ha	36	0.20			
Grow any crops	518	0.43	0.50	0	1
Crop diversity	518	1.05	1.32	1	5
Proportion of income from agriculture	518	0.16	0.32	0	1
Any quadruped livestock	518	0.25	0.43	0	1
Any milk cattle	518	0.18	0.39	0	1
Any poultry	518	0.39	0.49	0	1
<i>Water, sanitation, and hygiene</i>					
Improved sanitation facility	518	0.57	0.50	0	1
Flushing toilet	518	0.20	0.40	0	1
Water from the tap	518	0.50	0.50	0	1
<i>Demographic and socio-economic characteristics</i>					
Child age (months)	663	30.17	16.08	6	68
Gild gender (1 female)	663	0.51	0.50	0	1
HH size	518	4.78	2.21	2	16
Female head of HH	518	0.05	0.21	0	1
Mother's education level	518				
Primary or below	140	0.28			
Secondary	228	0.44			
Higher	150	0.29			
Wealth index (quintiles)	518	2.99	1.41	1	5
Ethnicity	518				
Other	171	0.33			
Kalenjin	205	0.40			
Luhya	79	0.15			
Kikuyu	40	0.08			
Luo	23	0.04			
Sub-county	518				
Ainabkoi	61	0.12			

Table 1 (continued)

<i>Dietary behaviour</i>	<i>N</i>	<i>Mean</i>	<i>Std. Dev</i>	<i>Min</i>	<i>Max</i>
Kapseret	91	0.18			
Kesses	95	0.18			
Moiben	108	0.21			
Soy	81	0.16			
Turbo	82	0.16			

Source: authors' calculations

and 5 years old), with the number of children per sub-county varying from 79 in Ainabkoi to 139 in Moiben^{5,6}.

The survey was designed by researchers from Royal Holloway University of London, King's College London, the University of Central Lancashire (all UK), and the University Eldoret (Kenya) and was administered, in person, by research assistants from the University of Eldoret. The survey gathered data on households' demographic and socio-economic characteristics, their agricultural activities, their WASH facilities as well as on their dietary behaviour and their children's nutrition outcomes, namely their height, weight, and blood haemoglobin levels.

2.2 Data analysis methods

The main empirical models, in line with our hypotheses, examine first the households' dietary behaviour as a function of the households' agricultural engagement and the children's and households' demographic and socio-economic characteristics. Second, the models scrutinise links between children's nutrition outcomes and households' dietary behaviour and their agricultural engagement, access to WASH, and the children's and households' demographic and socio-economic characteristics⁷. The models are estimated using Ordinary Least Squares (OLS), Probit, Ordered Probit, and Tobit regressions⁸, contingent on the nature of the dependent variable, with household-clustered robust standard errors. In our choice of estimators, we have followed existing studies on similar topics, such as Azzarri et al. (2015) and Petrikova (2022).

⁵ Overall, the sample was gathered from 16 wards: Huruma, Kamagut, Kapsaos, Kapseret, Kapsoya, Kimumu, Kipchamo, Kipkenyo, Kiplombe, Kuinet, Langas, Moiben, Racecourse, Sergoit, Soy, and Tembelio.

⁶ The results displayed in Figs. 1, 1 and 1 graphically are shown in numbers in Table 1.

⁷ The models' equations are summarised in Appendix A.

⁸ OLS regressions were used with continuous dependent variables, Probit regressions with binary dependent variables, Ordered Probit regressions with ordinal dependent variables, and Tobit regressions with left- and right-censored continuous dependent variables, which in our case were height-for-age, weight-for-age, and weight-for-height Z scores.

We have noted the potential endogeneity in the relationships between agricultural engagement/WASH and dietary behaviour/nutrition outcomes, where, for example, households with better access to WASH could be different from households with worse access to WASH in unobservable (or hard to measure) ways that could simultaneously influence their dietary behaviour and their children's nutrition outcomes (we of course control for households' wealth in all our models as it is well known that better-off households tend to both have better access to WASH and better nutrition outcomes – e.g., Graham et al., 2018). We try to control for the potential endogeneity using a linear regression model augmented with an endogenous binary-treatment variable ('etregress' command in STATA 16). We explain this robustness test later in greater detail.

2.3 Variables

2.3.1 Dependent variables – dietary behaviour and nutrition outcomes

The first set of our models examine households' dietary behaviour. We use five main variables in this section. From survey questions about the frequency with which households consume different types of food, we calculated two different measures – a Food Consumption Score (FCS) and a Dietary Diversity Score (DDS). The FCS is an index developed by the World Food Programme (WFP) that 'aggregates household-level data on the diversity and frequency of food groups consumed over the previous seven days, which is then weighted according to the relative nutritional value of the consumed food groups' (Data4Diets, 2023). The FCS is often used as an approximate measure of household caloric availability. It is calculated by aggregating different foods consumed in eight groups – 1. staples, 2. pulses, 3. vegetables, 4. fruit, 5. meat, fish, and eggs, 6. dairy, 7. sugar, and 8. oil – and multiplying their frequency of consumption over seven days by 2, 3, 1, 1, 4, 4, 0.5, and 0.5, respectively. The results are summed into one score with a theoretical range from 0 to 112, with higher numbers indicating better caloric availability and dietary quality. We use the FCS first in its total amount, as a continuous variable, and second as an ordinal variable, with the total score divided into seven

levels, with 0 indicating very insufficient caloric availability and 6 satisfactory⁹.

The DDS that we utilise has been adapted from the FAO's Minimum Dietary Diversity measure, which considers whether 10 food groups – 1. grains, roots, and tubers, 2. pulses, 3. nuts and seeds, 4. dairy, 5. meat, poultry, and fish, 6. eggs, 7. dark leafy greens and vegetables, 8. other Vitamin A-rich fruits and vegetables, 9. other vegetables, and 10. other fruit – have been consumed over the last 24 h (Data4Diets, 2023). Dietary diversity scores have been shown to be strongly positively correlated with micronutrient adequacy of diets (e.g., Chakona & Shackleton, 2017; Rodriguez-Ramirez et al., 2022), making the DDS a better indicator of nutrition security than the FCS. We estimated the DDS from answers about the frequency of household consumption of the 10 food groups, giving households a score of 1 for any food group that they have reported to consume daily and summing the scores. We use the DDS in its total amount as a continuous variable, where it ranges from 0 to 10, and also as an ordinal variable, after dividing the total score into three levels¹⁰. However, in Table B2 in the Appendix we also display results for the different food groups that make up the FCS and DDS measures as separate dependent variables. Finally, as the fifth main dependent variable, we utilise a household Food Insecurity Index (FII), calculated from a series of questions about households' access to food and associated feelings (e.g., anxiety about secure access to food) on a scale from 0 (no food insecurity) to 10 (severe food insecurity)¹¹. The FII, unlike the FCS and DDS, captures also the psychological and emotional aspects of food insecurity.

The second set of our models assesses as dependent variables children's nutrition outcomes, calculated on the basis of the children's height, weight, and blood haemoglobin-level measurements. Specifically, we consider children's height-for-age, weight-for-age, and weight-for-height Z-scores (calculated using World Health Organisation [WHO] guidelines) and a measure of anaemia – an ordinal variable where 0 represents no anaemia (more than 11 g haemoglobin [hb] per dcl blood), 1 mild anaemia (10–11 g hb), 2 moderate anaemia (7–10 g hb), and 3 severe anaemia (< 7 g hb).

Haemoglobin levels were determined using a finger-prick blood test analysed by portable HemoCue™ diagnostic kits. We also utilise a binary variable of undernourishment, which takes a value of 1 if a child is either stunted (too short for age), underweight (too light for age), or wasted (too light for height)¹².

2.3.2 Independent variables

The main independent variables in our study measure households' agricultural engagement. We use seven key variables here. Three relate predominantly to crop cultivation: the first, binary, one enquires if households have the use, through ownership or rent, of any agricultural land,¹³ the second, ordinal, one considers the size of owned land (1- less than 0.25 ha, 2- 0.25 to 1 ha, or 3- more than 1 ha), and the third one measures the diversity of crops grown, on a scale from 0 (none) to 6 (cereals, roots and tubers, pulses, green leafy vegetables, other vegetables, and fruit)¹⁴. Three agricultural variables relate to livestock – binary questions about household ownership of poultry, quadruped livestock, and dairy cattle. The final variable assesses the contribution of households' agricultural production to their overall income¹⁵, a proportion measure on a scale from 0 to 1. This variable can be understood as a measure of the intensity of households' agricultural production, particularly as it relates to their engagement in the market¹⁶. The reference time-frame of the agricultural engagement variables is within the year prior to the survey.

Since our hypotheses also maintain the importance of water, sanitation, and hygiene (WASH) in the link between agricultural engagement/dietary behaviour and nutrition outcomes, we explore another three key independent variables, all binary, on whether the households surveyed have an improved sanitation facility, whether they have a private flushing toilet, and whether they obtain clean water from a private pipe or tap rather than from other sources. The World

⁹ FCS levels from total scores: 0–59 (0), 60–69 (1), 70–79 (2), 80–89 (3), 90–99 (4), 100–109 (5), 110–112 (6).

¹⁰ DDS levels from total scores: 0–3 (0), 4–6 (1), and 7–10 (2).

¹¹ This is an adapted version of the Food and Agriculture Organisation's Food Insecurity Experience Scale (FAO, 2024). It contains all eight questions from the FIES and two additional questions, one about parents having to restrict food consumption to ensure children could eat and one about having to borrow food or money for food from friends or relatives. One other change from the FIES is that the questions' reference period is past 30 days rather than the past 12 months.

¹² A child is deemed stunted if her/his height-for-age Z score falls below two standard deviations (-1.96 Z score); underweight and wasting are estimated in the same way.

¹³ This question refers mostly to arable land, but some households also have land specifically for livestock – although most livestock is kept in household yards.

¹⁴ In the construction of the crop diversity variable, we followed M'Kaibi et al. (2017).

¹⁵ This was a household estimate of how much their agricultural production contributed to their overall household income in monetary terms in the last 12 months.

¹⁶ The survey did not collect data on households' total income – as existing research suggests data on income in lower-income countries tends to be inaccurate (e.g., Deaton, 1997)—and hence could only consider agricultural engagement as a proportion of total income rather than in total.

Health Organisation defines improved sanitation facilities as those that hygienically separate human waste from human contact – including flushing toilets, septic-tank pit latrines, improved-pit latrines, pit latrines with slab, and composting toilets – and are not shared with other households (WHO, 2024). As most households in our sample have an improved sanitation facility, we also consider separately the effects of having access to private flushing toilets, as these are arguably the most hygienic type of sanitation facility (Abney et al., 2021).

Following numerous studies examining dietary behaviour and nutrition outcomes (e.g., Bharati et al., 2020; Masset et al., 2011; M’Kaibi et al., 2017; Petrikova, 2019, 2022; Roba et al., 2019), our analytical models further control for the children’s age and gender, their mothers’ education, their households’ size, wealth, and ethnicity, whether the households are female-headed, and the sub-county in which they reside.

2.4 Descriptive statistics

Table 1 displays summary statistics of all the variables used. The uppermost part contains results regarding the dietary behaviour variables. The mean FCS score is 89, which is well above the lowest ‘acceptable’ score of 35 as defined by the WFP (Data4Diets, 2023). The range is large, however, from 14 to 112, with 15 households with a score below 35, indicating a sizeable spread of household caloric availability in our sample. The average DDS score is 5.5. While not directly comparable to the Minimum Dietary Diversity (MDD) measure, from which our DDS is derived, the average MDD scores are similar among adults in Mexico (Rodriguez-Ramírez et al., 2022) and slightly lower than among South African urban populations (Chakona & Shackleton, 2017). The mean FII among the households surveyed is 2.6 out of possible 10, indicating a moderate average level of food insecurity. Table B1 shows the breakdown of the FCS and DDS constituent food groups and demonstrates that the most commonly consumed groups include grains, roots, and tubers, vegetables, fruit, and dairy. Animal proteins other than dairy, nuts, and seeds are consumed less frequently – for example, only 9 percent of households in our sample reported eating eggs daily.

The following section of Table 1 shows that in nutrition outcomes, the children in our sample are shorter and slightly lighter for their age than the WHO average of 0 but slightly heavier for their height than the average. Meanwhile, 45 percent of the children suffer from some form of anaemia – 21 percent from mild, 24 percent from moderate, and 1 percent from severe anaemia. In terms of undernourishment, our sample of children is similar to the Kenyan national average but with a higher rate of stunting. Twenty-seven percent of the children in our sample were found to be stunted, 9 percent underweight, and 4

percent wasted; the latest nationally representative results for Kenya have been 18 percent, 10 percent, and 4 percent, respectively (DHS, 2022). Overall, 30 percent of the surveyed children suffered from at least one of the three types of undernourishment measured. From the six sub-counties surveyed, the highest undernourishment prevalence was in Ainabkoi – 37 percent – while the lowest, 19 percent, was in Kapseret (Fig. 2).

Regarding agricultural engagement, 43 percent households in our sample reported to own (36 percent) or rent (7 percent) at least some agricultural land. This largely aligns with results from the latest Kenyan DHS (2022), where 43 percent of respondents from urban areas in Uasin Gishu County reported to own or rent agricultural land (compared with 76 percent of rural Uasin Gishu inhabitants). Forty-three percent of households in our sample also grow some crops¹⁷ but crop diversity is relatively low, with households growing on average only two types of crops (out of cereals; roots and tubers; pulses; green leafy vegetables; other vegetables; and fruit). Most frequently grown crops include maize, beans, kale, potatoes, spinach, managu (African nightshade), and bananas.

Figure 3 and Table D1 show that the sub-counties with the highest usage of agricultural land are Soy and Turbo – 46 percent – while the lowest one is Kapseret at 31 percent. Agriculture contributes the most to household incomes in Soy (24 percent) and the least in Kesses (8 percent). The average proportion of household income derived from agriculture is 16 percent in our sample (Table 1). About two thirds of the income relates to crop cultivation and one third to raising livestock. In line with existing research (e.g., Carletto et al., 2017), many agriculturally-engaged households in our sample sell some of their produce – 33 percent of livestock-owning households reported to earn some income from the livestock and 47 percent of crop-growing households from the crops grown. Twenty-five percent of households own some quadruped livestock, 18 percent dairy cattle, and 39 percent poultry. Fifty-seven percent of households have improved sanitation, 20 percent have a private flushing toilet, and 50 percent obtain their water from taps.

Vis-à-vis the control variables, the children surveyed varied in age between six and 68 months¹⁸ and slightly more – 51 percent – were girls than boys (but this difference is not statistically significant). Twenty-eight percent of mothers had received only primary or lower, 44 percent up to

¹⁷ There is a very high but not perfect overlap between households that have the use of agricultural land and those that grow crops – as some grow crops in their backyard that they do not consider agricultural land per se while some of those with agricultural land use it only for livestock.

¹⁸ Fourteen children, 2 percent of our sample, were several months older than the requested 60 months but none had yet completed 6 years of age.

secondary, and 29 percent higher education. The average household size is five but varies between two and 16. Using principal component analysis, we calculated the household wealth index from information about the ownership of a series of household items (stove, gas cooker, electric cooker, jiko, fridge, freezer, watch/clock, phone, radio, TV, bicycle, motorcycle, scooter, car, and energy from mains)¹⁹ and then reclassified the index into quintiles (five equal groups). The ethnic make-up of our sample is quite varied, with the largest group – 40 percent – of Kalenjin ethnicity. This is followed by people of ‘other’ ethnicities (30 percent), Luhya (15 percent), Kikuyu (8 percent), and Luo (4 percent).

Earlier, we mentioned the potentially endogenous relationship between the households’ agricultural engagement and WASH and the outcomes of interest, i.e., households’ dietary behaviour and children’s nutrition outcomes. Table 2 to some extent confirms our fears, demonstrating that households in our sample that are agriculturally engaged and have better WASH are also significantly wealthier than other households. Our main empirical models control for households’ wealth as well as their location of residence and mothers’ education, which are also related to wealth, but it is possible that there are other unobservable or hard-to-measure characteristics related to agricultural engagement and/or WASH that have an effect on dietary behaviour or nutrition outcomes. We try to address this issue through a sensitivity analysis, explained in more detail below, but also bear it in mind when discussing our findings.

3 Results

3.1 Dietary behaviour as a function of households’ agricultural engagement

Results of the regressions examining the relationship between households’ agricultural engagement and dietary behaviour are presented in Tables 3 and 2. Somewhat unexpectedly, we find a negative association between households’ usage of agricultural land and their dietary quality, where households with agricultural land have significantly lower Food Consumption and Dietary Diversity Scores. However, this negative association is reversed in households owning larger plots of land and growing a greater diversity of crops – but not by livestock ownership. In other words, households that own larger plots of agricultural land and/or grow a greater variety of crops tend to have more varied diets, consuming pulses, vegetables, meat, and eggs more frequently than households growing fewer types of crops or those with

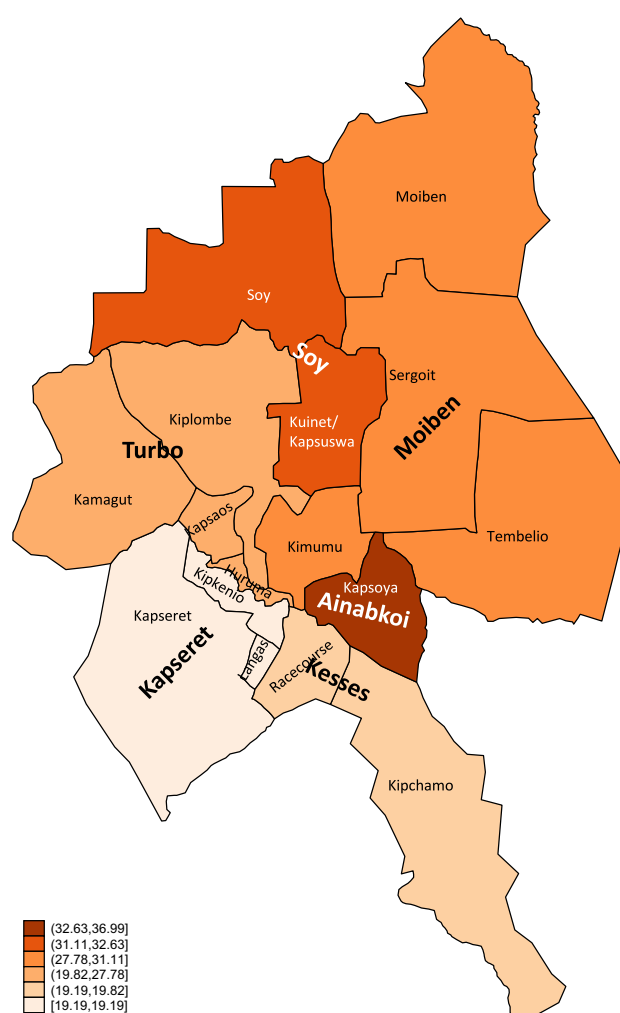


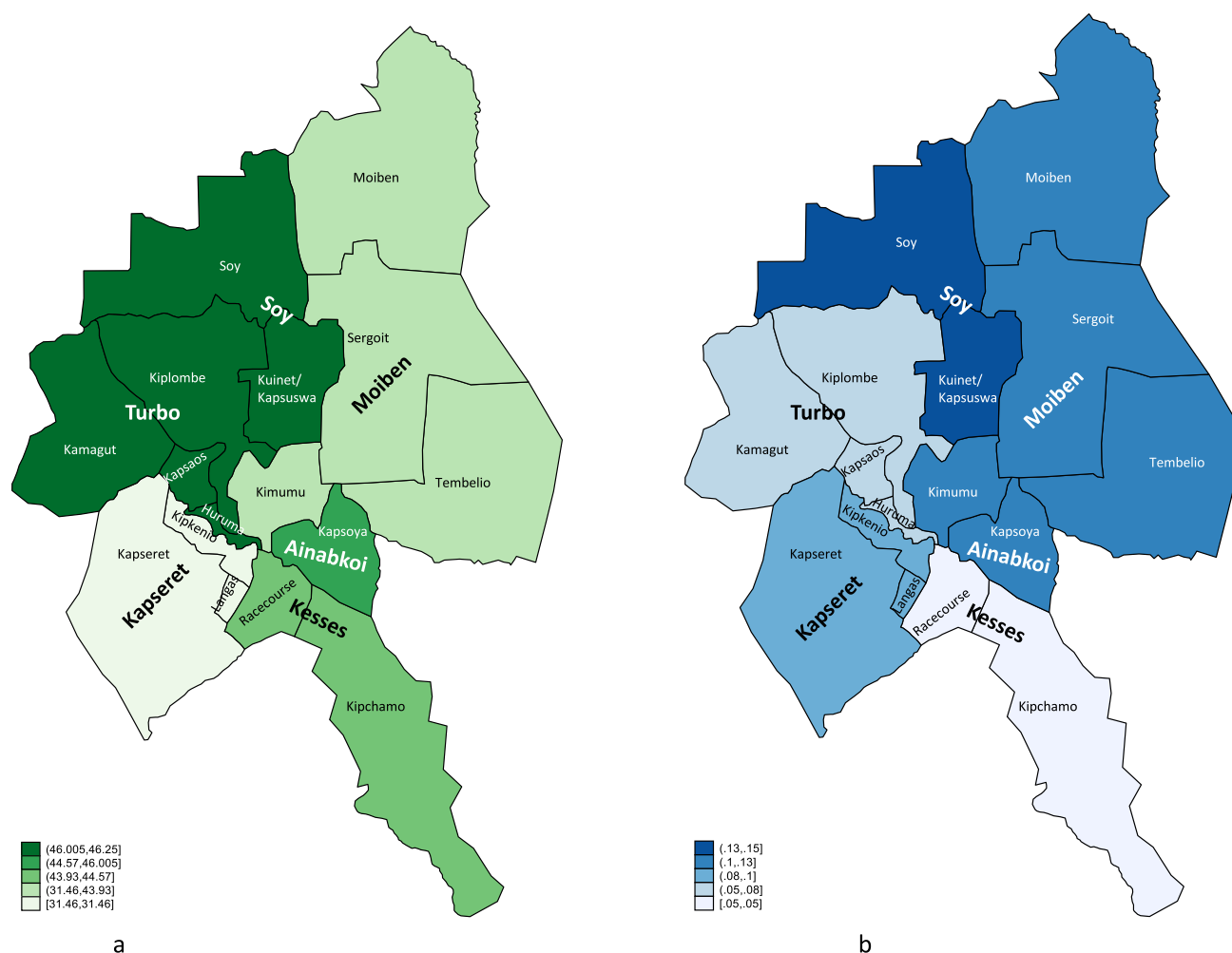
Fig. 2 Undernourishment rates among children under five

smaller or no plots of agricultural land²⁰. We also find a significant positive relationship between agricultural income and household dietary quality, with households deriving a higher proportion of income from agriculture exhibiting higher levels of Food Consumption and Dietary Diversity Scores. Particularly fruit and meat consumption is relatively more frequent in households with higher proportion of income from agriculture (Table B2).

In contrast, livestock ownership is not positively associated with Dietary Diversity and in some instances negatively correlated with the Food Consumption Score (Table 3). Looking at the specific variables examined, households with quadruped livestock actually consume, *ceteris paribus*,

¹⁹ We do not include the WASH variables in the wealth index calculation since we use them as separate independent variables.

²⁰ The relationship between crop diversity and the food insecurity index is significant and positive. While this might seem at first glance surprising, the likely explanation is that households anxious about their food access are more prone to planting a greater variety of crops to strengthen the resilience of their food supply.



Source: Authors' own work

Fig. 3 Agricultural land usage (a) and the proportion of income from agriculture (b)

meat, pulses, and vegetables less frequently than households without such livestock (Table B2). On the other hand, poultry ownership is linked with a more frequent consumption of pulses, meat, and eggs, although the latter two relationships are not statistically significant (ibid).

Overall, the results in this part of our analysis provide some support for our first hypothesis, but more so regarding crop cultivation than livestock raising.

Looking at the control variables, the main difference in household consumption patterns by children's age is that households with older children have slightly lower dietary diversity, driven predominantly by their lower dairy consumption. This is an expected finding since dairy consumption is higher among younger children than older children in most countries (e.g., Nguyen Bao et al., 2018). Unsurprisingly, wealthier households and those with more educated

mothers are more food secure and enjoy better dietary quality (i.e., higher FCS and DDS) than their counterparts. The same is true of female-headed households, a result also in line with other existing studies (e.g., Chirwa & Ngalawa, 2008; Petrikova, 2022). In terms of ethnic groups and different sub-counties, Kalenjin households and households in Kapseret have according to our measures the best, while Luo households and those living in Moiben and Turbo the worst diets.

3.2 Links between agricultural engagement, dietary behaviour, and nutrition outcomes

Table 4 displays our findings on children's nutrition outcomes as a function of their households' agricultural engagement and dietary behaviour. Dietary diversity, measured

Table 2 T-tests of average wealth index quintiles by agricultural engagement and WASH

	<i>Average wealth index quintile</i>		<i>T-test</i>
	<i>No</i>	<i>Yes</i>	
Any agricultural land	2.66	3.51	-6.87
Own more than 1 ha of agr. land	2.96	3.49	-5.41
Any income from agriculture	2.81	3.50	-12.20
Any quadruped livestock	2.90	3.54	-4.59
Any milk cattle	2.90	3.69	-5.31
Any poultry	2.79	3.46	-5.30
Flushing private toilet	2.78	4.29	-10.29
Water from the tap	2.89	3.30	-3.21

Source: authors' calculations

through DDS, is significantly associated only with reduced anaemia rate. However, looking specifically at the effects of the daily consumption of different animal-sourced food²¹ shows that eating eggs daily is linked to significantly greater height-for-age scores and lower prevalence of undernourishment.

Turning attention to the water, sanitation, and hygiene variables²², both obtaining water from a tap and owning a private flushing toilet have a significant positive link with children's nutrition outcomes. In households with tap water, children have on average greater height-for-age scores and are less likely to be undernourished. In households with flushing toilets, meanwhile, children have on average greater height-for-age as well as weight-for-age scores and are less likely to be undernourished (i.e., stunted, underweight or wasted) or anaemic.

From the agricultural engagement variables, particularly the proportion of income derived from agriculture shows significant links with children's nutrition outcomes. Namely, households that derive a larger portion of their income from agriculture have, other things being equal, on average children with greater height-for-age and weight-for-age scores and lower likelihood of being undernourished. On the other hand, such children are also more likely to suffer from anaemia. In contrast, having access to agricultural land has a borderline-significant relationship with higher undernourishment prevalence but also lower anaemia rates while poultry

ownership is linked with borderline-significantly lower weight-for-height scores²³.

Table 4 also displays results on the links between children's nutrition outcomes and a range of control variables. Regarding the surveyed children's demographics, female children and older children have higher mean height-for-age scores than others. Older children are also less likely to be anaemic and more likely to be leaner (lower weight-for-age and weight-for-height scores). As expected, food-insecure and poorer households have on average shorter, lighter, and more anaemic children. Children whose mothers received higher education have on average higher weight-for-age scores than children of mothers with no or primary only education but in other instances the effect of education does not appear significant. This may, however, be due to the high correlation between mother's education and households' wealth index quintile. Finally, regarding children's ethnicity, Kalenjin and Kikuyu children are significantly shorter and Kalenjin children also significantly lighter than the children of 'other' ethnicities.

3.3 Sensitivity analysis

Tables C1 and C2 show the results of re-estimating the basic models with linear regression models augmented with an endogenous binary-treatment variable. The tables report the average treatment effect of households receiving any income from agriculture²⁴, modelled as a function of the households' wealth index. The regressions' Wald tests show that much of the time, the treatment-assignment errors and the outcome errors for the control and treatment groups are indeed significantly positively correlated, justifying the use of the 'etregress' estimator²⁵.

The results on the link between households' proportion of income from agriculture and their dietary behaviour and children's nutrition outcomes are similar to those found in the basic models, both in their direction and their significance. Looking first at the models of dietary behaviour as a function

²¹ As mentioned in Sect. 1, these have been often linked in existing literature with better children's nutrition outcomes (e.g., Headey et al., 2018; Petrikova, 2022).

²² We do not report results here for 'improved sanitation' because that variable did not show any significant association with children's nutrition outcomes when included in regressions instead of the 'flushing toilet' variable.

²³ The fact that some variables have positive links with height-for-age and weight-for-age Z scores but negative with anaemia, or vice versa, brings up interesting questions about the relationship between height/weight-for-age and anaemia. However, a brief examination of these relationships has produced results in line with theoretical expectations – namely, both height-for-age and weight-for-age scores are negatively, albeit only weakly, associated with anaemia rates. In other words, taller/and or heavier children are less likely to be anaemic.

²⁴ We used the binary variable of 'any income from agriculture' rather than the continuous variable of 'income proportion from agriculture' because the estimator used requires a binary treatment variable.

²⁵ We have tested the use of the etregress estimator also with our other agricultural-engagement variables (any agricultural land, any cattle, any poultry) as well as the WASH variables (flushing toilet and tap water) but the Wald tests were in those cases consistently insignificant.

Table 3 Households' agricultural engagement and dietary behaviour

Dependent variable	FCS (full)			FCS (levels)			DDS (full)			DDS (levels)			Food insecurity index		
Model no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Any agricultural land	-7.210***	-9.927***	-7.224	0.663***	0.569***	0.659	0.510***	0.440***	0.516***	0.404***	0.372***	0.416***	0.993	0.922	0.991
	-2.617	-3.451	-2.584	-2.661	-3.313	-2.668	-3.795	-4.369	-3.712	-4.545	-4.434	-4.402	-0.037	-0.409	-0.047
Owned land size															
Up to 0.25 ha		4.080			1.194			1.249			1.076			1.506*	
		1.236			0.915			1.140			0.299			1.652	
0.25 to 1 ha		10.665***			1.899***			1.708***			1.407			0.887	
		3.121			3.046			2.617			1.236			-0.398	
More than 1 ha		10.472**			2.062***			1.650*			1.543			0.380***	
		2.194			2.756			1.798			1.397			-2.624	
Crop diversity	1.919**	1.212	1.998	1.113*	1.071	1.116	1.152**	1.112	1.156**	1.156*	1.132*	1.162**	1.198**	1.190**	1.197**
	1.978	1.265	2.050	1.756	1.117	1.794	1.990	1.436	2.040	1.884	1.536	1.946	2.153	1.993	2.146
Agricultural income (% all)	7.935***	6.979**	8.093	1.604***	1.487**	1.587	1.291	1.240	1.342 ^x	1.617**	1.537**	1.747***	0.720	0.856	0.714
	2.702	2.323	2.728	2.614	2.169	2.551	1.426	1.189	1.635	2.249	1.989	2.627	-1.197	-0.551	-1.238
Any quadruped livestock	-6.952***	-7.845***	-7.517	0.666***	0.623***	0.653	0.844	0.810	0.829	0.959	0.922	0.941	0.931	1.005	0.929
	-2.604	-2.939	-2.803	-2.725	-3.149	-2.869	-1.155	-1.407	-1.268	-0.237	-0.457	-0.352	-0.373	0.023	-0.388
Any poultry	2.855	2.522	2.893	1.209	1.190	1.202	1.055	1.035	1.070	0.903	0.900	0.931	0.799	0.760	0.797
	1.108	0.958	1.111	1.416	1.265	1.380	0.415	0.269	0.524	-0.681	-0.698	-0.479	-1.102	-1.411	-1.113
Child age	-0.072 ^x	-0.076*	-0.074	0.996*	0.995*	0.996	0.994***	0.994***	0.994***	0.994**	0.994**	0.994**	0.999	0.999	0.999
	-1.636	-1.719	-1.676	-1.706	-1.811	-1.726	-2.583	-2.678	-2.630	-2.014	-2.062	-2.091	-0.354	-0.376	-0.333
HH size	1.122***	1.064***	1.148	1.075***	1.069***	1.077	1.055**	1.053**	1.054**	1.105***	1.101***	1.102***	0.948*	0.963	0.949*
	3.068	2.843	3.089	3.327	3.078	3.391	2.431	2.382	2.404	3.498	3.355	3.437	-1.685	-1.186	-1.675
Female head of HH	7.334**	8.372**	8.180	1.517*	1.599**	1.554	2.152***	2.285***	2.236***	2.054**	2.111**	2.166**	0.714	0.754	0.719
	2.284	2.513	2.708	1.865	2.028	2.060	3.167	3.342	3.394	2.318	2.384	2.537	-0.929	-0.763	-0.908
Mother's education (rel. to primary or below)															
Secondary	4.950**	5.097**	4.987	1.349**	1.367**	1.354	1.159	1.168	1.154	1.120	1.128	1.110	0.605***	0.567***	0.607***
	2.097	2.173	2.107	2.330	2.418	2.366	1.209	1.274	1.171	0.768	0.817	0.708	-3.176	-3.599	-3.139
Higher	4.437 ^x	3.969	4.699	1.282 ^x	1.243	1.304	1.083	1.061	1.075	1.052	1.029	1.026	0.509***	0.518***	0.513***
	1.592	1.434	1.664	1.642	1.425	1.738	0.550	0.410	0.491	0.282	0.159	0.141	-3.604	-3.501	-3.562
Water from the tap	2.602	3.349 ^x	2.507	1.096	1.149	1.105	1.026	1.064	1.001	1.213 ^x	1.243*	1.152	0.691**	0.677***	0.694**
	1.275	1.629	1.228	0.797	1.200	0.856	0.227	0.548	0.010	1.476	1.657	1.051	-2.559	-2.637	-2.547
Improved toilet/flushing toilet (Models 3, 6, 9, 12, and 15)	3.049	3.258 ^x	-1.738	1.064	1.093	0.882	1.200 ^x	1.210 ^x	1.086	1.363**	1.391**	1.269 ^x	0.990	0.899	0.938
	1.371	1.511	-0.700	0.497	0.702	-0.798	1.455	1.501	0.543	2.030	2.143	1.466	-0.064	-0.635	-0.308
Wealth quintile															
II	6.300*	5.842*	6.777	1.470**	1.437**	1.488	1.451**	1.422**	1.482**	1.925***	1.902***	1.986***	0.738 ^x	0.753	0.736 ^x

Table 3 (continued)

Dependent variable	FCS (full)			FCS (levels)			DDS (full)			DDS (levels)			Food insecurity index		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<i>Model no.</i>															
<i>III</i>	1.863	1.741	2.009	2.172	2.045	2.261	2.210	2.088	2.340	3.326	3.270	3.464	-1.500	-1.400	-1.521
	8.200***	8.015***	9.449	1.693***	1.687***	1.767	1.752***	1.742***	1.820***	2.184***	2.179***	2.287***	0.467***	0.472***	0.469***
<i>IV</i>	2.689	2.688	3.141	3.048	3.054	3.327	3.372	3.352	3.639	3.904	3.872	4.160	-3.431	-3.375	-3.557
	11.568***	10.975***	13.956	2.091***	2.008***	2.245	2.131***	2.086***	2.344***	2.564***	2.498***	2.953***	0.450***	0.497***	0.452***
<i>V</i>	3.568	3.416	4.623	3.834	3.614	4.503	4.049	3.949	4.916	4.287	4.188	5.117	-3.442	-2.952	-3.759
	9.484***	9.278**	12.787	1.858***	1.842***	2.086	1.914***	1.905***	2.103***	2.025***	2.013***	2.250***	0.461***	0.474***	0.472***
	2.601	2.567	3.678	2.924	2.888	3.578	3.419	3.465	4.015	3.074	3.091	3.515	-2.739	-2.622	-2.576
Ethnicity (rel. to 'other')															
<i>Kalenjin</i>	4.899**	5.456**	4.291	1.085	1.123	1.065	1.303**	1.340**	1.270*	1.346**	1.370**	1.296*	1.201	1.182	1.202
	2.287	2.529	2.037	0.661	0.935	0.512	2.067	2.283	1.906	1.992	2.100	1.761	1.126	1.010	1.127
<i>Luhya</i>	1.083	1.466	0.375	0.948	0.982	0.926	1.052	1.070	1.027	1.145	1.172	1.108	1.537**	1.418*	1.537**
	0.326	0.442	0.112	-0.304	-0.102	-0.434	0.318	0.419	0.166	0.718	0.829	0.537	1.983	1.600	1.972
<i>Kikuyu</i>	6.581*	7.078*	5.716	1.224	1.277	1.189	1.236	1.266	1.199	1.243	1.279	1.187	1.181	1.093	1.179
	1.732	1.888	1.548	0.918	1.113	0.803	1.016	1.132	0.857	0.868	0.976	0.667	0.713	0.377	0.706
<i>Luo</i>	-0.053	1.567	-0.295	0.791	0.868	0.781	1.321	1.437	1.320	1.036	1.087	1.044	1.824*	1.819*	1.832*
	-0.012	0.363	-0.070	-0.794	-0.483	-0.843	1.107	1.430	1.129	0.131	0.305	0.166	1.685	1.654	1.690
Sub-county (rel. to Ainabkoi)															
<i>Kapseret</i>	9.039***	8.164***	9.511	2.073***	1.985***	2.110	2.015***	1.936***	2.034***	1.874***	1.828***	1.878***	0.763	0.743	0.766
	3.102	2.860	3.223	3.411	3.219	3.476	3.739	3.485	3.751	2.762	2.637	2.729	-1.040	-1.106	-1.032
<i>Kesses</i>	-6.370*	-7.739**	-6.201	0.634**	0.587**	0.647	0.759	0.705*	0.741	0.731	0.701	0.687*	0.977	0.928	0.987
	-1.687	-2.048	-1.595	-2.062	-2.389	-1.937	-1.296	-1.593	-1.377	-1.260	-1.379	-1.462	-0.101	-0.304	-0.055
<i>Moiben</i>	-4.746*	-8.691***	-4.500	0.605***	0.466***	0.609	0.673**	0.553***	0.680**	0.742	0.641*	0.752	0.872	1.028	0.873
	-1.696	-2.743	-1.598	-2.756	-3.717	-2.744	-2.131	-2.789	-2.073	-1.353	-1.800	-1.284	-0.552	0.102	-0.549
<i>Soy</i>	-3.436	-5.435*	-3.100	0.672**	0.603***	0.682	0.496***	0.444***	0.498***	0.477***	0.454***	0.477***	1.021	0.878	1.021
	-1.209	-1.786	-1.085	-2.196	-2.622	-2.110	-3.667	-4.081	-3.587	-3.318	-3.418	-3.249	0.080	-0.475	0.078
<i>Turbo</i>	-5.354 ^x	-7.086*	-5.035	0.731 ^x	0.663*	0.747	0.865	0.789	0.855	0.886	0.843	0.854	0.751	0.689	0.755
	-1.457	-1.877	-1.319	-1.515	-1.940	-1.380	-0.749	-1.133	-0.782	-0.536	-0.704	-0.674	-1.068	-1.324	-1.035
<i>N</i>	630	630	630	630	630	630	630	630	630	630	630	630	554	554	554

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$ ^x $p < 0.15$. Models 1–3, 7–9, and 13–15 were estimated using OLS regressions, models 4–6 and 10–12 using Ordered Probit regressions. The numbers next to the variables are coefficients in the case of OLS regressions and Adjusted Odds Ratios (AOR) in the case of Ordered Probit regressions, below are corresponding Z scores

Table 4 Agricultural engagement, dietary behaviour, and nutrition outcomes

Dependent variable	ZHA		ZWA				ZWH			
	1	2	3	4	5	6	7	8	9	10
Model no.										
DDS (full)	1.032			1.032	1.003			1.002	0.984	
	0.692			0.721	0.074			0.053	-0.379	
DD—meat		0.952				1.023				1.035
		-0.307				0.203				0.247
DD—dairy		0.874				0.818				0.692*
		-0.639				-1.246				-1.830
DD—eggs		1.533*				1.253				0.947
		1.778				1.283				-0.256
Flushing toilet	1.437*	1.364 ^x	1.275	1.252	1.290 ^x	1.240	1.274 ^x	1.231	1.068	1.035
	1.656	1.442	1.225	1.069	1.530	1.269	1.508	1.257	0.321	0.163
Water from the tap	1.334*	1.321*	1.412**	1.262 ^x	1.058	1.063	1.148	1.057	0.924	0.947
	1.911	1.802	2.445	1.521	0.478	0.502	1.161	0.494	-0.558	-0.381
Any agricultural land	0.962	0.932	0.975		1.127	1.131	1.097		1.320	1.343 ^x
	-0.172	-0.321	-0.120		0.706	0.743	0.561		1.394	1.521
Crop diversity	1.050	1.069	1.015		0.966	0.975	0.943		0.942	0.944
	0.576	0.817	0.191		-0.489	-0.360	-0.812		-0.739	-0.720
Agricultural income	1.515 ^x	1.530*	1.482 ^x		1.421*	1.423*	1.326		1.115	1.129
	1.611	1.657	1.593		1.735	1.766	1.316		0.465	0.535
Any quadruped livestock	0.971	0.935	0.980		0.954	0.940	0.998		0.867	0.866
	-0.158	-0.370	-0.112		-0.304	-0.407	-0.014		-0.758	-0.771
Any poultry	1.211	1.202	1.216		0.922	0.924	0.934		0.781	0.784
	1.112	1.093	1.197		-0.506	-0.499	-0.426		-1.339	-1.337
Child age	1.020***	1.020***	1.019***	1.020***	0.992**	0.992**	0.993**	0.993**	0.987***	0.986***
	5.066	4.998	5.175	5.143	-2.465	-2.568	-2.329	-2.402	-3.065	-3.358
Female child	1.288*	1.302**	1.298**	1.273*	1.094	1.090	1.174*	1.095	0.920	0.912
	1.948	2.032	2.200	1.858	0.890	0.850	1.674	0.896	-0.712	-0.788
HH size	0.956	0.954 ^x	0.964	0.973	0.951*	0.948*	0.969	0.954*	0.959	0.957
	-1.420	-1.473	-1.225	-0.895	-2.148	-2.295	-1.357	-2.106	-1.402	-1.476
Female head of HH	0.701	0.649	0.988	0.665	0.953	0.914	1.048	0.949	2.035*	2.110*
	-0.852	-1.028	-0.037	-0.971	-0.118	-0.224	0.136	-0.129	1.726	1.815

Table 4 (continued)

Dependent variable	ZHA				ZWA					ZWH
Model no.	1	2	3	4	5	6	7	8	9	10
Mother's education (rel. to primary or less)										
Secondary	1.003	1.039	1.074	1.025	0.967	0.993	1.164	0.953	0.891	0.912
	0.015	0.220	0.466	0.142	-0.248	-0.051	1.164	-0.360	-0.641	-0.519
Higher	1.185	1.221	1.217	1.208	1.188	1.198	1.387**	1.140	1.004	0.993
	0.781	0.906	1.028	0.875	1.012	1.029	1.997	0.805	0.019	-0.035
Food insecurity	0.989	0.985		0.989	0.973 ^x	0.972 ^x		0.973 ^x	0.977	0.976
	-0.567	-0.731		-0.587	-1.507	-1.531		-1.489	-1.012	-1.067
Wealth quintile										
II	1.412 ^x	1.434 ^x	1.210	1.431 ^x	1.425*	1.438**	1.296 ^x	1.426**	1.214	1.250
	1.489	1.543	0.924	1.547	1.959	1.998	1.531	1.954	0.938	1.082
III	1.250	1.286	1.161	1.414 ^x	1.776***	1.782***	1.420**	1.837***	1.571**	1.621**
	0.945	1.056	0.710	1.479	3.333	3.282	1.999	3.593	2.185	2.349
IV	1.485 ^x	1.540*	1.306	1.662**	1.474**	1.511**	1.338 ^x	1.539**	1.342	1.430 ^x
	1.585	1.768	1.160	2.146	2.018	2.151	1.523	2.299	1.290	1.563
V	1.069	1.117	1.057	1.344	1.276	1.304	1.176	1.385 ^x	1.265	1.312
	0.230	0.385	0.206	1.127	1.037	1.156	0.702	1.455	0.809	0.948
Ethnicity (rel. to 'other')										
Kalenjin	0.699**	0.698**	0.671***	0.717**	0.645***	0.651***	0.594***	0.648***	0.729**	0.764*
	-2.246	-2.166	-2.724	-2.046	-3.563	-3.478	-4.358	-3.441	-2.147	-1.836
Luhya	0.754	0.757	0.666*	0.692	1.329	1.335	1.091	1.270	2.006***	2.033***
	-1.236	-1.221	-1.889	-1.634	1.603	1.635	0.512	1.391	3.352	3.462
Kikuyu	0.616**	0.621*	0.557**	0.555**	1.017	1.037	0.904	0.972	1.463	1.539 ^x
	-1.981	-1.888	-2.543	-2.411	0.082	0.183	-0.517	-0.145	1.422	1.625
Luo	0.865	0.902	0.905	0.816	1.204	1.223	1.110	1.168	1.299	1.298
	-0.336	-0.241	-0.247	-0.461	0.691	0.752	0.416	0.581	0.763	0.730
Sub-county (rel. to Ainabkoi)										
Kapseret	1.421	1.525*	1.626**	1.486 ^x	1.233	1.286	1.285	1.228	0.857	0.888
	1.420	1.678	2.060	1.556	1.094	1.308	1.277	1.040	-0.728	-0.577
Kesses	1.791**	1.831**	1.911**	1.762**	2.008***	2.052***	2.080***	1.921**	1.352	1.385 ^x

Table 4 (continued)

Dependent variable	ZHA			ZWA			ZWH			
Model no.	1	2	3	4	5	6	7	8	9	10
Moiben	2.260	2.312	2.549	2.106	3.549	3.645	3.783	3.295	1.343	1.512
	0.974	0.938	1.074	1.013	1.567**	1.573**	1.635***	1.505**	1.528**	1.606**
	-0.112	-0.274	0.327	0.054	2.461	2.551	2.675	2.231	2.148	2.454
Soy	1.152	1.079	1.274	1.255	0.828	0.800	1.011	0.831	0.714	0.693 ^x
Turbo	0.537	0.288	1.012	0.867	-0.823	-0.991	0.049	-0.809	-1.296	-1.464
	0.861	0.813	0.932	0.877	1.704***	1.676**	1.788***	1.653**	1.775**	1.813**
	-0.553	-0.761	-0.269	-0.476	2.630	2.512	2.973	2.438	2.480	2.568
N	498	498	559	498	517	517	584	517	473	473
Dependent variable	ZWH	Undernourished			Anaemia					
Model no.	11	12	13	14	15	16	17	18	19	20
DDS (full)		0.982	1.025			1.016	0.939			0.962
		-0.430	0.580			0.391	-1.444			-0.914
DD—meat				1.199				0.928		
				1.267				-0.501		
DD—dairy				1.080				1.009		
				0.405				0.048		
DD—eggs				0.583**				0.935		
				-2.544				-0.308		
Flushing toilet	1.043	1.115	0.694*	0.744 ^x	0.722*	0.773	0.868 ^x	0.852	1.228	0.803
	0.217	0.541	-1.865	-1.504	-1.866	-1.333	-1.518	-1.438	0.931	-1.351
Water from the tap	0.975	0.960	0.783*	0.791 ^x	0.769**	0.807 ^x	0.864	0.865	0.819 ^x	0.860
	-0.188	-0.306	-1.730	-1.630	-1.978	-1.602	-1.028	-1.021	-1.536	-1.114
Any agricultural land	1.327 ^x		1.343 ^x	1.340 ^x	1.279		0.707*	0.741 ^x	0.694*	
Crop diversity	1.475		1.456	1.464	1.230		-1.668	-1.456	-1.898	
	0.909		0.990	0.975	1.027		1.099	1.082	1.084	
	-1.168		-0.133	-0.331	0.340		1.180	0.982	1.119	
Agricultural income	1.045		0.685 ^x	0.707 ^x	0.758		1.562**	1.521**	1.413*	
	0.186		-1.611	-1.494	-1.193		2.149	2.012	1.748	
Any quadruped livestock	0.916		0.835	0.863	0.803		1.208	1.225	1.120	

Table 4 (continued)

Dependent variable	ZWH	Undernourished					Anaemia				
		I1	I2	I3	I4	I5	I6	I7	I8	I9	I10
Model no.											
Any poultry	-0.480		-1.027	-0.833	-1.264			1.087	1.151	0.712	
	0.576 ^x		0.814	0.823	0.796			0.795	0.793	0.931	
	-1.522		-1.261	-1.200	-1.427			-1.383	-1.353	-0.442	
Child age	0.986***	0.987***	0.981***	0.980***	0.982***	0.981***		0.974***	0.975***	0.975***	0.974***
Female child	-3.481	-3.059	-4.989	-5.136	-5.226	-5.111		-6.285	-6.008	-6.241	-6.133
	0.929	0.928	1.017	1.010	0.949	1.017		0.792*	0.788*	0.770**	0.795*
	-0.671	-0.636	0.145	0.080	-0.465	0.144		-1.903	-1.941	-2.263	-1.919
HH size	0.974	0.957	1.069*	1.075**	1.064*	1.065*		1.053	1.051	1.043	1.051
	-0.892	-1.549	2.389	2.695	2.340	2.371		1.813	1.709	1.743	1.877
	Female head of HH	1.674 ^x	2.139*	1.810 ^x	2.171**	1.353	1.901*	1.606	1.496	0.929	1.628
Mother's education (rel. to primary or less)	1.538	1.804	1.597	1.996	0.992	1.730		1.284	1.103	-0.216	1.369
	Secondary	1.052	0.879	1.029	0.992	0.909	1.044	0.928	0.913	0.879	0.893
	Higher	0.324	-0.714	0.177	-0.052	-0.661	0.272	-0.434	-0.517	-0.861	-0.668
Food insecurity	1.212	0.955	0.855	0.806	0.825	0.869		0.930	0.926	0.792	0.884
	1.019	-0.232	-0.788	-1.068	-1.090	-0.724		-0.348	-0.359	-1.261	-0.621
		0.981	1.051***	1.055***			1.054***	1.006	1.006		1.007
Wealth quintile		-0.815	2.773	2.888		2.906		0.312	0.321		0.399
	II	1.113	1.202	1.039	1.065	1.143	1.027	0.742 ^x	0.727 ^x	0.736*	0.759
		0.555	0.905	0.187	0.297	0.727	0.130	-1.451	-1.535	-1.692	-1.393
III	1.321 ^x	1.490**	0.929	0.948	1.027	0.859		0.829	0.799	0.812	0.887
	1.434	1.978	-0.324	-0.228	0.134	-0.694		-0.930	-1.108	-1.172	-0.629
	IV	1.203	1.317	1.071	1.141	1.193	1.017	0.804	0.742	0.773	0.814
V	0.897	1.237	0.296	0.554	0.857	0.075		-1.015	-1.402	-1.396	-0.982
	1.157	1.222	1.423	1.461	1.396	1.271		0.602*	0.569**	0.674 ^x	0.697
	0.528	0.699	1.352	1.425	1.374	1.029		-1.806	-1.991	-1.539	-1.210
Ethnicity (rel. to 'other')											
	Kalenjin	0.732**	0.723**	1.336*	1.398**	1.437**	1.346*	1.004	0.994	1.021	0.967
	-2.191	-2.188	1.869	2.114	2.519	1.934		0.026	-0.034	0.147	-0.212

Table 4 (continued)

Dependent variable	ZWH		Undernourished			Anaemia				
	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10
Model no.										
Luhya	1.932***	2.022***	1.095	1.102	1.406*	1.195	1.025	1.030	1.010	0.941
	3.506	3.449	0.417	0.445	1.683	0.836	0.113	0.135	0.054	-0.291
Kikuyu	1.439	1.485 ^x	1.280	1.300	1.487*	1.394 ^x	0.736	0.720	0.734	0.659
	1.397	1.510	1.054	1.089	1.828	1.457	-1.012	-1.099	-1.085	-1.404
Luo	1.087	1.333	1.219	1.170	1.175	1.355	1.702	1.670 ^x	1.416	1.471
	0.256	0.853	0.588	0.458	0.473	0.925	1.664	1.622	1.097	1.224
Sub-county (rel. to Ainabkoi)										
Kapseret	0.885	0.818	0.631*	0.592**	0.577**	0.620**	1.534 ^x	1.508 ^x	1.563*	1.591*
	-0.595	-0.930	-1.952	-2.204	-2.465	-2.056	1.570	1.505	1.728	1.714
Kesses	1.400 ^x	1.278	0.694 ^x	0.638**	0.613**	0.700 ^x	0.909	0.937	0.961	0.900
	1.548	1.084	-1.617	-1.961	-2.259	-1.592	-0.359	-0.249	-0.157	-0.401
Moiben	1.604**	1.403*	1.037	1.057	0.887	0.992	1.422 ^x	1.461*	1.540**	1.493*
	2.459	1.735	0.173	0.262	-0.620	-0.040	1.567	1.656	2.049	1.889
Soy	0.842	0.677 ^x	1.204	1.196	1.035	1.150	2.783***	2.951***	2.625***	2.792***
	-0.683	-1.476	0.794	0.770	0.161	0.597	4.407	4.710	4.478	4.470
Turbo	1.814***	1.663**	1.022	1.039	0.865	1.007	1.147	1.187	1.436*	1.088
	2.702	2.220	0.094	0.165	-0.655	0.028	0.598	0.746	1.648	0.379
N	533	473	473	473	533	473	415	415	466	415

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$ ^x $p < 0.15$. Models 1–12 were estimated using Tobit models (with upper limit of 5 and lower limit of -5), models 13–16 using Probit regressions, and models 17–20 using Ordered Probit regressions. The numbers next to the variables are Adjusted Odd Ratios (AOR), below are corresponding Z scores

of households' agricultural engagement (Table C1), in the sensitivity analysis as in the basic models having any agricultural income is linked with statistically higher FCS and DDS and statistically lower FII. Looking at the regressions modelling children's nutrition outcomes (Table C2), in the sensitivity analysis as in the basic models, agricultural income frequently appears to be significantly positively linked with better outcomes, particularly when it comes to greater height-for-age, weight-for-age, and weight-for-height scores. While we cannot conclude that the 'etregress' estimator has helped us control all endogeneity within the relationships between our key independent and dependent variables, it is reassuring that the findings in this robustness test are broadly in line with those attained in the basic models.

3.4 Conditional effects of WASH

We hypothesised (H2) that the relationship between households' agricultural engagement/dietary behaviour and children's nutrition outcomes is mediated by households' access to WASH. One of the indications that this might indeed be the case in our dataset is shown in Table 4, where 'proportion of income from agriculture', despite being significantly associated with better diets in Table 3, does not have an unequivocally positive relationship with children's nutrition outcomes. It seems to be associated with a reduction in the prevalence of undernourishment but also an increase in the prevalence of anaemia.

To examine the potential mediatory effect, we estimated multiple regressions with the nutrition outcomes as dependent variables where the effects of households' agricultural engagement and/or dietary behaviour were interacted with households having access to tap water and flushing toilets. We found significant results particularly when it came to the proportion of income from agriculture but also having use of agricultural land and poultry keeping, principally in their links with height-for-age, undernourishment prevalence, and anaemia. The six graphs below constitute a small subset of possible graphs demonstrating that households' agricultural engagement is associated with significant improvements, or in some cases *not* associated with significant deterioration, in children's nutrition outcomes when the households have access to good WASH.

Figure 4a and b show that a higher proportion of household income from agriculture is linked with children taller for their age in households with flushing toilets and tap water but not in those without. Figure 5a indicates that a greater proportion of income from agriculture is also linked with lower children's undernourishment rates in households with flushing toilets, while Fig. 5b demonstrates that the proportion of income from agriculture is associated with a higher prevalence of anaemia only in households without flushing

toilets, not otherwise. Finally, graphs in Fig. 6 point to similar conclusions vis-à-vis household ownership of agricultural land and poultry. The ownership of agricultural land is linked with higher undernourishment rates among children only in households without access to flushing toilets (Fig. 6a). Similarly, poultry ownership is associated with higher anaemia rates in households without access to flushing toilets but is insignificant otherwise (Fig. 6b).

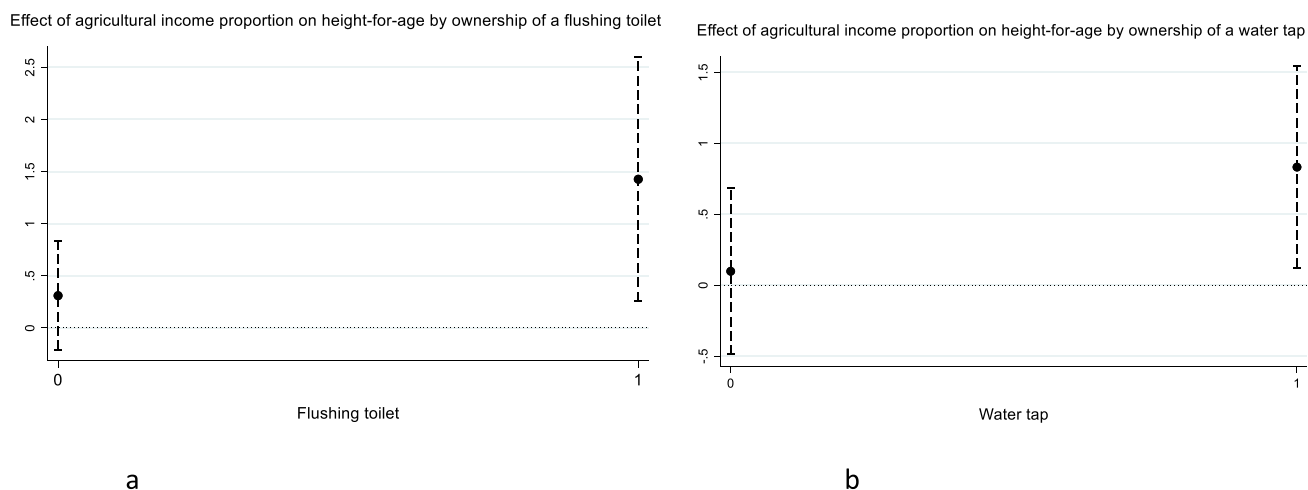
4 Discussion and conclusions

In light of the rapid urbanisation in LMICs, which encroaches on rural and traditionally agricultural lands without a necessarily concurrent expansion of improved water and sanitation services, in this article we have investigated the links between the agricultural engagement of households in transitional peri-urban areas and their food and nutrition security. We did so by surveying 518 households with children between 6 months and 5 years old, living around the Kenyan town of Eldoret, enquiring about their agricultural engagement, dietary behaviour, and their children's nutrition outcomes. Our findings suggest that some aspects of households' agricultural engagement in the peri-urban areas are associated with significantly improved dietary behaviour and nutrition outcomes but that this relationship is mediated by good water, sanitation, and hygiene access.

We discovered that households which derive a larger proportion of their income from agricultural activities – growing crops, raising livestock, or both – have, all other things being equal, more diverse diets than households with a smaller proportion of income from agriculture, consuming fruit, meat, and eggs more frequently. Interestingly, mere access to agricultural land (whether through owning or renting it) is associated with worse diets but this negative link seems reversed within agriculturally engaged households that own larger tracts of land and/or cultivate a broader array of crops.²⁶ Our findings here align with other existing research (e.g., Bundala et al., 2020; Dillon et al., 2015; Murendo et al., 2019) that has argued in favour of crop diversification and domestic produce sales to strengthen agricultural households' food and nutrition security. In contrast to crop-growing, household animal ownership does not appear to have an equivalent positive relationship with households' dietary behaviour, with households that own quadruped livestock reporting actually a lower frequency of meat consumption than households without such animals.

Even so, the results in this first part of our study provide some support to our first hypothesis (H1) and are consistent with the existing body of literature on the links

²⁶ But it does not seem to be reversed through livestock ownership alone.



Source: Authors' own work

Fig. 4 Effects of agricultural income on height-for-age by access to tap water (a) and flushing toilets (b)

between (peri)urban crop cultivation and diets in Kenya and elsewhere (e.g., Bellon et al., 2020; Gallaher et al., 2013; Omondi et al., 2017). Where our findings diverge somewhat from prior studies (e.g., Choudhury & Headey, 2018; Kim et al., 2019) is in the lack of a positive association found between livestock ownership and dietary diversity/ASF consumption. This could be a function of the way we measured household food consumption, the specificity of the Eldoret peri-urban area, the role of livestock in Kenya as savings, insurance, or status symbol rather than a source of ASF (Tabe-Ojong et al., 2022), or other mechanisms at play and warrants further investigation in subsequent research.

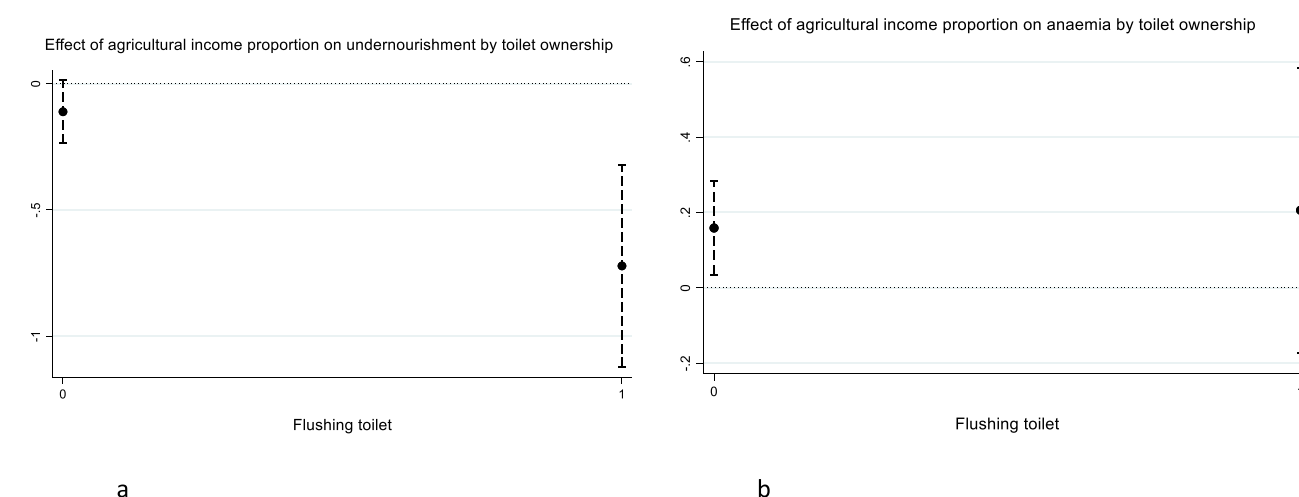
The results in the second part of our study provide more robust support for our second hypothesis (H2). Households' greater dietary diversity is linked to a significantly lower prevalence of anaemia and more frequent consumption of eggs to significantly higher height-for-age scores and lower undernourishment rates. Likewise, a higher proportion of household income from agriculture is positively correlated with children's height-for-age scores and lower undernourishment prevalence while poultry ownership with a lower incidence of anaemia. However, agricultural income proportion is simultaneously associated with a higher likelihood of anaemia and poultry ownership with reduced weight-for-height scores. These latter results might seem paradoxical, given the variables' previously discovered links with better diets.

Exploration of the conditional effects of WASH – specifically, whether households have a private flushing toilet and obtain water from taps – helps clarify the relationships. As expected, both the ownership of flushing toilets and of water taps have a positive relationship with nutrition outcomes in their own right, even after controlling for household

wealth²⁷. Both variables are associated with statistically greater height-for-age scores and lower prevalence of undernourishment and anaemia and flushing-toilet ownership also with higher weight-for-age scores. Nonetheless, examining the various interacting relationships between agricultural engagement, WASH, and nutrition outcomes has indicated that households with better sanitation and hygiene arrangements are also better able to derive nutritional benefits from their agricultural engagement. Specifically, a higher proportion of income from agriculture is associated with greater children's height and weight only in households with flushing toilets, not otherwise. The same is true for height-for-age outcomes in households with tap water versus those without. In households with flushing toilets, agricultural income proportion further has no significant relationship with children's anaemia rates, unlike in households without flushing toilets, where the link is positive (i.e., correlated with higher anaemia rates). Similarly, owning or renting agricultural land is linked with a greater prevalence of undernourishment only in households that do not have flushing toilets and poultry ownership is associated with greater height-for-age scores only in households with flushing toilets, not otherwise.

These findings can most satisfactorily be explained by the proposition that households' agricultural engagement, while contributing to better household diets, might be simultaneously counteracting children's ability to benefit from improved nutrition due to a greater presence of potentially

²⁷ Interestingly, the ownership of an improved sanitation facility – which in addition to flushing toilets also includes improved latrines – does not exhibit a significant positive association with better nutrition outcomes.



Source: Authors' own work

Fig. 5 Effects of agricultural income on undernourishment (a) and anaemia (b) by toilet ownership

harmful substances, viruses, and bacteria in the homestead environment. The pathways through which the negative effect on growth might occur are multiple, including higher incidence of diarrhoea (Checkley et al., 2008), higher incidence of environmental enteric dysfunction (Mbuya & Humphrey, 2016), and higher incidence of aflatoxicosis (e.g., Anyango et al., 2018; Kaaya & Warren, 2005). These issues have been previously highlighted in existing literature when it comes to livestock and poultry ownership (e.g., Gelli et al., 2019; Kaur et al., 2017; Ngunjiri et al., 2019) but our finding of a similar relationship vis-à-vis crop cultivation is more novel. It is not particularly surprising, in view of previous research warning about the pollutants and contamination frequently associated with urban and peri-urban agriculture in LMICs (e.g., Gerster-Bentaya, 2013; Minhas et al., 2015; Nasinyama et al., 2010; Orsini et al., 2013; Twinomucunguzi et al., 2020), but it is consequential in its implications and warrants further study.

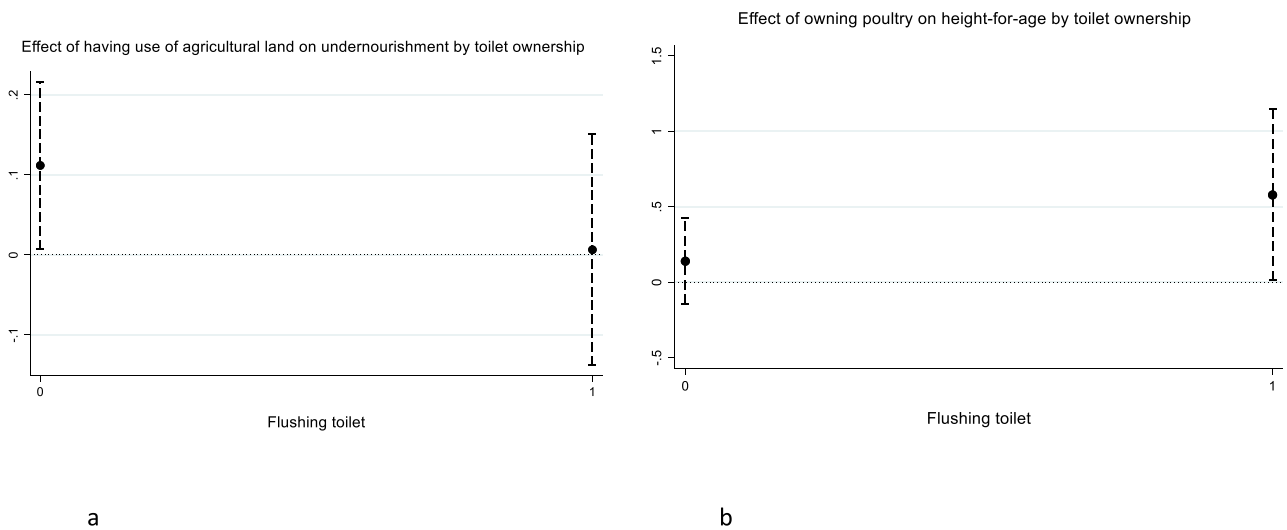
Our results hence suggest that growing crops in peri-urban spaces might be fraught with the risk that the resultant greater exposure to potentially contaminated agricultural soils and water used for irrigation might undermine households' nutrition security²⁸. Nevertheless, we have also shown that the negative link between households' agricultural engagement, whether in crops or livestock, and children's health is ameliorated in the presence of access to improved water and sanitation while retaining the positive link between agricultural engagement and improved dietary behaviour and nutrition outcomes. As explained earlier, our study has suffered from some limitations, namely the potentially endogenous relationship among our key dependent and

independent variables. The general alignment of the results from our basic models with those from the sensitivity analysis as well as with those in existing literature should, however, hopefully lessen any concerns about spurious nature of our findings.

What implications do our findings hold for the rapid urbanisation trends in LMICs and associated government policy? They point towards the potential of agricultural activities to contribute significantly to enhancing food and nutrition security in peri-urban areas, both by facilitating access to more varied home-produced foods and by allowing households to diversify their incomes through sales of the home-produced food in local markets. Unlike in urban areas, where population density tends to be higher and agricultural land availability very limited, in peri-urban areas the scope for negotiating land use is greater and so is likely the potential of peri-urban agriculture to contribute to local households' food and nutrition security. In addition, evidence from higher-income countries suggests that peri-urban farming can also enhance the quality, resilience, and sustainability of food and nutrition security in the urban areas, alongside its utility in municipal waste management and energy production (e.g., Brinkley, 2012; Diehl et al., 2020; Olsson et al., 2016).

Our results also strongly highlight the importance of water, sanitation, and hygiene when it comes to children's health outcomes generally (e.g., Choudhary et al., 2021; Cumming & Cairncross, 2016; Meshram et al., 2019; Pickering et al., 2012; Spears, 2013) and specifically in households engaged in agricultural production that brings children into closer contact with potentially harmful substances, bacteria, and viruses. To mitigate the adverse effects that these might bear on children's growth as much as possible, existing research has suggested the use of 'baby WASH' interventions – WASH interventions aimed specifically at households with children

²⁸ To understand this potential pathway better, more qualitative research is needed.



Source: Authors' own work

Fig. 6 Effects of agricultural land (a) and poultry ownership (b) on children's nutrition outcomes by households' toilet ownership

under 1,000 days old (Mbuya & Humphrey, 2016) – and of safe community or individual play pens for infants and young children that could minimise or at least reduce their contact with harmful substances (Budge et al., 2019; Rosenbaum et al., 2021). Our findings should provide encouraging evidence for Kenya's national and local governments to facilitate and promote peri-urban agriculture with their policies and initiatives but also to invest in more widespread improved water, sanitation, and hygiene services, particularly among households with young children. In fact, our results emphasise the interdependence of these two facets, as without access to improved water and sanitation, the nutritional benefits gained from peri-urban agriculture are evidently compromised.

Appendix A: Summary of models tested in the analysis

First set of models

Dietary behaviour = households' agricultural engagement + households' demographics and socio-economic characteristics + sub-county.

Second set of models

Children's nutrition outcomes = households' dietary behaviour + households' agricultural engagement + children's demographics + households' demographics and socio-economic characteristics + sub-county.

Appendix B: Examination of FCS and DDS individual components

Table B1 Summary statistics of individual FCS and DDS components

Dietary behaviour	N	Mean	Std. Dev	Min	Max
FCS—staples	518	7.00	0.00	7	7
FCS—pulses	518	4.21	2.44	0	7
FCS—vegetables	518	6.83	0.95	0	7
FCS—fruit	518	5.97	2.05	0	7
FCS—meat and eggs	518	4.98	2.60	0	7
FCS—dairy	518	6.20	1.96	0	7
FCS—sugar	518	7.00	0.00	7	7
FCS—oil	518	6.07	2.10	0	7
DD—grains, roots, and tubers	518	1.00	0.00	1	1
DD—pulses	518	0.29	0.46	0	1
DD—nuts and seeds	518	0.05	0.22	0	1
DD—green leaves	518	0.65	0.48	0	1
DD—orange fruits and vegetables	518	0.89	0.31	0	1
DD—other vegetables	518	0.87	0.34	0	1
DD—other fruit	518	0.42	0.49	0	1
DD—meat	518	0.37	0.48	0	1
DD—eggs	518	0.09	0.29	0	1
DD—dairy	518	0.83	0.37	0	1

Source: authors' calculations

Table B2 Households' agricultural engagement and consumption of different food groups (individual components of FCS and DDS as dependent variables)

Dependent variable	FFQ-pulses	FFQ-vege-tables	FFQ-fruits	FFQ-meat and eggs	FFQ-dairy	DD-pulses	DD-green leaves	DD-orange f and v	DD-other veg	DD-other fruit	DD-meat	DD-eggs	DD-dairy
Any agri-cultural land	0.713*	0.253***	0.624**	0.640**	1.082	0.541***	0.646*	0.416***	0.661 ^x	0.484**	0.613**	1.037	1.048
Crop diversity	-1.850	-3.231	-2.032	-2.524	0.335	-2.742	-1.868	-2.888	-1.580	-3.251	-2.381	0.152	0.188
Agricultural income (% all)	1.054	1.775***	1.099	1.180**	0.980	1.208**	1.105	1.476***	1.239**	1.078	1.052	0.864	1.006
	0.773	3.172	1.042	2.297	-0.207	2.214	1.081	2.823	2.101	0.862	0.615	1.439	0.060
	1.376	0.859	2.288***	1.633**	1.515	1.102	1.243	2.266*	1.071	1.333	1.711*	0.997	1.587
Any quad-ruped livestock	1.639	-0.293	3.005	2.187	1.289	0.355	0.786	1.836	0.209	1.154	1.742	-0.010	1.331
(Milk cattle for FFQ-dairy and DD-dairy)	0.699**	0.662	0.897	0.618***	1.004	0.548***	1.186	0.633 ^x	0.601**	1.215	0.777	1.410 ^x	1.016
	-2.275	-1.146	-0.510	-2.617	0.017	-2.841	0.775	-1.626	-2.215	1.016	-1.292	1.484	0.062
Any poultry	1.378**	0.924	0.823	1.100	1.219	1.595***	0.901	0.813	0.748	1.073	1.190	1.091	1.182
	2.321	-0.223	-1.075	0.653	0.978	2.653	-0.580	-0.830	-1.291	0.391	0.631	0.455	0.807
Child age	1.002	1.000	0.997	0.997	0.989***	0.998	0.996	0.998	0.997	0.994*	0.997	0.993*	0.989***
	0.595	-0.035	-1.035	-1.135	-3.352	-0.611	-1.330	-0.485	-0.853	-1.781	-1.013	-1.806	-3.140
HH size	1.080***	1.093	1.046 ^x	1.037	1.042	1.090***	0.990	1.050	1.037	1.027	1.080**	1.011	1.028
	3.105	1.376	1.471	1.317	1.192	2.577	-0.283	1.208	0.942	0.887	2.439	0.205	0.755
Female head of HH	1.283	9.676***	2.589*	1.385	2.339**	1.823*	1.331	0.899	2.089 ^x	2.321**	1.183	2.312***	2.025
Mother's education (rel. to primary or less)	0.977	3.666	1.806	1.268	2.095	1.897	0.974	-0.262	1.578	2.513	0.509	2.585	1.438
Secondary	1.048	1.310	1.476**	1.367**	1.634**	0.933	1.369*	1.921***	1.281	0.828	1.173	0.841	1.613***
	0.341	0.710	2.316	2.231	2.565	-0.388	1.811	2.804	1.183	-1.160	0.943	-0.769	2.454
Higher	0.935	0.814	1.482*	1.610***	1.133	0.849	1.249	1.147	0.870	0.859	1.516**	0.871	1.105
	-0.402	-0.534	1.885	2.719	0.577	-0.763	1.094	0.507	-0.572	-0.774	2.115	-0.582	0.438
Water from the tap	0.870	4.377***	1.429**	1.153	1.803***	0.701**	0.770 ^x	1.819***	1.525**	1.079	0.925	1.378	1.747***
Improved toilet	-1.093	4.089	2.427	1.107	3.487	-2.318	-1.606	2.743	2.346	0.524	-0.530	1.394	3.179
	1.065	1.731*	1.064	1.080	1.420*	0.990	1.074	0.867	1.493*	1.107	0.807	2.565***	1.390 ^x

Dependent variable	FFQ-pulses	FFQ-vege- tables	FFQ-fruits	FFQ-meat and eggs	FFQ-dairy	DD-pulses	DD-green leaves	DD-orange f and v	DD-other veg	DD-other fruit	DD-meat	DD-eggs	DD-dairy
	0.491	1.807	0.395	0.524	1.795	-0.057	0.434	-0.625	1.739	0.598	-1.254	3.525	1.581
Wealth quintile													
II	1.033	1.492	1.383 ^x	1.551***	1.135	1.220	1.066	1.543 ^x	1.494 ^x	1.329	1.462*	1.195	1.076
	0.177	1.194	1.504	2.738	0.535	0.879	0.288	1.612	1.509	1.308	1.763	0.515	0.293
III	1.307 ^x	1.725	1.741**	1.833***	1.246	1.149	1.311	1.829**	1.279	1.536*	2.595***	1.206	1.214
	1.490	1.424	2.421	3.221	0.881	0.545	1.145	2.232	0.924	1.760	4.055	0.524	0.733
IV	1.320	3.794***	2.175***	2.335***	1.540 ^x	1.736**	1.429	3.722***	1.539	2.076***	1.711**	1.192	1.563 ^x
	1.433	3.328	3.127	3.940	1.566	2.062	1.373	3.884	1.426	2.848	2.011	0.467	1.441
V	1.420 ^x	1.887 ^x	2.168***	2.112***	0.836	2.003**	1.789*	2.721***	1.301	1.951**	1.975**	0.817	0.804
	1.472	1.486	2.757	3.192	-0.552	2.328	1.919	2.728	0.801	2.319	2.343	-0.497	-0.627
Ethnicity (rel. to 'other')													
Kalenjin	0.778**	3.261***	0.586***	1.940***	1.293 ^x	0.635***	1.798***	2.059***	1.316	0.818	1.234	2.313***	1.227
	-1.930	4.243	-2.845	4.583	1.442	-2.669	3.304	3.083	1.428	-1.186	1.274	3.912	1.067
Luhya	0.824	3.123*	0.709 ^x	1.624***	0.858	0.841	1.552**	1.792**	0.674 ^x	0.757	1.272	1.708*	0.783
	-1.087	1.871	-1.565	2.584	-0.658	-0.772	1.991	2.023	-1.499	-1.362	1.141	1.906	-1.046
Kikuyu	0.702	2.058	0.772	2.026***	1.813*	0.696	1.453	2.218*	1.080	0.965	1.203	2.400**	1.650
	-1.419	1.265	-1.008	2.816	1.777	-1.071	1.276	1.906	0.220	-0.124	0.710	2.428	1.379
Luo	0.992	9.096***	0.912	1.052	0.845	0.986	1.900*	1.000	1.528	0.684	1.243	0.755	0.781
	-0.027	6.875	-0.224	0.141	-0.453	-0.044	1.888	0.000	0.690	-1.107	0.608	-0.599	-0.582
Sub-county (rel. to Ainabkoi)													
Kapseret	1.467**	0.011***	1.082	1.964***	1.667 ^x	1.733**	2.248**	1.760	2.142**	1.255	1.796**	0.941	1.838*
	1.996	-10.312	0.288	2.941	1.477	2.281	2.347	0.990	2.475	0.908	2.272	-0.181	1.784
Kesses	0.686 ^x	0.012***	0.424***	0.923	0.946	0.565**	0.695	0.496 ^x	1.580 ^x	0.401***	1.366	0.738	1.012
	-1.614	-8.145	-3.090	-0.330	-0.181	-1.973	-1.238	-1.506	1.589	-3.195	1.215	-0.823	0.041
Moiben	0.735*	0.006***	0.498***	0.775	1.619 ^x	0.805	0.396***	0.426**	2.228***	0.445***	0.773	1.456	1.652*
	-1.798	-10.531	-2.826	-1.233	1.577	-0.890	-3.343	-2.059	2.685	-3.282	-1.008	1.288	1.729
Soy	0.877	0.005***	2.366***	1.068	0.826	0.631*	0.313***	0.395**	1.837**	0.373***	0.891	1.147	0.636 ^x
	-0.782	-13.407	2.615	0.300	-0.723	-1.839	-4.337	-2.191	2.166	-3.865	-0.456	0.464	-1.613
Turbo	0.663**	0.012***	0.584**	1.057	1.026	0.815	0.267***	0.845	3.313***	0.914	0.986	1.570	1.141
	-2.049	-7.781	-2.163	0.247	0.086	-0.789	-4.724	-0.371	3.319	-0.361	-0.054	1.404	0.455
N	630	630	630	630	630	630	630	630	630	630	630	630	630

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$ ^x $p < 0.15$. FFQ models were estimated using Ordered Probit regressions and DDS models Probit regressions. The numbers next to the variables are Adjusted Odd Ratios (AOR), below are corresponding Z scores

Appendix C: Sensitivity analysis

Table C1 Sensitivity analysis (1)

Dependent variable	FCS (full)			FCS (levels)			DDS (full)			DDS (levels)			Food insecurity index		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Any income from agriculture	22.361***	22.189***	21.534***	2.146***	2.316***	2.188	***	2.207***	2.243***	2.265***	0.815***	0.802***	0.899***	-3.311**	-3.383***
<i>N</i>	4.09	3.90	4.04	3.17	4.00	3.95	2.91	2.96	2.94	3.21	3.21	3.47	2.530	2.07	2.57
	630	630	630	630	630	630	630	630	630	630	630	630	554	554	554
Wald test (Prob > chi2)	0.001	0.000	0.001	0.001	0.001	0.001	0.025	0.022	0.026	0.017	0.013	0.013	0.011	0.011	0.001

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$ × $p < 0.15$. Re-estimation of models from Table 3, using linear regression models augmented with an endogenous binary-treatment variable (any income from agriculture modelled as a function of households' wealth index). The numbers next to the variables are coefficients, below are Z scores

Table C2 Sensitivity analysis (2)

Dependent variable	ZHA			ZWA			ZWH			Undernourished			Anaemia		
	1	2	3	5	6	7	9	10	11	13	14	15	17	18	19
Any income from agriculture	1.3811 ^x	1.2413	0.7605	1.4991 ^{***}	1.4198 ^{***}	1.1374 ^{***}	1.4361 ^{**}	1.4098 ^{**}	1.1265 [*]	-0.620 ^x	-0.246	-0.191	-0.635 ^x	-0.710 ^x	-0.724 ^x
N	1.45 498	1.07 498	0.38 559	3.21 517	2.88 517	2.26 584	2.38 473	2.33 473	1.74 533	1.59 473	1.11 473	1.32 533	1.55 415	1.74 415	1.76 466
Wald test (Prob > chi2)	0.4736	0.4532	0.8335	0.01	0.021	0.0737	0.032	0.04	0.1227	0.217	0.6592	0.7272	0.185	0.152	0.148

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$ ^x $p < 0.15$. Re-estimation of models from Table 4, using linear regression models augmented with an endogenous binary-treatment variable (any income from agriculture modelled as a function of households' wealth index). The numbers next to the variables are coefficients, below are Z scores

Appendix D: Results graphically displayed in Figs. 1, 2, and 3

Table D1 Undernourishment prevalence, use of agricultural land, and proportion of income from agriculture by sub-county

	Undernourishment (%)	Agricultural land	Income from agriculture
Ainabkoi	37%	46%	21%
Kapseret	19%	31%	15%
Kesses	20%	45%	8%
Moiben	31%	44%	18%
Soy	38%	46%	25%
Turbo	33%	46%	11%

Source: authors' calculations

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Availability of data and code Data were collected as part of the research project and will be shared publicly after the end of the embargo period.

Declarations

Ethical approval Ethical approval for the study was obtained through Amref Health Africa in Kenya (AMREF-ESRC P1009/2021).

Conflicts of interest No conflicts of interest to report.

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