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1

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Abstract

Livestock ownership may influence anemia through complex and possibly contradictory mechanisms. In this study, we aimed to determine the association of household livestock ownership with anemia among women aged 15-49 years and children aged 6-59 months in Ghana, and to examine the contribution of animal-source foods (ASFs) to consumption patterns as a potential mechanism mediating this association. We analyzed data on 4,441 women and 2,735 children from the 2014 Ghana Demographic and Health Survey and 16,772 households from the Ghana Living Standards Survey Round 6. Hemoglobin measurements were used to define anemia (non-pregnant women: < 120 g/L; children: < 110 g/L). Child- and household-level ASF consumption data were collected from 24-hour food group intake and food consumption and expenditure surveys, respectively. In multiple logistic regression models, household livestock ownership was associated with anemia among children (OR (95% CI): 1.5 (1.1, 2.0)), but not women (1.0 (0.83, 1.2)). Household ownership of chickens was associated with higher odds of anemia among children (1.6 (1.2, 2.2)), but ownership of other animal species was not associated with anemia among women or children. In path analyses, we observed no evidence of mediation of the association of household livestock ownership with child anemia by ASF consumption. Ownership of livestock likely has limited importance for consumption of

ASFs among young children in Ghana, and may in fact place children at an increased risk of anemia. Further research is needed to elucidate if and how pathogen exposure associated with livestock rearing may underlie this increased risk of anemia.

Keywords: anemia, livestock, poultry, Ghana, animal-source foods, malaria

KEY MESSAGES

Household livestock ownership in Ghana, and ownership of poultry in particular, is associated with higher odds of anemia among young children, but not women.

Households that own livestock are more likely to consume larger amounts of animal-source foods (ASFs), though ASF consumption among young children does not mediate the association of household livestock ownership with anemia among children.

While rearing poultry may facilitate greater household access to eggs and chicken meat, which can contribute to meeting the micronutrient needs of women and children, the potential benefits of these ASFs may be offset by exposure to poultry-associated pathogens that may increase the risk of anemia.

INTRODUCTION

Anemia among women of reproductive age (WRA) and preschool-aged children remains an intractable public health problem in many low- and middle-income countries (LMICs), especially in Sub-Saharan Africa (SSA) (World Health Organization, 2015). Anemia is associated with a higher risk of maternal mortality (Ezzati, Lopez, Rodgers, & Murray, 2004), poorer behavioral and developmental outcomes among children (Lozoff et al., 2006; Lozoff, Jimenez, Hagen, Mollen, & Wolf, 2000), and reduced aerobic work capacity and productivity (Horton & Ross, 2003). Though iron deficiency may be responsible for as much as half of all anemia (Stevens et al., 2013), its contribution is highly variable across geographic and social contexts (Petry et al., 2016), and many other factors influence anemia risk including parasitic infections, inherited blood disorders, vitamin deficiencies (e.g., folic acid, vitamins B12 and A)

(Balarajan, Ramakrishnan, Ozaltin, Shankar, & Subramanian, 2011), and acute or chronic immune activation (Weiss & Goodnough, 2005). This complex etiology suggests the importance of understanding how environmental conditions shape anemia risk.

Animal husbandry is a ubiquitous practice among rural and peri-urban households in LMICs, and has important potential implications for local environments, household behaviors, and health outcomes (Herrero et al., 2013). Access to meat, milk, and eggs from livestock rearing may increase consumption of anemia-mitigating animal-source foods (ASFs) either directly through consumption of such foods from own production, or indirectly through the purchase of ASFs using earned income from the sale of own-produced animal products (Hurrell, Reddy, Juillerat, & Cook, 2006; Leroy & Frongillo, 2007; Murphy & Allen, 2003). Yet, animal rearing may also exacerbate anemia risk by 1) increasing exposure to blood-feeding parasites such as soil-transmitted helminths (Moore et al., 2015; Pasricha, Drakesmith, Black, Hipgrave, & Biggs, 2013), 2) contributing to non-specific fecal-oral contamination from animal feces associated with anemia of inflammation (Humphrey, 2009), and 3) altering exposure to mosquito-vectors of *Plasmodium* parasites by diverting mosquitoes away from human hosts (i.e., zooprophylaxis) or increasing mosquito population density via increased blood meals (i.e., zoopotentiation) (Burkot, Dye, & Graves, 1989; Minakawa, Mutero, Githure, Beier, & Yan, 1999) that can induce malarial anemia (Haldar & Mohandas, 2009). The few livestock rearing intervention studies that have assessed impacts on anemia or hemoglobin (Hb) concentrations among women or children were implemented in combination with other interventions, thus obfuscating the independent role of livestock. These interventions, introducing small-scale, homestead poultry production in concert with promotion of vegetable gardens, field crop production, and/or provision of nutrition education, have shown mixed impacts on anemia (Galal, Harrison, Abdou, & Zein el Abedin, 1987; Olney, Pedehombga, Ruel, & Dillon, 2015; Olney, Talukder, Iannotti, Ruel, & Quinn, 2009; Osei et al., 2016). The scant observational evidence for the association of livestock rearing with anemia has similarly shown mixed results with studies reporting higher (Ahenkorah, Nsiah, & Baffoe, 2016; Iannotti et al., 2015) and lower (Flores-Martinez, Zanello, Shankar, & Poole, 2016; Miller, 2010) odds of anemia associated with livestock rearing. None of these studies have examined the role of co-infection when assessing associations between livestock and anemia among children, and no epidemiological studies have addressed differential associations among women and children. Given this limited and inconsistent evidence base, as well as other data indicating a deleterious effect of livestock on child health (Headey et al., 2017; Zambrano, Levy, Menezes, & Freeman, 2014), it is essential to understand how livestock may influence anemia risk among nutritionally vulnerable populations to help inform interventions that maximize the nutrition and health benefits of livestock, while preventing harm. In this study, we use data from two nationally representative surveys of Ghana to determine the association of household livestock ownership with anemia among women and children in Ghana and to examine the contribution of ASFs to consumption patterns as a potential mechanism mediating this association.

SUBJECTS AND METHODS

Data

We analyzed data from the 2014 Ghana Demographic and Health Survey (GDHS) and the 2012-2013 Ghana Living Standards Survey Round 6 (GLSS6). The 2014 GDHS was a nationally representative household survey of Ghana that collected data on the fertility, socioeconomic, health, and nutritional status of participating households and individuals using the DHS Phase VI core questionnaire. A two-stage stratified sampling design was used to select survey enumeration areas (EAs) identified from the 2010 Ghana Population and Housing Census (Ghana Statistical Service, Ghana Health Service, & ICF International, 2015). In the first sampling stage, 427 EAs were selected with probability proportional to size (i.e., number of residential households in the EA) and with independent selection in each of 20 sampling strata. Strata were defined by region and urbanicity. In the second stage of sampling, households were selected using equal-probability systematic sampling within each EA. All women aged 15-49 from selected households were eligible to be interviewed, and in half of the selected households, eligible women and children aged 6-59 months were tested for anemia. Children were also tested for malaria. Field work for the GDHS was carried out from September to December 2014. The GLSS6, a nationally representative survey of Ghana that collected data on household sociodemographic characteristics, agricultural production, consumption, and income, used a similar two-stage stratified sampling design as the GDHS wherein enumeration areas were selected in a first stage followed by systematic sampling of households within enumeration areas in a second stage (Ghana Statistical Service, 2014). Strata for the GLSS6 were similarly defined based on region and urban location. Fieldwork for the GLSS6 was carried out from October 2012 to October 2013. Our primary analyses were conducted using the GDHS data and complementary analyses of household consumption patterns were carried out using data from the GLSS6.

Measurement of variables

Household livestock ownership was the principal independent variable examined. Data on current ownership of nine different animals or animal groupings were collected in the GDHS (i.e., cattle, horses/donkeys/mules, goats, pigs, rabbits, grasscutters (*Thryonomys swinderianus),* sheep, chickens, and other poultry). Dichotomous variables indicating any household livestock ownership and ownership of specific animals were used in analyses. Data from the GLSS6 on ownership of any livestock (i.e., cattle, sheep, goats, pigs, rabbits, chicken, guinea fowl (*Numida meleagris*), turkeys, ducks, ostriches, snails, grasscutters) and participation in wild fish harvesting and aquaculture were also analyzed.

Data on the anemia status of non-pregnant WRA (15-49 years) and preschool-aged children (6-59 months) from the GDHS were used as the principal dependent variables, respectively. Capillary blood samples from a finger prick were analyzed using HemoCue photometer systems

(Hemocue, Inc., Brea, CA) to assess Hb concentrations. Mild, moderate and severe anemia, respectively, were defined among non-pregnant WRA as an Hb concentration of 110-119 g/L, 80-109 g/L, and < 80 g/L; and among children aged 6-59 months as a Hb concentration of 100-109 g/L, 70-99 g/L and < 70 g/L (World Health Organization, 2011).

We used several household-level sociodemographic variables from the GDHS in our analyses, as well as data on individual-level nutrition behaviors and biomarkers of malaria status. These model covariates were selected *a priori* based on existing theory of determinants of anemia status in women and children (Bentley & Griffiths, 2003; Tengco, Rayco-Solon, Solon, Sarol, & Solon, 2008). Sociodemographic variables included the age of women and children, the sex of the head of household and children, the education status of women and mothers of children, the total number of household members, household access to an improved water source (WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation) and/or an improved sanitation source (WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation), urban residence of the household, and the wealth status of the household assessed using an asset-based index. Assigned asset weights were generated using a principal components analysis to create standardized asset scores (Rutstein & Johnson, 2004), which were then categorized into quintiles. Additional variables included recent anti-malaria indoor residual spraying of the household, household access to a mosquito bed net for sleeping, current tobacco use among women (Nordenberg, Yip, & Binkin, 1990), weight and parity of women at the time of the interview, and among children, fever or diarrhea in the previous two weeks, consumption of a high-dose vitamin A supplement in the previous six months, consumption of any iron supplement (i.e., pill, sprinkles with iron, or iron syrup) in the previous seven days, provision of any drug for intestinal worms in the last six months, and breastfeeding status (i.e., ever breastfed and not currently breastfeeding, still breastfeeding, or never breastfed). Thick-smear slides of blood from children aged 6-59 months were assessed for malaria parasites via microscopy at the National Public Health Reference Laboratory in Accra. The Noguchi Memorial Institute for Medical Research performed external quality assurance testing for these malaria analyses (Ghana Statistical Service et al., 2015). Data on recent consumption (i.e., previous 24 hours) among children aged 6-59 months of five different categories of ASFs were also assessed. These categories included: 1) any meat, such as beef, pork, lamb, goat, chicken, or duck; 2) liver, kidney, heart or other organ meats; 3) fresh or dried fish or shellfish; 4) eggs; 5) milk, cheese or other food made from milk. Because these dietary data were only available for a sub-sample of children from households that were randomly selected for more extensive interviewing, they were not included as covariates in main analyses, but were rather examined in separate sub-analyses.

Food consumption and expenditure data from the GLSS6 were also analyzed. These data were collected during seven repeat visits to households in a 35-day period. A trained household member recorded daily food consumption and expenditures in a diary that was submitted to a survey enumerator on each visit. In households with no literate members to keep such a diary, an enumerator visited the household daily to record consumption and expenditures (Ghana Statistical Service, 2014). The monetary value of expenditures for 84 purchased food items and of the amount of 62 own-produced foods consumed during the 35-day period was collected as part of the diary. These data were aggregated to calculate the total value of household food consumption and expenditures per adult equivalent based on age- and sex-specific energy requirements (FAO, WHO, & UNU, 2004). The following sociodemographic variables were also included in models using GLSS6 data: sex, age, education level, and employment status of household head; household size; urban location; and quintiles of total household expenditure.

Statistical analysis

All analyses were carried out using the Stata statistical software package version 14.2 (2017; StataCorp, College Station, TX, USA). We used the ‘‘svyset’’ command to identify sampling weights, cluster and strata variables for both the GDHS and GLSS6 data sets. Both data sets required the use of sampling weights to account for the non-proportional allocation of the samples to different regions of the country and to ensure results are representative at the national and domain levels (Ghana Statistical Service et al., 2015). We used the ‘‘svy’’ command in all analyses to estimate Taylor-linearized standard errors that adjust for the multi-stage sampling frames of both the GDHS and GLSS6, as well as intra-household clustering of individuals.

Using GDHS data, means and proportions of key characteristics of households and individuals were calculated separately for samples of women and children. Two-sided Student's t-statistics and Pearson's chi-squared test statistics were also calculated to test for differences in means and proportions, respectively, among households with livestock and with no livestock. Logistic regression was used to model the association of household livestock ownership with anemia among women and children. Adjusted models controlled for the variables described above as well as regional fixed effects. We also examined separate adjusted models that included the interaction of urban location of household, education status of women and mothers of children, access to an improved water source, and access to an improved sanitation source, respectively, with household livestock ownership. We hypothesized, based on previous evidence, that higher education of women and access to improved water and/or sanitation (linked to urban location) may modify the association between livestock and anemia by contributing to improved environmental hygiene, animal management practices, and in turn, decreased exposure to harmful pathogens (Prüss-Ustün et al., 2014; Wagstaff et al., 2004).

We further assessed, using three different approaches, the contribution of ASF consumption as a potential mechanism mediating the association of household livestock ownership with anemia. First, using GDHS data, we examined the association of recent child consumption of ASFs with child anemia, and the association of household livestock ownership with recent consumption of ASFs using multiple logistic regression models. Second, path analysis was used to examine the potential role of ASF consumption among children in mediating the association of livestock ownership with child anemia. In separate models, we calculated standardized path coefficients (i.e., regression coefficients converted to standardized Z-scores) using maximum-likelihood estimation of direct, indirect, and total effects of household livestock ownership on child anemia assessing mediation by consumption of any ASFs, meat, dairy, and organ meats, respectively. Robust standard errors were calculated using the Huber-White sandwich estimator. Third, we examined complementary GLSS6 data to understand the contribution of ASFs to household diets in Ghana, and to examine the association of household livestock ownership with household food consumption and expenditures on ASFs. Using GLSS6 data, the monetary value per adult equivalent of household food consumption and expenditures was calculated. Differences in the value of consumption and expenditures among households with livestock and with no livestock were tested using the Student’s t-statistic. Multiple linear regression analysis, adjusting for the covariates noted above and regional fixed effects, was used to assess the association of household ownership of livestock with the monetary value per adult equivalent of household food consumption and expenditures.

Associations were considered consistent with random variation at $P>0.05$.

Ethical approval

The core data sets of the 2014 GDHS are in the public domain. Access to data for the results of malaria testing among children in the GDHS was obtained with permission from the Survey and Census Directorate of the Ghana Statistical Service. The survey protocol for the 2014 GDHS, including biomarker collection, was reviewed and approved by the Ghana Health Service Ethical Review Committee and the Institutional Review Board of ICF International. The study team was granted access to the GLSS6 data set following a request to the Ghana Statistical Service. Written informed consent of all participants was carried out for both the 2014 GDHS and GLSS6.

RESULTS

In total, 11,835 households and 9,396 women were successfully interviewed for the 2014 GDHS. Data on anemia were available for 4,798 of these women from 3,753 households. We excluded 357 pregnant women from analyses yielding a total sample of 4,441 non-pregnant WRA from 3,480 households. In addition, anemia data were available for 2,735 children aged 6-59 months from 2,085 households. Dietary data were available for 1,373 of these children. In the GLSS6, 16,772 households were surveyed, all of which were included in analyses using this data set (**Supplemental Table 1**).

From the GDHS, 42.3% of women and 65.9% of children were anemic (**Supplemental Table 2**). Among anemic women, most (78.7%) had mild anemia, though among anemic children, moderate anemia was more prevalent than mild anemia (56.4% and 40.2% of anemic children were moderately and mildly anemic, respectively). Among WRA, two-fifths of their households owned livestock (40.5%) (Supplemental Table 2)—a similar percentage to that of households with preschool-aged children (46.4%). The prevalence of anemia among women from households that owned livestock was 43.4% as compared to 41.5% among women from households with no livestock. The prevalence of anemia among children from households that owned livestock was 73.1% as compared to 59.7% among children from households with no livestock.

Household livestock ownership and anemia

In multiple logistic regression analyses using the GDHS data, and adjusting for household socioeconomic status, demographic characteristics, malaria infection among children, regional fixed effects, and other covariates described above, household livestock ownership was not associated with anemia among women (OR (95% CI): 1.0 (0.83, 1.2)), but was associated with anemia among children (1.5 (1.1, 2.0)) (**Table 1**). This child-level association persisted after adjusting models for diet diversity among the sub-sample of children for whom these dietary data were collected (1.6 (1.0, 2.4)) (**Supplemental Table 3**). In separate models, we observed no statistical interaction of urban location of household, education status of women or mothers of children, or access to an improved water or sanitation source, respectively, with household livestock ownership (**Supplemental Table 4**).

In sub-analyses, again using multiple logistic regression models with GDHS data, the association of household ownership of specific livestock species with anemia among women and children, respectively, was assessed. Only chicken ownership was associated with higher odds of anemia, and only among children, both from households owning chickens and other livestock (1.6 (1.2, 2.2)) and from households owning chickens and no other livestock (1.9 (1.3, 2.6)) (**Table 2**).

Consumption of ASFs and associations with livestock ownership and anemia

Examining the GLSS6 data, ASFs contributed more than a quarter (28.3%) of the value of all household food consumption and expenditures, and 10% of the value of food consumed from own production (**Table 3; Supplemental Table 5**). Fish accounted for most of the value of total household consumption and expenditure on ASFs (58.4%), while chicken meat and eggs accounted for 11.8% and 4.9%, respectively. Complementary descriptive data from the GDHS indicated that 39.8% of children aged 6-59 months consumed fish in the past 24 hours, while 11.4% consumed any meat (i.e., beef, pork, lamb, goat, chicken, or duck), 16.7% consumed eggs, and 2.1% consumed dairy (Supplemental Table 2). From the GLSS6, the value of household consumption and expenditures for all foods, all ASFs, and all categories of ASFs (except chicken) was higher among households that did not own livestock as compared to households with livestock ($P<0.05$) (Table 3). Similarly, the value of expenditures on all purchased food, ASFs, and all categories of ASFs was also higher among households that did not own livestock as compared to households with livestock (*P*<0.05) (Supplemental Table 5).

In multiple linear regression models using GLSS6 data, livestock ownership was associated with a higher value of household food consumption and expenditures per adult equivalent of all food (partial regression coefficient (95% CI): 26.1 (17.9, 34.3)); ASFs (6.8 (4.1, 9.6)); chicken meat (2.0 (1.4, 2.6)); and fish (3.2 (1.8, 4.6)) (**Table 4**, **Supplemental Table 6**). Ownership of chickens was associated with a higher value of household food consumption and expenditures per adult equivalent of chicken meat (2.6 (1.9, 3.2)) and eggs (0.14 (0.00, 0.28)). Similarly, ownership of chickens was associated with a higher value of household food consumption from own production per adult equivalent of chicken meat (3.2 (2.7, 3.7)) and eggs (0.46 (0.37, 0.55)) (Supplemental Table 6). Using data from the 2014 GDHS, in multiple logistic regression models, the associations of household ownership of any livestock or specific animals (i.e., cattle, sheep, goats, pigs, and chicken) with recent consumption of different ASFs (i.e., meat, fish, eggs, dairy, and organ meats) by children aged 6-59 months were all consistent with random variation.

Using GDHS data, children who recently consumed organ meat had lower odds of anemia (0.43 (0.19, 0.99), while recent consumption of dairy was marginally associated with higher odds of anemia (2.1 (0.95, 4.8) (*P*=0.07)). The associations of recent consumption of all other ASFs with anemia among children were consistent with random variation. In path analyses, we similarly observed no evidence of mediation of the association of livestock ownership with child anemia by consumption of ASFs (**Supplemental Figure 1; Supplemental Table 7**). The indirect effect of household livestock ownership on child anemia as mediated by consumption of ASFs was consistent with random variation in models examining children's recent consumption of any ASFs, meat, dairy, and organ meats, respectively.

DISCUSSION

Independent of socioeconomic status and infection indicators, livestock ownership in Ghana was associated with higher odds of anemia among children aged 6-59 months, but not among WRA. In particular, household ownership of chickens was associated with higher odds of anemia among children. Ownership of no other animal species was independently associated with anemia among either women or children. Except for fish, all other ASF types individually contributed <5% of the value of total household food consumption and expenditures, and all own produced ASFs contributed <2% of this value. Children from households that owned livestock were not more likely to have recently consumed ASFs. Furthermore, recent consumption of ASFs was not associated with lower odds of anemia among children except for consumption of organ meat, and we observed no evidence of mediation of the association of household livestock ownership with child anemia by ASF consumption. Therefore, while livestock ownership was associated with a higher value of household ASF consumption and expenditures, livestock ownership may have limited importance for ASF consumption among young children in Ghana and is most strongly associated with anemia through non-nutritional pathways.

Livestock serve many different functions among households in LMICs (Randolph et al., 2007); use of animals for direct consumption is often a low priority use. Some evidence suggests that livestock ownership translates into increased consumption of dairy and meat (Azzarri, Zezza, Haile, & Cross, 2015; Rawlins, Pimkina, Barrett, Pedersen, & Wydick, 2014). However, keeping livestock or enhancing livestock productivity does not guarantee increased consumption of ASFs, particularly if the livestock are predominantly sold for income (Hoffman, Riethmuller, & Steane, 2003). Furthermore, ASFs vary with respect to their potential to mitigate anemia. Organ meat and whole fish are rich sources of bioavailable iron and vitamin A which can mitigate anemia (Neumann, Harris, & Rogers, 2002), though there is little evidence of this potential for eggs and unfortified dairy (Dror & Allen, 2011; Shapira, 2009). At the same time, eggs and dairy are the ASFs most likely to be produced for own consumption among households that keep livestock (Wilson et al., 2005). If not iron fortified (Stekel et al., 1988; Villalpando, Shamah, Rivera, Lara, & Monterrubio, 2006), cow's milk may actually increase anemia (Oliveira & Osório, 2005; Ziegler, 2011). Indeed, recent consumption of dairy by Ghanaian children in this study showed a trend consistent with higher odds of anemia. Though plausible that differences in ethnicity or cultural traditions that are also associated with food access and distinct feeding behaviors may underlie this observed trend, we found that neither ethnic group nor region were associated with dairy consumption in this study (data not shown). However, we cannot rule out reverse causality as an explanation for the observed trend between dairy consumption and anemia among children (i.e., caregivers may preferentially feed cow's milk or other dairy foods to undernourished, anemic children) (Marquis, Habicht, Lanata, Black, & Rasmussen, 1997).

Household ownership of chickens, but no other livestock type, was independently associated with increased odds of anemia among young children. The magnitude of this association was even stronger among households that owned no other livestock but chickens. The small number of households that owned dairy cattle and pigs limited the statistical power available to assess associations among these two animal groupings. However, this is not a likely explanation for the associations examined with small ruminants (i.e., nearly one-third and one-half of households owned sheep and goats, respectively), and does not explain the statistically significant associations observed for poultry ownership. Evidence from other settings indicates that corralling poultry inside human dwellings is associated with lower child height-for-age Z-score (George, Oldja, Biswas, Perin, Lee, Ahmed, et al., 2015; Headey & Hirvonen, 2016; Weisz et al., 2012). Young children in close contact with chickens are known to handle or even consume chicken feces and contaminated soil, which may increase infections of pathogenic bacteria (e.g., *Campylobacter jejuni*, *Escherichia coli*) (George, Oldja, Biswas, Perin, Lee, Kosek, et al., 2015; Marquis et al., 1990; Ngure et al., 2013). Such infections are a major cause of childhood diarrhea in LMICs (Guerrant, Hughes, Lima, & Crane, 1990). Asymptomatic infections may also impair child growth (Kotloff et al., 2013; Lee et al., 2013), possibly due to changes in intestinal structure and barrier function brought about by repeated exposure to enteric pathogens (Campbell, Elia, & Lunn, 2003; Lin et al., 2013). The same inflammation-mediated mechanisms via which this gut disorder—termed environmental enteric dysfunction (EED)—is thought to stunt linear growth (Humphrey, 2009; Prendergast et al., 2014), could be integral to its role in the etiology of anemia in children (Morceau, Dicato, & Diederich, 2009; Prendergast et al., 2015). If children are especially susceptible to the pathogenic bacteria associated with livestock production (Osbjer et al., 2016; Vasco, Graham, & Trueba, 2016), this may explain why children, but not women, from livestock owning households were more likely to be anemic.

The observed association of livestock ownership with child anemia was independent of infection with malaria parasites. Much previous evidence suggests that malaria is an important determinant of anemia among children in this population (Ehrhardt et al., 2006; Korenromp, Armstrong-Schellenberg, Williams, Nahlen, & Snow, 2004; Wirth et al., 2016). *Plasmodium* parasites simultaneously consume heme, remove circulating erythrocytes, and decrease production of erythrocytes in bone marrow, thus inducing or exacerbating anemia (Haldar & Mohandas, 2009). However, the extent to which animal husbandry may alter malaria risk is not clear, and both zooprophylactic and zoopotentiating effects have been observed depending on the preference of local mosquito species for human hosts, livestock distance from human sleeping quarters, and the use of protective measures (Asale, Duchateau, Devleesschauwer, Huisman, &

Yewhalaw, 2017; Donnelly, Berrang-Ford, Ross, & Michel, 2015). Most studies assessing the relationship between livestock keeping and malaria have examined the rearing of cattle and small ruminants with almost no evidence supporting a biological mechanism linking exposure to chickens and risk of malaria (Donnelly et al., 2015; Jaleta, Hill, Birgersson, Tekie, & Ignell, 2016). Therefore, malaria was not hypothesized to be on the causal pathway between chicken ownership and anemia. Rather, we adjusted for it in regression models as a confounder because it is a known independent determinant of anemia among children in this population. Given that the association between household livestock ownership and child anemia was observed independent of the malaria status of children, and that no evidence was observed for mediation of this association by diet, it is plausible that other infections, possibly asymptomatic, related to livestock keeping and poultry rearing in particular, may in part underlie the observed results.

Although this study used large, nationally representative data sets and adjusted for many potentially confounding covariates, there are several limitations. First, the data were observational and collected at a single time points. Therefore, though multiple regression models were used to control for confounding bias, we cannot strictly determine the causal nature or temporal patterns of the observed associations. Second, dietary data in the 2014 GDHS were limited to a qualitative assessment of food group diversity among a sub-sample of children. These data were not strong predictors of anemia status, and including dietary variables in regressions did not alter the observed associations of livestock and anemia. However, it is possible that quantitative diet data for all children would have yielded different results, particularly if the amount of ASF consumed, and not simply the presence of ASFs in diet, is an important determinant of anemia status among children. Indeed, ASFs included in family meals in Ghana are frequently consumed by children only in small amounts (Colecraft et al., 2006). Furthermore, dietary data based on a single 24-hour recall period are not necessarily representative of a child's usual diet. In addition, child diets and caregiver feeding practices differ for infants as compared to children nearing school age. These differences could alter the magnitude of or mechanisms underlying the association of household livestock ownership with anemia. However, we did not find any evidence of child age acting as an effect modifier of this association (data not shown), and therefore analyses were presented in aggregate for all preschool-aged children. Third, it is possible that the observed association between livestock ownership and anemia is confounded by household wealth. The proportion of poultry-owning households increased in a linear fashion with decreasing wealth quintile among both the samples of women and children in the 2014 GDHS (data not shown). Yet, the observed association of livestock ownership and anemia was independent of household wealth, and when examining this association stratified by wealth quintiles, no differences across quintiles were observed (data not shown). The contrasting results for the associations of livestock and anemia among women and children also suggest that wealth may not be responsible for the observed associations given that women and children are both vulnerable to the deleterious effects of poverty. Nonetheless, residual confounding by household economic status cannot be ruled out in these analyses.

Fourth, although our models control for recent treatment for intestinal worms, no data were available in the 2014 GDHS for current helminth infection in children at the time of the survey, nor were data available to assess iron deficiency in children or women, nor to consider genetic blood disorders such as Thalassemia—a potentially important causal factor for anemia in West African populations (Weatherall, 2001). We also had no information from the available data sets on where animals were housed, and therefore, could not assess differences in anemia among women and children from households that corral animals inside living quarters compared to those that do not. Fifth, the GLSS6 only provided data on the value of household consumption and expenditures, and therefore, individual food intake data could not be analyzed. Nonetheless, though data from consumption and expenditures surveys are not a direct assessment of individual dietary intake, such data do produce nutrient intake estimates that are strongly associated with nutrient intake estimates from dietary intake surveys (Jariseta, Dary, Fiedler, & Franklin, 2012; Naska, Vasdekis, & Trichopoulou, 2001). Furthermore, analyzing these data on a per adult equivalent basis accounts for intra-household differences in energy and nutrient needs based on household composition and allows for more consistent comparisons across households (Claro, Levy, Bandoni, & Mondini, 2010). Sixth, assessing livestock ownership in a binary fashion could mask heterogeneity important for understanding the association of livestock ownership with anemia. In addition to the analyses presented in this study, we also evaluated livestock as a continuous count variable and as livestock units based on animal body weight (Jahnke, 1982). In both cases, we observed similar, though somewhat attenuated magnitudes of association between livestock ownership and anemia as those using the binary livestock ownership variable (data not shown). Including squared terms for these continuous livestock variables in models provided no evidence of non-linearity in the association of livestock ownership and anemia. Given these results, the binary livestock ownership variable assessed is likely appropriate for representing these relationships, and also aligns with the specification of variables in other similar studies (Flores-Martinez et al., 2016; Iannotti et al., 2015). Finally, though we analyzed anemia among women and children in separate models, it is possible to treat these dependent variables as correlated responses and analyze them using bivariate mixed models. This approach could be explored in future research.

CONCLUSION

Progress in reducing anemia in Ghana, as in most LMICs, has been slow, and large numbers of women and children continue to suffer from the disease (i.e., 45% and 42% of WRA, and 76% and 66% of children aged 6-59 months in Ghana were anemic in 2003 and 2014, respectively (Ghana Statistical Service et al., 2015)). Novel interventions that address the underlying environmental determinants of anemia are needed to complement existing approaches that largely center on addressing proximal causes of the problem (i.e., control of malaria and helminth infections, and nutritional deficiencies) (SPRING & Ghana Health Service, 2016). Exposure to livestock may be one such environmental determinant that is especially important for influencing anemia risk among children; however, the mechanisms underlying this association are complex, possibly contradictory, and require further clarification. Improved hygiene and sanitation practices can positively impact child health (Curtis & Cairncross, 2003; Esrey, 1996), though emerging evidence suggests that improving such practices alone may not be sufficient to resolve poor health outcomes among children (Luby, 2017). Reducing contact with chicken feces may be especially important, though the barriers to doing so could be substantial. Corralling chickens, for example, can incur added costs for feed and coop materials, and/or additional labor burdens—all of which may be difficult for low-income families to bear (Harvey et al., 2003; Martinez et al., 2013). Corralling chickens may also concentrate pathogens, thus leading to greater infection (Oberhelman et al., 2006). Furthermore, if infection risk is predominantly driven by contact with neighboring animals, local corralling may not address the problem (Oberhelman et al., 2003). Research is needed that jointly assesses the diverse direct and indirect pathways linking livestock and anemia (e.g., diet; exposure to animal feces, animal slaughter waste (Osbjer et al., 2016), and zoonotic pathogens linked to livestock disease (Mosites et al., 2016)); altering human-vector interactions (Donnelly et al., 2015)). Understanding the relative importance of these factors across contexts, and their relationships will help to elucidate the complex etiology of anemia among agricultural households and inform solutions that maximize the potential dietary benefits of animal production while minimizing disease risks.

REFERENCES

Ahenkorah, B., Nsiah, K., & Baffoe, P. (2016). Sociodemographic and Obstetric Characteristics of Anaemic Pregnant Women Attending Antenatal Clinic in Bolgatanga Regional Hospital. Scientifica, 2016, 1-8.

Asale, A., Duchateau, L., Devleesschauwer, B., Huisman, G., & Yewhalaw, D. (2017). Zooprophylaxis as a control strategy for malaria caused by the vector Anopheles arabiensis (Diptera: Culicidae): a systematic review. Infect Dis Poverty, 6, 160.

Azzarri, C., Zezza, A., Haile, B., & Cross, E. (2015). Does Livestock Ownership Affect Animal Source Foods Consumption and Child Nutritional Status? Evidence from Rural Uganda. Journal of Development Studies, 51, 1034-1059.

Balarajan, Y., Ramakrishnan, U., Ozaltin, E., Shankar, A. H., & Subramanian, S. V. (2011). Anaemia in low-income and middle-income countries. Lancet, 378, 2123-2135.

Bentley, M. E., & Griffiths, P. L. (2003). The burden of anemia among women in India. Eur J Clin Nutr, 57, 52-60.

Burkot, T. R., Dye, C., & Graves, P. M. (1989). An analysis of some factors determining the sporozoite rates, human blood indexes, and biting rates of members of the Anopheles punctulatus complex in Papua New Guinea. Am J Trop Med Hyg, 40, 229-234.

Campbell, D. I., Elia, M., & Lunn, P. G. (2003). Growth faltering in rural Gambian infants is associated with impaired small intestinal barrier function, leading to endotoxemia and systemic inflammation. J Nutr, 133, 1332-1338.

Claro, R. M., Levy, R. B., Bandoni, D. H., & Mondini, L. (2010). Per capita versus adult-equivalent estimates of calorie availability in household budget surveys. Cad Saude Publica, 26, 2188-2195.

Colecraft, E., Marquis, G. S., Aryeetey, R., Sakyi-Dawson, O., Lartey, A., Ahunu, B., ... Huff-Lonergan, E. (2006). Constraints on the Use of Animal Source Foods for Young Children in Ghana: A Participatory Rapid Appraisal Approach. Ecology of Food and Nutrition, 45, 351-377.

Curtis, V., & Cairncross, S. (2003). Effect of washing hands with soap on diarrhoea risk in the community: a systematic review. Lancet Infect Dis, 3, 275-281.

Donnelly, B., Berrang-Ford, L., Ross, N. A., & Michel, P. (2015). A systematic, realist review of zooprophylaxis for malaria control. Malar J, 14, 313.

Dror, D. K., & Allen, L. H. (2011). The importance of milk and other animal-source foods for children in low-income countries. Food Nutr Bull, 32, 227-43.

Ehrhardt, S., Burchard, G. D., Mantel, C., Cramer, J. P., Kaiser, S., Kubo, M., ... Mockenhaupt, F. P. (2006). Malaria, anemia, and malnutrition in african children-defining intervention priorities. J Infect Dis, 194, 108-114.

Esrey, S. A. (1996). Water, Waste, and Well-Being: A Multicountry Study. American Journal of Epidemiology, 143, 608-623.

Ezzati, M., Lopez, A.D., Rodgers, A.A., & Murray, C.J.L. (2004). Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors. Geneva, Switzerland: World Health Organization.

FAO, WHO, & UNU. (2004). Human energy requirements. Report of a Joint FAO/WHO/UNU Expert Consultation. Rome, Italy: FAO.

Flores-Martinez, A., Zanello, G., Shankar, B., & Poole, N. (2016). Reducing Anemia Prevalence in Afghanistan: Socioeconomic Correlates and the Particular Role of Agricultural Assets. PLOS ONE, 11, e0156878.

Galal, O. M., Harrison, G. G., Abdou, A. I., & Zein el Abedin, A. (1987). The impact of a small-scale agricultural intervention on socio-economic and health status. Food Nutr (Roma), 13, 35-43.

George, C. M., Oldja, L., Biswas, S., Perin, J., Lee, G. O., Kosek, M., ... Faruque, A. G. (2015). Geophagy is associated with environmental enteropathy and stunting in children in rural Bangladesh. Am J Trop Med Hyg, 92, 1117-1124.

George, C. M., Oldja, L., Biswas, S. K., Perin, J., Lee, G. O., Ahmed, S., ... Faruque, A. G. (2015). Fecal Markers of Environmental Enteropathy are Associated with Animal Exposure and Caregiver Hygiene in Bangladesh. Am J Trop Med Hyg, 93, 269-275.

Ghana Statistical Service. (2014). Ghana Living Standards Survey Round 6 Main Report. Accra, Ghana: Ghana Statistical Service.

Ghana Statistical Service, Ghana Health Service, & ICF International. (2015). Ghana Demographic and Health Survey 2014. Rockville, MD: ICF International.

Guerrant, R. L., Hughes, J. M., Lima, N. L., & Crane, J. (1990). Diarrhea in developed and developing countries: magnitude, special settings, and etiologies. Rev Infect Dis, 12, S41-50.

Haldar, K., & Mohandas, N. (2009). Malaria, erythrocytic infection, and anemia. Hematology Am Soc Hematol Educ Program, 87-93.

Harvey, S. A., Winch P. J., Leontsini, E., Torres Gayoso, C., Lopez Romero, S., Gilman, R. H., & Oberhelman, R. A. (2003). Domestic poultry-raising practices in a Peruvian shantytown: implications for control of Campylobacter jejuni-associated diarrhea. Acta Trop, 86, 41-54.

Headey, D., & Hirvonen, K. (2016). Is Exposure to Poultry Harmful to Child Nutrition? An Observational Analysis for Rural Ethiopia. PLOS ONE, 11, e0160590.

Headey, D., Nguyen, P., Kim, S., Rawat, R., Ruel, M., & Menon, P. (2017). Is Exposure to Animal Feces Harmful to Child Nutrition and Health Outcomes? A Multicountry Observational Analysis. Am J Trop Med Hyg, 96, 961-969.

Herrero, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S., & Rufino, M. C. (2013). The roles of livestock in developing countries. Animal, 7 Suppl 1, 3-18.

Hoffman D, Riethmuller P, & Steane D. (2003). Some issues associated with the livestock industries of the developing countries of Asia: Opening Pandora's Box. J Food Agric Environ, 1, 148-154.

Horton, S., & Ross, J. (2003). The economics of iron deficiency. Food Policy, 28(1), 51-75.

Humphrey, J. H. (2009). Child undernutrition, tropical enteropathy, toilets, and handwashing. Lancet, 374, 1032-1035.

Hurrell, R. F., Reddy, M. B., Juillerat, M., & Cook, J. D. (2006). Meat protein fractions enhance nonheme iron absorption in humans. J Nutr, 136, 2808-2812.

Iannotti, L. L., Delnatus, J. R., Odom, A. R., Eaton, J. C., Griggs, J. J., Brown, S., & Wolff, P. B. (2015). Determinants of Anemia and Hemoglobin Concentration in Haitian School-Aged Children. Am J Trop Med Hyg, 93, 1092-1098.

Jahnke H.E. (1982). Livestock production systems and livestock development in tropical Africa. Kiel: Kieler Wissenschaftsverlag Vauk.

Jaleta, K. T., Hill, S. R., Birgersson, G., Tekie, H., & Ignell, R. (2016). Chicken volatiles repel host-seeking malaria mosquitoes. Malar J, 15, 354.

Jariseta, Z. R., Dary, O., Fiedler, J. L., & Franklin, N. (2012). Comparison of estimates of the nutrient density of the diet of women and children in Uganda by Household Consumption and Expenditures Surveys (HCES) and 24-hour recall. Food Nutr Bull, 33, S199-207.

Korenromp, E.L., Armstrong-Schellenberg, J.R.M., Williams, B.G., Nahlen, B.L., & Snow, R.W. (2004). Impact of malaria control on childhood anaemia in Africa – a quantitative review. Trop Med Int Health, 9, 1050–1065.

Kotloff, K. L., Nataro, J. P., Blackwelder, W. C., Nasrin, D., Farag, T. H., Panchalingam, S., ... Levine, M. M. (2013). Burden and aetiology of diarrhoeal disease in infants and young children in developing countries (the Global Enteric Multicenter Study, GEMS): a prospective, case-control study. Lancet, 382, 209-222.

Lee, G., Pan, W., Peñataro Yori, P., Paredes Olortegui, M., Tilley, D., Gregory, M., ... Kosek, M. (2013). Symptomatic and Asymptomatic Campylobacter Infections Associated with Reduced Growth in Peruvian Children. PLoS Neglected Tropical Diseases, 7, e2036.

Leroy JL, & Frongillo EA. (2007). Can Interventions to Promote Animal Production Ameliorate Undernutrition? J Nutr, 137, 2311-2316.

Lin, A., Arnold, B. F., Afreen, S., Goto, R., Huda, T. M., Haque, R., ... Luby, S. P. (2013). Household environmental conditions are associated with enteropathy and impaired growth in rural Bangladesh. Am J Trop Med Hyg, 89, 130-137.

Lozoff, B., Beard, J., Connor, J., Barbara, F., Georgieff, M., & Schallert, T. (2006). Long-lasting neural and behavioral effects of iron deficiency in infancy. Nutrition, 64, S34-43.

Lozoff, B., Jimenez, E., Hagen, J., Mollen, E., & Wolf, A. W. (2000). Poorer Behavioral and Developmental Outcome More Than 10 Years After Treatment for Iron Deficiency in Infancy. Pediatrics, 105, e51.

Luby, S.P. (2017). Results From WASH-Benefits Bangladesh on Child Growth, Diarrheal Disease and Cognitive Development. Paper presented at Experimental Biology, Chicago, IL.

Marquis, G.S., Habicht, J.P., Lanata, C.F., Black, R.E., & Rasmussen, K.M. (1997). Association of breastfeeding and stunting in Peruvian toddlers: an example of reverse causality. Int J Epidemiol, 26, 349-356.

Marquis, G. S., Ventura, G., Gilman, R. H., Porras, E., Miranda, E., Carbajal, L., & Pentafiel, M. (1990). Fecal contamination of shanty town toddlers in households with non-corralled poultry, Lima, Peru. Am J Public Health, 80, 146-149.

Martinez, L., Collazo, G., Cabrera, L., Bernabe-Ortiz, A., Ramos-Peña, Y., & Oberhelman, R. (2013). Free-Ranging Chickens in Households in a Periurban Shantytown in Peru—Attitudes and Practices 10 Years after a Community-Based Intervention Project. Am J Trop Med Hyg, 89, 229-231.

Miller, E. M. (2010). Maternal hemoglobin depletion in a settled northern Kenyan pastoral population. Am J Hum Biol, 22, 768-774.

Minakawa, N., Mutero, C. M., Githure, J. I., Beier, J. C., & Yan, G. (1999). Spatial distribution and habitat characterization of anopheline mosquito larvae in Western Kenya. Am J Trop Med Hyg, 61, 1010-1016.

Moore, C. E., Nget, P., Saroeun, M., Kuong, S., Chanthou, S., Kumar, V., ... Parry, C. M. (2015). Intestinal Parasite Infections in Symptomatic Children Attending Hospital in Siem Reap, Cambodia. PLOS ONE, 10, e0123719.

Morceau, F., Dicato, M., & Diederich, M. (2009). Pro-Inflammatory Cytokine-Mediated Anemia: Regarding Molecular Mechanisms of Erythropoiesis. Mediators of Inflammation, 2009, 11. doi.10.1155/2009/405016.

Mosites, E., Thumbi, S. M., Otiang, E., McElwain, T. F., Njenga, M. K., Rabinowitz, P. M., ... Walson, J. L. (2016). Relations between Household Livestock Ownership, Livestock Disease, and Young Child Growth. J Nutr 146, 1118-1124.

Murphy, S. P., & Allen, L. H. (2003). Nutritional Importance of Animal Source Foods. J Nutr, 133, 3932S-3935S.

Naska, A., Vasdekis, V. G., & Trichopoulou, A. (2001). A preliminary assessment of the use of household budget survey data for the prediction of individual food consumption. Public Health Nutr, 4, 1159-1165.

Neumann, C., Harris, D. M., & Rogers, L. M. (2002). Contribution of animal source foods in improving diet quality and function in children in the developing world. Nutrition Research, 22, 193-220.

Ngure, F. M., Humphrey, J. H., Mbuya, M. N. N., Majo, F., Mutasa, K., Govha, M., ... Stoltzfus, R. J. (2013). Formative Research on Hygiene Behaviors and Geophagy among Infants and Young Children and Implications of Exposure to Fecal Bacteria. Am J Trop Med Hyg 89, 709-716.

Nordenberg, D., Yip, R., & Binkin, N. J. (1990). The effect of cigarette smoking on hemoglobin levels and anemia screening. JAMA, 264, 1556-1559.

Oberhelman, R. A., Gilman, R. H., Sheen, P., Cordova, J., Taylor, D. N., Zimic, M., ... Price, L. J. (2003). Campylobacter transmission in a Peruvian shantytown: a longitudinal study using strain typing of campylobacter isolates from chickens and humans in household clusters. J Infect Dis, 187, 260-269.

Oberhelman, R. A., Gilman, R. H., Sheen, P., Cordova, J., Zimic, M., Cabrera, L., ... Perez, J. (2006). An intervention-control study of corralling of free-ranging chickens to control Campylobacter infections among children in a Peruvian periurban shantytown. Am J Trop Med Hyg 74, 1054-1059.

Oliveira, M. A. A., & Osório, M. M. (2005). Consumo de leite de vaca e anemia ferropriva na infância. J Pediatr (Rio J), 81, 361-367.

Olney, D. K., Pedehombga, A., Ruel, M. T., & Dillon, A. (2015). A 2-Year Integrated Agriculture and Nutrition and Health Behavior Change Communication Program Targeted to Women in Burkina Faso Reduces Anemia, Wasting, and Diarrhea in Children 3–12.9 Months of Age at Baseline: A Cluster-Randomized Controlled Trial. J Nutr. doi: 10.3945/jn.114.203539.

Olney, D. K., Talukder, A., Iannotti, L. L., Ruel, M. T., & Quinn, V. (2009). Assessing impact and impact pathways of a homestead food production program on household and child nutrition in Cambodia. Food Nutr Bull, 30, 355-369.

Osbjer, K., Boqvist, S., Sokerya, S., Chheng, K., San, S., Davun, H., ... Magnusson, U. (2016). Risk factors associated with Campylobacter detected by PCR in humans and animals in rural Cambodia. Epidemiol Infect, 144, 2979-2988.

Osei, A., Pandey, P., Nielsen, J., Pries, A., Spiro, D., Davis, D., ... Haselow, N. (2016). Combining Home Garden, Poultry, and Nutrition Education Program Targeted to Families With Young Children Improved Anemia Among Children and Anemia and Underweight Among Nonpregnant Women in Nepal. Food Nutr Bull, 38, 49-64.

Pasricha, S. R., Drakesmith, H., Black, J., Hipgrave, D., & Biggs, B. A. (2013). Control of iron deficiency anemia in low- and middle-income countries. Blood, 121, 2607-2617.

Petry, N., Olofin, I., Hurrell, R. F., Boy, E., Wirth, J. P., Moursi, M., ... Rohner, F. (2016). The Proportion of Anemia Associated with Iron Deficiency in Low, Medium, and High Human Development Index Countries: A Systematic Analysis of National Surveys. Nutrients, 8. doi:10.3390/nu8110693.

Prendergast, A. J., Humphrey, J. H., Mutasa, K., Majo, F. D., Rukobo, S., Govha, M., ... Stoltzfus, R. J. (2015). Assessment of Environmental Enteric Dysfunction in the SHINE Trial: Methods and Challenges. Clin Infect Dis, 61, S726-732.

Prendergast, A. J., Rukobo, S., Chasekwa, B., Mutasa, K., Ntozini, R., Mbuya, M. N. N., ... Humphrey, J. H. (2014). Stunting is characterized by chronic inflammation in Zimbabwean infants. PLOS ONE. doi:10.1371/journal.pone.0086928.

Prüss-Ustün, A., Bartram, J., Clasen, T., Colford, J. M., Cumming, O., Curtis, V., ... Cairncross, S. (2014). Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: a retrospective analysis of data from 145 countries. Tropical Medicine & International Health, 19, 894-905.

Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., ... Ruel, M. (2007). Invited review: Role of livestock in human nutrition and health for poverty reduction in developing countries. J Anim Sci, 85, 2788-2800.

Rawlins, R., Pimkina, S., Barrett, C. B., Pedersen, S., & Wydick, B. (2014). Got milk? The impact of Heifer International’s livestock donation programs in Rwanda on nutritional outcomes. Food Policy, 44, 202-213.

Rutstein, S.O., & Johnson, K. (2004). The DHS Wealth Index. Calverton, MD: ORC Macro.

Shapira, N. (2009). Modified egg as a nutritional supplement during peak brain development: a new target for fortification. Nutr Health, 20, 107-118.

SPRING, & Ghana Health Service. (2016). Ghana: Landscape Analysis of Anemia and Anemia Programming. Arlington, VA: SPRING.

Stekel, A., Olivares, M., Cayazzo, M., Chadud, P., Llaguno, S., & Pizarro, F. (1988). Prevention of iron deficiency by milk fortification. II. A field trial with a full-fat acidified milk. Am J Clin Nutr, 47, 265-269.

Stevens, G. A., Finucane, M. M., De-Regil, L. M., Paciorek, C. J., Flaxman, S. R., Branca, F., ... Ezzati, M. (2013). Global, regional, and national trends in haemoglobin concentration and prevalence of total and severe anaemia in children and pregnant and non-pregnant women for 1995–2011: a systematic analysis of population-representative data. Lancet Global Health, 1, e16-e25.

Tengco, L. W., Rayco-Solon, P., Solon, J. A., Sarol, J. N., Jr., & Solon, F. S. (2008). Determinants of anemia among preschool children in the Philippines. J Am Coll Nutr, 27, 229-243.

Vasco, K., Graham, J. P., & Trueba, G. (2016). Detection of Zoonotic Enteropathogens in Children and Domestic Animals in a Semirural Community in Ecuador. Applied and Environmental Microbiology, 82, 4218-4224.

Villalpando, S., Shamah, T., Rivera, J. A., Lara, Y., & Monterrubio, E. (2006). Fortifying milk with ferrous gluconate and zinc oxide in a public nutrition program reduced the prevalence of anemia in toddlers. J Nutr, 136, 2633-2637.

Wagstaff, A., Bustreo, F., Bryce, J., Claeson, M., the WHO–World Bank Child Health and Poverty Working. (2004). Child Health: Reaching the Poor. Am J Public Health, 94, 726-736.

Weatherall, D.J. (2001). The thalassemias. In Beutler B, Lichtman, M.A., Coller, B.S., Kipps, T.J., & Seligsohn, S. (Eds.), Williams Hematology (Vol. 6th ed., pp. 562–564). New York, NY: McGraw-Hill.

Weiss, G., & Goodnough, L. T. (2005). Anemia of chronic disease. N Engl J Med, 352, 1011-1023.

Weisz, A. J., Manary, M. J., Stephenson, K., Agapova, S., Manary, F. G., Thakwalakwa, C., ... Manary, M. J. (2012). Abnormal gut integrity is associated with reduced linear growth in rural Malawian children. J Pediatr Gastroenterol Nutr, 55, 747-750.

WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation. Improved and unimproved water sources and sanitation facilities. Retrieved from https://www.wssinfo.org/definitions-methods/watsan-categories/.

WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation. Millennium Development Goals Indicators. Proportion of population using an improved drinking water source. Retrieved from https://millenniumindicators.un.org/unsd/mdg/Metadata.aspx?IndicatorId=30.

Wilson, T., Pearson, A., Bradbear, N., Jayasuriya, A., Laswai, H., Mtenga, L., ... Smith, R. (2005). Livestock products–Valuable and more valuable. In Owen, E.A., Kitalyi, A., Jayasuriya, N., & Smith, T. (Eds.), Livestock and Wealth Creation: Improving the Husbandry of Animals Kept by Resource-Poor People in Developing Countries (pp. 109–126). Nottingham, UK: Nottingham University Press.

Wirth, J. P., Rohner, F., Woodruff, B. A., Chiwile, F., Yankson, H., Koroma, A. S., ... Hodges, M. H. (2016). Anemia, Micronutrient Deficiencies, and Malaria in Children and Women in Sierra Leone Prior to the Ebola Outbreak - Findings of a Cross-Sectional Study. PLOS ONE, 11, e0155031.

World Health Organization. (2011). Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity. Geneva, Switzerland: World Health Organization.

World Health Organization. (2015). The global prevalence of anaemia in 2011. Geneva, Switzerland: World Health Organization.

Zambrano, L. D., Levy, K., Menezes, N. P., & Freeman, M. C. (2014). Human diarrhea infections associated with domestic animal husbandry: a systematic review and meta-analysis. Trans R Soc Trop Med Hyg, 108, 313-325.

Ziegler, E. E. (2011). Consumption of cow's milk as a cause of iron deficiency in infants and toddlers. Nutr Rev, 69, S37-42.

Table 1. Results of unadjusted and adjusted logistic regression analyses for the association of household livestock ownership with anemia among non-pregnant women aged 15-49 years and children aged 6-59 months, respectively.

	Women aged 15-49 years	Children aged 6-59 months
	OR (95% CI)	OR (95% CI)
Unadjusted associations		
Household livestock ownership	1.1 (0.93, 1.3)	1.8*** (1.5, 2.3)
Adjusted associations		
Household livestock ownership	1.0 (0.83, 1.2)	1.5** (1.1, 2.0)
Household size	0.99 (0.96, 1.0)	1.0 (0.99, 1.1)
Age, years	0.99* (0.98, 0.99)	.
Age, months	.	0.97*** (0.96, 0.98)
Sex of head of household		
Male (reference)	.	.
Female	0.90 (0.75, 1.1)	1.4* (1.0, 1.9)
Sex of child	.	
Male (reference)	.	.
Female	.	0.94 (0.74, 1.2)
Highest attained education level of woman		
No education (reference)	.	.
Incomplete or complete primary	0.87 (0.69, 1.1)	.
Incomplete or complete secondary	0.81* (0.66, 0.99)	.
Education beyond secondary	0.58** (0.39, 0.87)	.
Highest attained education level of mother		
No education (reference)	.	.
Incomplete or complete primary	.	0.70* (0.50, 0.99)
Incomplete or complete secondary	.	0.60** (0.44, 0.83)
Education beyond secondary	.	0.42* (0.18, 0.99)
Location of household residence		
Urban (reference)	.	.
Rural	0.81* (0.68, 0.96)	0.95 (0.69, 1.3)
Wealth quintiles		
Lowest (reference)	.	.
Low	1.1 (0.86, 1.4)	1.1 (0.77, 1.7)
Middle	0.87 (0.67, 1.1)	0.73 (0.50, 1.1)
High	0.76 (0.57, 1.0)	0.91 (0.58, 1.4)
Highest	0.67* (0.50, 0.91)	0.77 (0.46, 1.3)
Household access to improved water source		
No (reference)	.	.
Yes	1.2* (1.0, 1.4)	1.1 (0.85, 1.5)
Household access to improved sanitation source		
No (reference)	.	.
Yes	1.4** (1.1, 1.8)	0.62* (0.42, 0.90)
Recent anti-malaria indoor residual spraying of household		

No (reference)	.	.
Yes	0.85 (0.66, 1.1)	0.48** (0.30, 0.78)
Household access to mosquito bed net for sleeping		
No (reference)	.	.
Yes	1.2* (1.0, 1.5)	0.96 (0.69, 1.3)
Current tobacco use		.
No (reference)	.	.
Yes	0.61 (0.09, 4.2)	.
Weight status, kg	0.99** (0.98, 0.99)	.
Parity	1.0 (0.98, 1.0)	.
Fever in previous two weeks		
No (reference)	.	.
Yes	.	2.1*** (1.5, 2.9)
Diarrhea in previous two weeks		
No (reference)	.	.
Yes	.	1.1 (0.77, 1.6)
Consumption of vitamin A supplement in previous 6 months		
No (reference)	.	.
Yes	.	0.98 (0.75, 1.3)
Consumption of iron supplement in previous 7 days		
No (reference)	.	.
Yes	.	1.1 (0.77, 1.4)
Treatment for intestinal worms in the last 6 months		
No (reference)	.	.
Yes	.	0.98 (0.76, 1.3)
Breastfeeding status		
Never breastfed (reference)	.	.
Ever breastfed and not currently breastfeeding	.	1.0 (0.39, 2.6)
Still breastfeeding	.	1.2 (0.44, 3.3)
Presence of malaria parasites		
No (reference)	.	.
Yes	.	3.0*** (2.1, 4.2)

[a] Values are odds ratios (95% CI) from logistic regression models of the association of household livestock ownership with anemia status. Adjusted models are multiple logistic regression models that control for all covariates shown as well as regional fixed effects. Standard errors are adjusted for intra-household clustering and the multistage sampling frame of the 2014 Ghana Demographic and Health Survey through the use of Taylor-linearized standard errors; [b] Anemia is modeled as a dichotomous variable defined among women as hemoglobin < 120 g/L, and among children as hemoglobin < 110 g/L; [c] Sample sizes: unadjusted model for women: n = 4,441; adjusted model for women: n = 4,392; unadjusted model for children: n = 2,735; adjusted model for children: n = 2,336; [d] **P*<0.05; ***P*<0.01; ****P*<0.001.

Table 2. Results of multiple logistic regression analyses for the association of household ownership of specific livestock species with anemia among women aged 15-49 years and children aged 6-59 months, respectively.

	Women aged 15-49 years		Children aged 6-59 months	
	n	OR (95% CI)	n	OR (95% CI)
Household livestock ownership				
Non-dairy cattle	4,392	1.3 (0.92, 1.9)	2,336	1.2 (0.70, 1.9)
Dairy cattle	4,392	0.77 (0.51, 1.2)	2,336	1.0 (0.58, 1.8)
Sheep	4,392	1.0 (0.77, 1.4)	2,336	0.92 (0.67, 1.3)
Goats	4,392	0.91 (0.75, 1.1)	2,336	1.1 (0.78, 1.5)
Pigs	4,392	0.77 (0.55, 1.1)	2,336	0.90 (0.48, 1.7)
Chickens	4,390	0.95 (0.79, 1.1)	2,336	1.6** (1.2, 2.2)
Chickens (and no other livestock)	4,392	1.1 (0.89, 1.3)	2,336	1.9*** (1.3, 2.6)

[a]Values are odds ratios (95% CI) from multiple logistic regression models of the association of household ownership of specific livestock species with anemia status. Full model results with estimates for select covariates are presented in Supplemental Tables 5 and 6. Standard errors are adjusted for intra-household clustering and the multistage sampling frame of the 2014 Ghana Demographic and Health Survey through the use of Taylor-linearized standard errors; [b]Anemia is modeled as a dichotomous variable defined among women as hemoglobin < 120 g/L, and among children as hemoglobin < 110 g/L; [c]**P*<0.05; ***P*<0.01; ****P*<0.001.

Table 3. Monetary value per adult equivalent of household food consumption and expenditures in the previous 35 days among participants of the Ghana Living Standards Survey Round 6.

	Total sample		Households with livestock		Households with no livestock		
	n	Mean (95% CI)	n	Mean (95% CI)	n	Mean (95% CI)	t-statistic
Value of household food consumption (own produced food) and expenditures (purchased food)							
All food consumption per adult equivalent	16,772	150 (145, 155)	7,273	136 (129, 143)	9,499	157 (150, 163)	7.5***
ASF consumption per adult equivalent	16,766	42.5 (40.7, 44.2)	7,273	34.4 (32.1, 36.6)	9,493	46.6 (44.4, 48.8)	16.2***
Meat consumption per adult equivalent	16,766	7.3 (6.7, 8.0)	7,273	6.6 (5.1, 8.1)	9,493	7.7 (7.1, 8.3)	2.9**
Chicken consumption per adult equivalent	16,766	5.0 (4.6, 5.3)	7,273	5.3 (4.8, 5.8)	9,493	4.8 (4.4, 5.2)	-3.1**
Fish consumption per adult equivalent	16,766	24.8 (23.6, 26.0)	7,273	19.4 (18.1, 20.8)	9,493	27.5 (26.0, 28.9)	18.3***
Milk consumption per adult equivalent	16,766	3.1 (2.9, 3.3)	7,273	1.4 (1.3, 1.5)	9,493	3.9 (3.7, 4.2)	28.8***
Egg consumption per adult equivalent	16,766	2.1 (1.9, 2.2)	7,273	1.1 (1.0, 1.2)	9,493	2.5 (2.3, 2.7)	16.1***

[a]Values are means (95% CI) in units of Ghanaian cedi adjusted for the multistage sampling frame of the Ghana Living Standards Survey Round 6 through the use of Taylor-linearized standard errors; [b]Sample sizes shown are nominal sample sizes; [c]The two-sided Student's t-statistics shown test for differences in means for characteristics among households with livestock and with no livestock. [d]*P<0.05; **P<0.01; ***P<0.001; [e]Own produced "meat" includes: beef, mutton, pork, goat, other domestic meat, and wild game; purchased "meat" includes: corned beef, pork, beef, goat, mutton, bushmeat or wild game, and other meat; purchased "fish" includes: crustaceans, fish (fresh, frozen, dried, canned, fried, smoked, salted); purchased "milk" includes: fresh, powdered, or tinned milk.

Table 4. Results of multiple linear regression analyses for the association of household ownership of livestock with the monetary value per adult equivalent of household food consumption and expenditures in the previous 35 days, by food type, among participants of the Ghana Living Standards Survey Round 6.

	Value of household food consumption (own produced food) and expenditures (purchased food) per adult equivalent						
	All food Coefficient (95% CI)	ASFs Coefficient (95% CI)	Meat Coefficient (95% CI)	Chicken Coefficient (95% CI)	Fish Coefficient (95% CI)	Milk Coefficient (95% CI)	Eggs Coefficient (95% CI)
Household ownership of any livestock	26.1*** (17.9, 34.3)	6.8*** (4.1, 9.6)	1.7 (-0.15, 3.5)	2.0*** (1.4, 2.6)	3.2*** (1.8, 4.6)	-0.28** (-0.47, -0.10)	0.03 (-0.12, 0.18)
Household ownership of cattle	.	.	4.9* (0.52, 9.2)	.	.	0.30 (-0.06, 0.65)	.
Household ownership of sheep	.	.	3.3 (-0.29, 6.9)	.	.	.	.
Household ownership of goats	.	.	1.6 (-0.38, 3.6)	.	.	.	.
Household ownership of pigs	.	.	5.8 (-0.49, 12.1)	.	.	.	.
Household ownership of chickens	.	.	.	2.6*** (1.9, 3.2)	.	.	0.14* (0.00, 0.28)
Household participation in wild fish capture	.	.	.	.	21.9* (1.6, 42.3)	.	.
Household participation in fish farming	.	.	.	.	6.4 (-1.6, 14.4)	.	.

[a] Values are partial regression coefficients (95% CI) from multiple linear regression models of the association of household ownership of livestock with the monetary value per adult equivalent of household food consumption and expenditures, by food type. Models are adjusted for the sex, age, education level, and employment status of household head,

household size, urban location, quintiles of total household expenditure, and regional fixed effects. Full model results with estimates for select covariates in select models are presented in Supplemental Table 3. Standard errors are adjusted for the multistage sampling frame of the of the Ghana Living Standards Survey Round 6 through the use of Taylor-linearized standard errors. Monetary value data are in units of Ghanaian cedi; [b]Sample size: n = 16,246; [c]**P*<0.05; ***P*<0.01; ****P*<0.001; [d]Abbreviations: ASFs: animal-source foods; [e]Animal-source foods include all other categories of such foods shown; own produced “meat” includes: beef, mutton, pork, goat, other domestic meat, and wild game; purchased “meat” includes: corned beef, pork, beef, goat, mutton, bushmeat or wild game, and other meat; purchased “fish” includes: crustaceans, fish (fresh, frozen, dried, canned, fried, smoked, salted); purchased “milk” includes: fresh, powdered, or tinned milk.