The heat never bothered me anyway: Gender-specific response of agricultural labor to climatic shocks in Tanzania

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Abstract
Agricultural production in Africa is generally highly labor intensive with gender-specific specialization across activities. Using panel data from Tanzania, we examine the effects of heat stress (temperature above 29°C) during the maize-growing season on gender-disaggregated agricultural labor use. Results show that heat stress reduces total male family labor but does not statistically affect female family labor. Households with only female adults seem to increase their labor supply under heat stress. Given these heterogeneous effects, gender-sensitive development interventions and adaptation strategies are suggested to enhance women’s adaptive capacity.

KEYWORDS
agricultural labor, gender, heat stress, panel data, Tanzania

JEL CLASSIFICATION
J16; J43; Q54

For millions of smallholders in sub-Saharan Africa (SSA), weather variability and extreme weather events such as flood and drought have devastating effects on well-being and food security. The magnitude, intensity, and frequency of such events will likely increase in SSA, with 1.4°C–1.6°C (2°C–4.5°C) rise in average annual temperature expected in 2050 (2100) (Helgeson et al., 2013; Kotir, 2011). These changes have both direct (through agricultural productivity) and indirect (through labor demand, food prices, and spread of diseases and infections) effects
(Alfani et al., 2015). For example, trends in temperature and precipitation between 1980 and 2008 have resulted in a global yield loss of maize and wheat, respectively, by 3.8% and 5.5% (Lobell et al., 2011).

Women play crucial roles in agricultural production and in their household’s food security including through their involvement in land preparation and weeding as well as food processing and preparation (Broussard, 2019; Doss et al., 2018; Ibnouf, 2009; Komatsu et al., 2018). While the existing claim—women’s contribution to agricultural activities ranges between 60% and 80% of the labor force—needs to be supported by empirical evidence (Doss et al., 2018), women are often heavily involved in agriculture, with a significant spatial variation, partly driven by differences in farming systems and gender-based division of labor (Johnston et al., 2018; Ndiritu et al., 2014). While there has been a surge of research on the effects of climatic shocks and effective coping and adaptation strategies, limited research has explicitly considered gender dimensions (Bryan et al., 2017; Kristjanson et al., 2017). The existing evidence shows that women’s vulnerability to climatic shocks are driven mostly by their limited access to and control over productive resources (e.g., land and credit) and reliance on climate-sensitive activities (e.g., collection of water and fuelwood) (FAO et al., 2018; Jost et al., 2016; Rao et al., 2019).

Rainfed agriculture remains the primary source of livelihoods in SSA, which exposes millions to various climatic shocks and their detrimental effects. In this study, we extend the literature on gender-differential effects of weather variability by empirically testing the effects of heat stress on gendered family agricultural labor supply using panel data from Tanzania. Agriculture accounts for 80% of the labor force in Tanzania (Ahmed et al., 2011) with females’ contribution estimated at 50% (Palacios-lopez et al., 2017). The Gender Inequality Index (GII), designed to measure gender equality in reproductive health, empowerment, and labor market outcomes, indicates that Tanzania ranks low (130 out of 160 countries) (UNDP, 2018). As in many countries in the region, gender gap and specialization of labor are widespread in Tanzania. Women are more likely to engage in farming (e.g., weeding and postharvest processing) and domestic activities (e.g., caring for children, preparation of meals, collection of water and firewood), while men tend to engage more heavily in income-generating activities and devote much less time to domestic chores (Ellis et al., 2007; FAO, 2014). Existing literature on gendered effects of exposure to weather-related events is extremely limited (excepting Asfaw & Maggio, 2018; Quisumbing et al., 2018), mostly because of lack of sex-disaggregated data. Therefore, given also the exacerbating intensity and frequency of climate extremes, in this study we provide some empirical evidence on gendered implications and potential risks of weather variability.

We contribute to the literature in three ways. First, rather than measuring weather shock using indicators such as average monthly temperature and rainfall, we construct an indicator of heat stress based on the concept of degree days and a threshold temperature (29°C) above which temperature has been found to have detrimental effects on maize plant growth. Second, we consider heterogeneity in the responses to shocks by gender and economic activity (land preparation/planting, weeding, and harvesting). Much of the existing evidence focuses on gender differences by household headship without taking intrahousehold gender differences into account. Third, while most empirical work on the effects of climatic shocks focuses on yields and household welfare, we examine the effects of such shocks on agricultural labor supply.

Fixed-effects estimates show that heat stress reduces male family labor irrespective of activity type but has largely no effect on female family labor. On the other hand, heat stress increases female family labor in female-only households. Heat stress also reduces hired labor, with a stronger effect observed for females. Given gender roles, interventions targeted at
improving skills, enhancing access to and control over productive resources, and reducing women’s time burdens can help improve women’s resilience to climatic shocks.

LITERATURE REVIEW

A large body of empirical research examines the effects of weather shocks in developing regions on outcomes such as agricultural production, productivity, technology adoption, migration, and household consumption expenditure (Asfaw & Maggio, 2018; Haile et al., 2018; Kubik & Maurel, 2016; Letta et al., 2018). An important lesson that has emerged from this research is the existence of gender differences in vulnerability and responsiveness to climatic shocks (Bryan et al., 2017; Goh, 2012; Kristjanson et al., 2017). These differences are due to differential access to agricultural resources and inputs (Bryan et al., 2017; FAO et al., 2018; Rao et al., 2019), decision-making authority (Kristjanson et al., 2017), perception and adaptation strategies (FAO et al., 2018; Quisumbing et al., 2018), and intrahousehold differences (Jost et al., 2016). Recent evidences on gender differences in adaptive strategies to climatic risks highlight the relatively limited resilience of women due mostly to gender-based differences in access to resources and specialization (Bryan et al., 2017; Bryan & Behrman, 2013; FAO et al., 2018; Goh, 2012).

For example, women have limited access to and effective control of quality agricultural land, financial capital, and labor relative to men (Bryan et al., 2017; FAO et al., 2018; Rao et al., 2019). Considerable evidence supports the presence of a gender gap in agricultural productivity in SSA, largely due to differences in resource endowment and input use efficiency (Aguilar et al., 2015; Kilic et al., 2015). As a result, they typically face a productivity gap and income inequality (Ali et al., 2016). In Tanzania, the gender gap in agricultural productivity is about 20% to 30%, mainly due to constraints in access to resources (Slavchevska, 2015). Our study tries to close the gap between literature on (i) gender differences in time use and (ii) women's limited adaptive capacities in the face of climatic hazards. There is a relative abundance of literature on gender-based differences in time use (Bardasi & Wodon, 2010; Blackden & Wodon, 2006; Johnston et al., 2018; Seymour et al., 2020) and adaptive capacities (Jost et al., 2016; Rao et al., 2019). One important trend of these studies is the relatively high time constraints women disproportionately face (Blackden & Wodon, 2006; Doss et al., 2018; FAO, 2011). In many places in SSA, women contribute about half of the agricultural production and bear primary responsibility in the household at the same time taking care of most of the time intensive domestic chores (Arbache et al., 2010; FAO, 2011; Komatsu et al., 2018).

In Tanzania, women devote nearly three times longer than men to domestic tasks such as fetching fuel and water, activities that are more prone to climatic risks (Ellis et al., 2007). Women’s multiple roles on climate-sensitive agricultural production and household responsibilities, limited access resources, coupled with increase migration (local or international) by men, all tend to increase women’s vulnerability to climatic risks and limit their adaptive capability (Jost et al., 2016; Rao et al., 2019). Our study also relates to work on the effects of rising temperatures. Heat stress can affect crop production both through its impact on plant growth (Fahad et al., 2017; Lamaoui et al., 2018) and on the supply and quality labor, as workers would spend longer hours under direct sunlight and heat. It has been shown that yields specifically of maize, the most common staple cereal in Tanzania and East Africa, decline by up to 40% because of drought (Daryanto et al., 2016). In sum, adaptive capacities associated with gender differences can be acknowledged as critical in our understanding of women’s vulnerability to climatic
shocks. While several studies assess the association between gender differences and vulnerability, fewer have focused on how climatic shocks affect men’s and women’s labor supply in agriculture, a gap this study attempts to fill.

**METHODOLOGY**

**Data and variables**

This study is based on data from the first three rounds of the Tanzania National Panel Survey (NPS) conducted in October 2008–September 2009 (round 1); October 2010–September 2011 (round 2); and October 2012–November 2013 (round 3). The original NPS sample was drawn from 409 Enumeration Areas (including 2063 rural and 1202 urban households) using a stratified, multistage cluster sampling, and is representative at the national, rural/urban, and major agro-ecological zones. The Tanzania NPS has a household attrition rate of about 3% between round 1 and 2 (NBS, 2011) and 4.8% between round 1 and 3 (NBS, 2013). The analysis here is based on 6502 observations (1913 households interviewed three times, 300 households interviewed twice, and 163 households interviewed just once) on households that have cultivated at least one plot during the long rainy season of the respective year spanning March to May. Additional four observations were excluded due to missing data on agricultural labor use.

For each cultivated plot, the NPS collect data on the number of days worked by household members disaggregated by activity (land preparation/planting, weeding, and harvesting). Data are also collected on gender-disaggregated labor hired during the reference period. To better understand the dynamics of household structure that may affect vulnerability, we disaggregate the analysis by household type, defined as dual-adult households (with at least one adult male and one adult female above 19 years old) or female-only households (with no adult male) (see Table 1).

For each activity and household, total family labor per hectare is defined as the ratio between the sum of plot-level family labor (in days) and total cultivated area (hectare), constructed for male and female labor separately. The same method is used to construct male and female hired labor. In addition to labor, we construct several socioeconomic variables that may affect agricultural time use or adaptive capability as summarized in Table S1. While the NPS is uniquely suitable for analyses of gender- and activity-disaggregated agricultural labor, we recognize that disaggregated agricultural labor data are likely prone to recall bias as noted by others before (Arthi et al., 2018; Beegle et al., 2012).

Data from the NPS are merged with gridded temperature and rainfall data corresponding to the geographic positions of surveyed households. Planting and harvesting generally take place, respectively, from September to November and from January to April, depending on the region. Minimum and maximum daily temperature (in °C) are obtained from the Noah 2.7.1 model in the Global Land Data Assimilation System (GLDAS), which is well known to produce satellite- and ground-based observational data. Monthly rainfall data are extracted from Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset, which captures recent changes in soil moisture and evapotranspiration (Funk et al., 2015). The GLDAS and CHIRPS data have 0.25° and 0.05° resolution, respectively.

Following Snyder (1985), we construct an indicator of heat stress called growing degree days (GDD) based on the daily minimum and maximum temperature. The choice to focus on GDD, as...
**TABLE 1** Descriptive summary by household composition

| Panel A. Weather condition | Dual-adult household | Female-only household |
|---------------------------|----------------------|-----------------------|
|                           | Mean     | S.D.     | Mean    | S.D.    |
| Heat stress (temperature > 29° C) (days) | 23.7     | 18.25    | 23.7    | 18.25   |
| Total growing season rainfall (mm) | 567.7    | 252.89   | 567.7   | 252.89  |

**Panel B. Agricultural labor**

| Male family labor (day/hectare) | Dual-adult household | Female-only household |
|---------------------------------|----------------------|-----------------------|
| Land preparation                | 14.3     | 29.50    | 0.0     | 0.00    |
| Weeding                         | 12.5     | 27.92    | 0.0     | 0.00    |
| Harvesting                      | 10.9     | 33.14    | 0.0     | 0.00    |
| Total family labor              | 40.9     | 91.54    | 0.0     | 0.00    |

| Female family labor (day/hectare) | Dual-adult household | Female-only household |
|-----------------------------------|----------------------|-----------------------|
| Land preparation                  | 4.7      | 15.83    | 29.0    | 37.56   |
| Weeding                           | 5.0      | 15.89    | 25.3    | 30.48   |
| Harvesting                        | 3.3      | 10.88    | 15.6    | 22.90   |
| Total family labor                | 13.7     | 40.20    | 71.7    | 79.49   |

| Male hired labor (day/hectare) | Dual-adult household | Female-only household |
|---------------------------------|----------------------|-----------------------|
| Land preparation                | 1.1      | 3.58     | 0.9     | 3.37    |
| Weeding                         | 0.9      | 3.04     | 0.9     | 3.29    |
| Harvesting                      | 0.6      | 2.57     | 0.6     | 2.51    |
| Total hired labor               | 2.7      | 7.11     | 2.4     | 6.62    |

| Female hired labor (day/hectare) | Dual-adult household | Female-only household |
|----------------------------------|----------------------|-----------------------|
| Land preparation                 | 1.1      | 4.49     | 1.8     | 8.18    |
| Weeding                          | 1.0      | 3.66     | 1.1     | 3.63    |
| Harvesting                       | 0.7      | 2.61     | 0.9     | 2.98    |
| Total hired labor                | 2.8      | 8.04     | 3.9     | 12.50   |

**Panel C. Other socioeconomic variables**

| Urban residence (urban = 1) | Dual-adult household | Female-only household |
|-----------------------------|----------------------|-----------------------|
|                             | 0.2      | 0.37     | 0.2     | 0.41    |

| Age of household head (years) | Dual-adult household | Female-only household |
|-------------------------------|----------------------|-----------------------|
|                               | 49.2     | 15.11    | 54.2    | 17.27   |

| Average male adult education (years) | Dual-adult household | Female-only household |
|--------------------------------------|----------------------|-----------------------|
|                                      | 5.2      | 3.55     | 0.0     | 0.00    |

| Average female adult education (years) | Dual-adult household | Female-only household |
|----------------------------------------|----------------------|-----------------------|
|                                       | 4.3      | 3.46     | 3.4     | 3.10    |

| Dependency ratio (# nonworking members/# working members) | Dual-adult household | Female-only household |
|----------------------------------------------------------|----------------------|-----------------------|
|                                                          | 0.5      | 0.22     | 0.4     | 0.30    |

| Number of children (<5) | Dual-adult household | Female-only household |
|-------------------------|----------------------|-----------------------|
|                         | 0.9      | 1.04     | 0.5     | 0.73    |

| Land area owned (hectares) | Dual-adult household | Female-only household |
|----------------------------|----------------------|-----------------------|
|                            | 1.8      | 2.26     | 0.9     | 1.10    |

| Tropical Livestock Unit | Dual-adult household | Female-only household |
|-------------------------|----------------------|-----------------------|
|                         | 1.9      | 4.89     | 0.4     | 1.67    |

| Asset-based wealth (normalized index) | Dual-adult household | Female-only household |
|--------------------------------------|----------------------|-----------------------|
|                                       | 0.1      | 0.67     | -0.3    | 0.42    |

| Distance to nearest market (km) | Dual-adult household | Female-only household |
|---------------------------------|----------------------|-----------------------|
|                                 | 7.8      | 10.28    | 6.6     | 8.77    |

| % of households growing maize (long-season) | Dual-adult household | Female-only household |
|--------------------------------------------|----------------------|-----------------------|
|                                            | 0.6      | 0.49     | 0.6     | 0.49    |
opposed to maximum temperature and average rainfall, is based on the premise that certain crop-specific temperature ranges are more conducive for normal plant growth and that the effect of temperature shocks is nonlinear (Porter & Semenov, 2005). Schlenker and Roberts (2009) identify the critical temperature threshold for maize (corn) in the United States to be 29°C above which there are harmful effects on plant growth and yields.

Given the dominance of maize-based systems in Tanzania, we follow Schlenker and Roberts (2009) and use 29°C as a single threshold ($Temp_{29°C}$) to define heat stress. We further assume that diurnal temperatures ($Temp$) expressed in heat unit (degrees) can be approximated using daily maximum ($Temp_{max}$), daily minimum ($Temp_{min}$), and a trigonometric sine curve as shown in Equation (1):

$$Temp = M + W \sin(t)$$

where $t$ is time in hours, expressed in terms of radians; $M = (Temp_{max} + Temp_{min})/2$; and $W = (Temp_{max} - Temp_{min})/2$. With a single threshold temperature, each day of the maize growing season when the minimum temperature is greater than the threshold ($Temp_{min} > Temp_{29°C}$) contributes to one-degree day (DD = 1). In days when the minimum temperature is lower than the threshold ($Temp_{min} < Temp_{29°C}$), we calculate the fraction of the degree day (DT) when temperature is above the threshold, as shown in Equation (2):

$$DT = (\pi - 2\theta_{29°C}) / 2\pi$$

where $\theta_{29°C} = \arcsin[(Temp_{29°C} - M)/W]$ is the fraction of the day when the upswing portion of the daily temperature exceeds $Temp_{29°C}$. We defined heat stress based on the number of days during the maize growing season when temperature is above the 29°C threshold, as shown in Equation (3):

$$GDD = \sum_s DT_s$$

where $s$ represents the number of days in the maize growing season. $GDD$ can thus be interpreted as a proxy of heat stress expressed in days.
Identification

Exploiting the panel structure of the NPS, we estimate a fixed-effects (FE) model in Equation (4) (see Cameron & Trivedi, 2005 and Wooldridge, 2010 for general discussion). The model is designed to control for unobserved time-invariant characteristics and heterogeneity (e.g., genetic traits, individual adaptive capacity), and is estimated for each type of labor (male vs. female, family vs. hired) and each activity (land preparation/planting, weeding, and harvesting) as shown below:

\[ Y_{ht} = \beta_0 + \beta_1 GDD_{ht} + \beta_2 \text{rainfall}_{ht} + \Lambda'X_{ht} + \alpha_h + \epsilon_{ht} \]  

where \( Y_{ht} \) is labor of a given type and activity; \( GDD \) is as defined above; \( \text{rainfall} \) refers to total rainfall during the maize growing season (in mm); \( X_{ht} \) is a matrix of household-level socioeconomic variables that may affect household exposure and adaptive capability to weather changes; \( \alpha_h \) captures household fixed-effects; and \( \epsilon \) is an independently and identically distributed (i.i.d.) error term. We conduct the Durbin–Wu–Hausman test to justify our choice between fixed effects (FE) and random effects (RE) estimator, which rejects the null that FE provides consistent estimates.

Guided by previous research, we control for several conditioning variables including area of residence (urban vs. rural), gender and age of household head, average education among adult members, dependency ratio, number of children (younger than 5 years old), total land area owned, livestock wealth (proxied by Tropical Livestock Units -TLU-), agricultural wealth (proxied by an index à la Filmer & Pritchett, 2001), distance to nearest market, indicator for households growing maize, and distance to the nearest water source, the last factor included to capture possible trade-off in women’s time use allocation between agricultural activities and domestic chores.

We also control for precipitation to reduce possible omitted variables bias (Dell et al., 2014; Letta et al., 2018). Cross-model Hausman tests for equality of coefficient estimates associated to heat stress indicator between the models for male labor (\( \beta_M^2 \)) and female labor (\( \beta_F^2 \)) are also conducted. Rejection of the null hypothesis suggests gender-specific responsiveness to heat stress, ceteris paribus. To examine differential responsiveness by household type, Equation (4) is estimated on subsamples of dual-adult and female-only households separately. Standard errors from all regressions are clustered at the Enumeration Area level.4

RESULTS AND DISCUSSION

Descriptive analysis

Table 1 reports descriptive statistics for key variables by survey round and for the pooled sample, with three panels for weather condition, agricultural labor, and other socioeconomic variables. The average \( GDD \) is 23.7 with mean rainfall of 568 mm (Panel A). We compare outcomes in agricultural labor (Panel B) and other socioeconomic variables (Panel C) of dual-adult households (with both male and female members) and female-only households (with only female members). Female-only households use higher female family agricultural labor (71.7 day/hectare), which is more than five times that of dual-adult households (13.7 day/hectare). In
addition, female-only households tend to have higher female hired agricultural labor supply (3.9 day/hectare) than dual-adult households (2.8 day/hectare).

In terms of other socioeconomic characteristics, 80% to 90% of sampled households reside in rural areas, with more than half growing maize during the reference period. We hypothesize that females face greater constraints than males in terms of access to human capital, productive resources and financial assets which may in turn weaken their adaptive capacity (Bryan et al., 2017; Rao et al., 2019). In our case, on average, dual-adult households show higher adult female education (4.3 years) than female-only households (3.4 years). Land area owned by dual-adult households is about 1.8 hectares, while female-only households own 0.9 hectares. Livestock ownership in dual-adult households (1.9 TLU) is also higher compared to corresponding asset in female-only households (0.4 TLU). Dual-adult households also tend to show higher average value in asset-based wealth than female-only households.

Regression results

Our multivariate analysis examines gender-specific responsiveness to heat stress on total labor, disaggregated by activity and household type. The same set of control variables (including district fixed effects) are included in each specification, with regressions by household type including separate variables for average education of male and female adults in the household. Table 2 shows FE estimates on total male and female family labor that control also for district fixed effects. For each full-day increase in temperature above 29°C during the maize growing season, male family labor supply declines by about 1.4 day/hectare, with no significant effect on female family labor. Households growing maize seem to use more family labor than non-growers. Female (male) family labor is higher (lower) in female-headed households, possibly due to higher time burdens that women may face in female-headed households. Table 3 reports FE estimates for different family labor activities. Each day of growing season with temperature above 29°C reduces male labor by about 0.36–0.44 day/hectare, depending on the activity. While males marginally decrease labor supply when exposed to heat stress, females show no statistically significant effect.

FE estimates for hired labor (Table 4) show heat stress to reduce both male and female hired labor, with relatively stronger effects on the latter. This result is in line with the heterogeneous effects of weather shocks on labor highlighted by previous research and with the choice of female labor occupation as a strategy of last resort in times of distress due to women’s usual time-intensive domestic responsibilities (Mahajan, 2017). Female hired labor significantly increases with distance to the nearest water source, while it declines with the number of young children in the household. Table 5 reports the disaggregated results for hired labor activity. Each day of heat stress above 29°C reduces male hired labor by about 0.02 day/hectare for land preparation/planting, 0.03 day/hectare for weeding, and 0.02 day/hectare for harvesting. Heat stress reduces female hired labor by 0.03–0.11 day/hectare for land preparation/planting and weeding with no effect on harvesting.

Table 6 reports FE estimates for total family labor for dual-adult households and female-only households. Each degree day of heat stress exerts a statistically significant effect on both male and female family labor supply—by −1.5 and 2.4 days, respectively—with the expected direction by household composition. Specifically, one day of heat stress is associated with a statistically significant increase in female family labor by 2.4 days in female-only households. In contrast, the effect of each day of heat stress on male family labor is negative by −1.5 day and
TABLE 2  Fixed effects estimates on total gendered family labor

|                         | (1) Total male family labor | (2) Total female family labor |
|-------------------------|----------------------------|-------------------------------|
| Heat stress (>29°C)     | −1.400***                  | 0.036                        |
|                         | (0.237)                    | (0.162)                      |
| Total growing season rainfall (mm) | 0.003                 | 0.001                        |
|                         | (0.009)                    | (0.005)                      |
| Urban residence (urban = 1) | −2.590                 | −8.522***                    |
|                         | (10.047)                   | (3.038)                      |
| Age of household head (years) | −1.425***              | 0.057                        |
|                         | (0.355)                    | (0.095)                      |
| Average adult education (years) | −0.598                 | −0.773*                      |
|                         | (0.543)                    | (0.411)                      |
| Head of household is female | −35.496***              | 32.916***                    |
|                         | (3.582)                    | (3.876)                      |
| Dependency ratio        | 1.223                      | −5.889                       |
|                         | (8.861)                    | (5.332)                      |
| Number of children (<5) | −0.446                     | −0.266                       |
|                         | (2.293)                    | (0.572)                      |
| Land area owned (hectares) | −2.384***              | −1.535***                    |
|                         | (0.343)                    | (0.250)                      |
| Tropical Livestock Unit | 0.198                      | −0.107*                      |
|                         | (0.172)                    | (0.061)                      |
| Asset-based wealth (normalized index) | 0.075               | −0.539***                    |
|                         | (0.566)                    | (0.202)                      |
| Distance to nearest market (km) | −0.116               | −0.160**                     |
|                         | (0.086)                    | (0.081)                      |
| % of households growing maize (long-season) | 7.172***              | 6.951***                     |
|                         | (2.653)                    | (1.773)                      |
| Distance to nearest water source (km) | 0.142***             | 0.041**                      |
|                         | (0.037)                    | (0.021)                      |
| District fixed effects  | Yes                        | Yes                          |
| F-Statistic             | 18.316                     | 16.845                       |
| Observations            | 6498                       | 6498                         |
| Unique panel households | 2375                       | 2375                         |

Note: District fixed effects are included. Results are based on a subsample of panel agricultural households with nonmissing agricultural labor use data. Robust standard errors clustered at the enumeration area level are in parentheses.

*** $p < 0.01$,  
** $p < 0.05$,  
*p* $p < 0.10$.  

does not affect female family labor significantly among dual-adult households. One additional non-working member, hectare of farmland, and kilometer to the nearest market all have a strong detrimental effect (−65, −14, and −0.7 days, respectively) on family agricultural labor supply in female-only households, compared to the effect in dual-adult households. The negative effect associated to the dependency ratio highlights an existing trade-off between women's ability to fulfill household caregiving tasks and their capacity to contribute to agricultural production.

Several factors may drive observed differences in responsiveness to heat stress. The first is related to gendered differences in access to productive resources, as noted in previous studies. In our case, for example, we find that female-only households operate smaller land size and own fewer livestock than dual-adult households. The literature on resilience to weather shocks highlights that women seem to possess lower adaptive capacity to respond to such shocks compared to men due to gendered factors in vulnerability contexts (Bryan & Behrman, 2013). Gender differences in access to and control of key assets in agriculture is often considered a main driver of the limited resilience to weather variability among women (Bryan et al., 2017). Given women’s limited access to agricultural resources, the heterogeneous effects of heat stress on female-only households and dual-adult households are consistent with previous literature.

The second is related to physiological sex-specific differences in body reaction to heat. Existing evidence demonstrates that females sweat significantly less than males, which possibly leads the latter to be more vulnerable to heat stress (Wästerlund, 2018). Heat stress potentially reduces maize yields not only due to effect on plants (Schlenker & Roberts, 2009) and subsequent labor (re)allocation, but also through reduced labor productivity induced by physiological responses (strain) to heat (Daryanto et al., 2016; Tatterson et al., 2000; Zamanian et al., 2017). Recent research indicates that sex-related differences in morphology, including average body size and muscle mass, may differentially affect sex-specific heat balance, associated with female’s lower sensitivity to warmer thermal environment compared to males (Liu et al., 2018).

**TABLE 3** Fixed-effects estimates for the effects of heat stress on family labor by agricultural activity

|                | (1) Male land preparation | (2) Female land preparation | (3) Male weeding | (4) Female weeding | (5) Male harvesting | (6) Female harvesting |
|----------------|----------------------------|----------------------------|-----------------|-------------------|---------------------|----------------------|
| Heat stress (>29°C) | −0.381*** (0.071)       | −0.031 (0.076)       | −0.360*** (0.074)       | −0.038 (0.060)       | −0.435*** (0.085)       | 0.049 (0.043)       |
| Total growing season rainfall (mm) | −0.001 (0.003)       | −0.002 (0.002)       | 0.000 (0.002)       | −0.002 (0.002)       | −0.002 (0.003)       | 0.000 (0.002)       |
| District fixed effects | Yes                        | Yes                        | Yes             | Yes                | Yes                 | Yes                 |
| F-Statistic | 21.583                     | 14.132                     | 30.194          | 23.002             | 13.094              | 11.744              |
| Observations | 6498                       | 6498                       | 6498            | 6498               | 6498                | 6498                |
| Unique panel households | 2375                       | 2375                       | 2375            | 2375               | 2375                | 2375                |

*Note: Columns 1–2, 3–4, and 5–6 present fixed effects estimates for total male and female family labor for land preparation/planting, weeding, and harvesting, respectively. District fixed effects are included. Results are based on a subsample of panel agricultural households with nonmissing agricultural labor use data. Robust standard errors clustered at the enumeration area level are in parentheses.*** p < 0.01, ** p < 0.05, * p < 0.10.
|                                | (1)                              | (2)                              |
|--------------------------------|----------------------------------|----------------------------------|
|                                | Total male hired labor            | Total female hired labor          |
| Heat stress (>29°C)            | $-0.058^{**}$                    | $-0.145^{***}$                   |
|                                | (0.023)                          | (0.030)                          |
| Total growing season rainfall (mm) | $0.003^{***}$                   | $-0.001$                          |
|                                | (0.001)                          | (0.001)                          |
| Urban residence (urban = 1)    | 1.085                            | 0.649                            |
|                                | (0.685)                          | (1.216)                          |
| Age of household head (years)  | $-0.001$                         | $-0.097^{***}$                   |
|                                | (0.016)                          | (0.021)                          |
| Average adult education (years)| $-0.018$                        | $-0.054$                         |
|                                | (0.080)                          | (0.097)                          |
| Head of household is female    | $-0.321$                         | 0.287                            |
|                                | (0.480)                          | (0.470)                          |
| Dependency ratio               | $-0.003$                         | $-0.037$                         |
|                                | (0.756)                          | (1.079)                          |
| Number of children (<5)        | $-0.073$                         | $-0.698^{***}$                   |
|                                | (0.156)                          | (0.191)                          |
| Land area owned (hectares)     | $-0.108^{**}$                    | $-0.228^{***}$                   |
|                                | (0.050)                          | (0.046)                          |
| Tropical Livestock Unit        | 0.018                            | $-0.084^{***}$                   |
|                                | (0.040)                          | (0.029)                          |
| Asset-based wealth (normalized index) | 0.036                          | $-0.030$                         |
|                                | (0.098)                          | (0.111)                          |
| Distance to nearest market (km)| 0.001                            | $-0.037^{**}$                    |
|                                | (0.009)                          | (0.014)                          |
| % of households growing maize (long-season) | 1.100^{***}                  | 0.992^{***}                      |
|                                | (0.263)                          | (0.297)                          |
| Distance to nearest water source (km) | $-0.005$                        | 0.033^{***}                      |
|                                | (0.013)                          | (0.009)                          |
| District fixed effects         | Yes                              | Yes                              |
| F-Statistic                    | 5.166                            | 10.755                           |
| Observations                   | 6498                             | 6498                             |
| Unique panel households        | 2375                             | 2375                             |

Note: District fixed effects are included. Results are based on a sub-sample of panel agricultural households with non-missing agricultural labor use data. Robust standard errors clustered at the enumeration area level are in parentheses.

*** $p < 0.01$,
**  $p < 0.05$,
*   $p < 0.10$. 
To examine potential psychological effects of heat stress, we estimated Equation 4 controlling for the Temperature Humidity Index (THI) instead of the GDD. The THI considers the effects of both temperature and relative humidity and measures the degree of discomfort experienced by humans and livestock in warm weathers (Steadman, 1979, 1984). Following Steadman (1984), we count the number of days during the maize growing season where temperature was above 40°C (days\(_{THI > 40}\)), a threshold for outdoor temperature that is considered high for humans. However, fixed effects parameter estimates of days\(_{THI > 40}\) (not shown here) predicting male and female labor supply were not statistically significant.

The third possible explanation of gender-specific differences in heat responsiveness is related to the men’s greater likelihood to respond to climatic shocks through local or international migration and income diversification (Gray & Mueller, 2012). While migration is considered as one of the possible adaptive strategies in responsiveness to climatic risks, women often face restricted mobility due to social and cultural norms (Rao et al., 2019). Given the traditional gender roles in rural areas of developing countries, women often devote disproportionate time to farming activities and domestic chores compared to men, who are more likely to adopt migration strategies for income source diversification while less likely to engage in household chores and caregiving activities (Dah-gbeto & Villamor, 2016; Rao et al., 2019). Restrictive gender norms in many areas of SSA limit women’s mobility and impose constraints to their time use allocation, in turn reducing their coping capabilities (Dah-gbeto & Villamor, 2016). Specifically, these constraints may result in women often bearing even greater workload burdens than men to mitigate weather shocks when they occur (Chanana-Nag & Aggarwal, 2018). However, our paper finds no definitive evidence on how gendered migration pattern affects gender-specific responsiveness to heat stress due to the lack of appropriate data.

While acknowledging the potential channels reported above, we do recognize that further research is needed to empirically examine the role of different pathways to heterogeneous

| TABLE 5 | Fixed-effects estimates for the effects of heat stress on hired labor by activity |
|---------|---------------------------------|
| (1)     | (2)       | (3)       | (4)       | (5)       | (6)       |
| Male hired land preparation | Female hired land preparation | Male hired weeding | Female hired weeding | Male hired harvesting | Female hired harvesting |
| Heat stress (>29°C) | −0.022* | −0.110*** | −0.029*** | −0.025* | −0.023** | −0.012 |
| (0.013) | (0.018) | (0.010) | (0.013) | (0.010) | (0.010) |
| Total growing season rainfall (mm) | 0.001* | −0.001** | 0.001 | −0.001 | 0.000 | 0.001 |
| (0.001) | (0.001) | (0.000) | (0.001) | (0.000) | (0.000) |
| District fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| F-Statistic | 6.985 | 12.605 | 4.771 | 11.060 | 6.606 | 3.366 |
| Observations | 6498 | 6498 | 6498 | 6498 | 6498 |
| Unique panel households | 2375 | 2375 | 2375 | 2375 | 2375 | 2375 |

Note: Columns 1–2, 3–4, and 5–6 present fixed effects estimates on total male and female hired labor for land preparation/planting, weeding, and harvesting, respectively. District fixed effects are included. Results are based on a subsample of panel agricultural households with nonmissing agricultural labor use data. Robust standard errors clustered at the enumeration area level are in parentheses.

***p < 0.01,
**p < 0.05,
*p < 0.10.
### TABLE 6  Fixed effects estimates on total family labor by household type

|                          | Dual-adult households | Female-only households |  |
|--------------------------|-----------------------|------------------------|---|
|                          | Total male family labor | Total female family labor | Total female family labor |
| Heat stress (>29°C)      | −1.527*** (0.258)     | −0.115 (0.081)         | 2.436** (1.137) |
| Total growing season rainfall (mm) | 0.003 (0.010) | 0.003 (0.005) | 0.022 (0.043) |
| Urban residence (urban = 1) | −2.506 (11.340) | −6.741*** (2.995) | −50.134* (28.303) |
| Age of household head (years) | −1.738*** (0.446) | 0.050 (0.092) | −2.598** (1.060) |
| Average male adult education (years) | 1.639** (0.636) | −0.354 (0.283) |  |
| Average female adult education (years) | −1.992*** (0.579) | 0.329 (0.234) | −2.015 (2.573) |
| Dependency ratio         | −0.553 (11.896)      | 4.466 (4.962)         | −65.271*** (22.043) |
| Number of children (<5)  | −0.326 (2.705)       | −0.532 (0.678)        | 5.997 (6.867) |
| Land area owned (hectares) | −2.404**** (0.369) | −1.054**** (0.201) | −14.555*** (4.944) |
| Tropical Livestock Unit  | 0.179 (0.166)        | −0.089* (0.054)       | −5.830 (4.426) |
| Asset-based wealth (normalized index) | 0.001 (0.605) | −0.545**** (0.174) | 0.101 (5.696) |
| Distance to nearest market (km) | −0.163 (0.106) | −0.072 (0.047) | −0.774* (0.416) |
| % of households growing maize (long-season) | 8.358*** (3.101) | 5.954*** (1.667) | 15.248 (9.799) |
| Distance to nearest water source (km) | 0.196*** (0.040) | 0.008 (0.023) | 0.054 (0.666) |
| District fixed effects    | Yes                   | Yes                    | Yes |
| F-Statistic               | 13.735                | 12.874                 | 2.491 |
| Observations              | 5820                  | 5820                   | 678 |
| Unique panel households   | 2201                  | 2201                   | 349 |

Note: District fixed effects are included. Results are based on a sub-sample of panel agricultural households with non-missing agricultural labor use data. Robust standard errors clustered at the enumeration area level are in parentheses.

*** p < 0.01, ** p < 0.05, * p < 0.10.
responses by gender. For example, the Women’s Empowerment in Agricultural Index (WEAI)\(^6\) can be used to capture the role of ownership and, perhaps more importantly, control of agricultural assets as well as workload on gender differences in responsiveness to heat stress. Data and indicators explicitly collected to capture psychological gender differences in heat stress responsiveness as well as sex-disaggregated migration data would greatly contribute to increase our understanding and provide further evidence on this rather underexamined topic.

**CONCLUSION**

While the adverse consequences of increasing drought vulnerability in sub-Saharan Africa have been widely documented, evidence of gender-specific effects has only just begun emerging. Although a large literature has addressed women’s vulnerability due to social, political, and economic marginalization, as well as their lower adaptive capacity to weather variability, gender-specific strategies in relation to climate resilience and mitigation have not received much attention.

Using sex- and activity-disaggregated agricultural labor and gridded weather data from Tanzania, we examine the effects of temperature shocks on agricultural labor reallocation, and their heterogeneity by agricultural activity (land preparation/planting, weeding, and harvesting). While women play a crucial role in agricultural production, significant spatial variation exists across farming systems and sex of agricultural workers, requiring activity-level analysis. We also analyze heterogeneous effects by gendered household structure (dual-adult vs. female-only members), measuring heat stress based on the number of full days in the maize growing season when temperature is above 29°C, a threshold above which significant negative effects have been reported on maize plant growth and yield. The use of panel data and fixed-effects estimator allows to identify effects of heat stress controlling for unobserved time-invariant characteristics.

Heat stress exerts differential effects on family and hired male and female agricultural labor. Males tend to reduce family agricultural labor following heat stress, similarly to the effect brought by female hired labor. However, heat stress does not seem to affect female family labor. These heterogeneous effects are even stronger for female-only households compared to dual-adult households. Specifically, heat stress significantly increases female family labor supply in female-only households. In contrast, it reduces male family labor in dual-adult households, with no effect on female family labor. Not only do we find heterogeneous impact of temperature shocks on agricultural labor allocation varying by gender and agricultural activity, but we also provide evidence that these effects are stronger the higher the number of women in the household, consistently with previous literature.

Our findings could have important implications for gendered policies on labor allocation. Gender-specific development interventions and adaptation strategies are suggested to promote women’s adaptive capacity and, thus, attain the Sustainable Development Goals (SDGs), especially SDG 5 and SDG 13. For example, skills development programs and farmer-to-farmer extension services targeting female farmers and enhancing adaptive capacity may improve adaptation to heat stress. These interventions may meet needs of female farmers who are often constrained by limited access to coping strategies helping to mitigate the adverse effects of climatic risks, for example policies increasing access to financial assistance and information on climate forecast. Furthermore, efforts on technical assistance such as small-scale irrigation and
mechanization schemes can support build women's resilience to heat stress by alleviating time burdens due to resource-intensive activities under shock exposure.

Further research is however needed on the long-term effects of women's empowerment on time use allocation, including in agriculture activities. Such research would enable policymakers and program implementers to develop more effective gender-based development interventions for promoting stronger resilience capacity for both men and women. While evidence presented here shows gender-differentiated responsiveness, additional research is recommended to understand the underlying impact pathway to identify possible entry points for policy.

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ENDNOTES

1 Family labor for which information on the identity of the member have not collected are excluded from the analyses. In addition, rounds 2 and 3 of the survey collected labor on three activities (ridging, fertilizing, and other post-harvest activities) are not included in round 1. For comparability, we focus on the three activities on which labor data were collected in all the three rounds.

2 Inaccuracy in farm labor data can be affected by several potential contributors such as the length of the recall period, cognitive burdens on respondents to recall information that they may have not measured (for example, about labor time by activity for each plot), as well as faults or failures in memory (Zamanian et al., 2017).

3 CHIRPS data available from http://chg.geog.ucsb.edu/data/chirps/.

4 Statistical significance of coefficient estimates does not appreciably vary when standard errors are clustered at the household level.

5 Mahajan (2017) finds that low rainfall drives down female daily wages in agriculture but increases male wages, thus exacerbating the gender wage gap and increasing demand for female labor in agriculture.

6 Women's Empowerment in Agricultural Index (WEAI) is a unique tool that can help to monitor women's empowerment described with five domains (production, resources, income, leadership, time). The indicators (e.g., ownership of assets, workload) are used for each of the domains (Alkire et al., 2013).

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