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Vulnerability to seasonal food insecurity as an exposure to risk: the case of the Southern Province of Zambia

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Abstract

Background Seasonality is an important aspect of food security for subsistence households in developing countries. Among the multidimensional aspects of food security, this paper focuses on how unexpected negative harvest shocks would affect the seasonal food consumption of households. This is particularly important because, with the increasing threat of climate change, the frequency of extreme weather events such as droughts and floods is expected to increase; this would adversely affect crop yields.

Methods Given seasonal price changes of staple foods, some households buy them when prices are low and store them for the hunger season (not buy high (NBH) households), while others run out of staple foods before the next harvest and therefore buy them when prices are high (buy high (BH) households). Using three years of weekly household panel data for the Choma and Sinazongwe Districts of the southern province of Zambia, we assess the ability of seasonal consumption smoothing separately for NBH and BH households.

Results NBH households successfully smooth their consumption over the 12 months of the crop year. In contrast, BH households, especially for households with few assets, reduce total consumption in response to harvest shocks, just after the harvest and during the "hunger season" just before the next harvest. However, in spite of this, the consumption of staple foods is generally insensitive to harvest shocks. Instead, they reduce consumption only of non-staple food items, such as vegetables and meats.

Conclusions Seasonal food insecurity is exacerbated by negative harvest shocks. We emphasize the significance of policies aimed at increasing public awareness of healthier food choices, empowering households to avoid purchasing maize at high prices, and reducing seasonal price disparities.

Keywords Seasonality, Food security, Consumption smoothing, Vulnerability, Negative harvest shocks, Zambia

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Background

Food security is achieved "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life", according to the 1996 World Food Summit definition [1]. Although there has been significant progress in reducing food security over the last two decades, between 690 and 783 million people in the world are estimated to face hunger, and 2.4 billion people do not have access to nutritious, safe, and sufficient food all year round [2]. In particular, the state of food security is severe in sub-Saharan Africa and Southern Asia, and the prevalence of stunting and wasting is higher in rural areas than in urban areas [2]. Food security in these areas is an urgent issue that should be resolved immediately.

Based on the definition by the Food and Agriculture Organization, the concept of food security includes the nutritional dimension, and there are four pillars of food security: availability, access, utilization, and stability [3]. Food availability refers to the physical existence of food, which is supplied through domestic production, national stocks, commercial imports and food aid. Food access refers to people's ability to obtain food through their own production and stocks, purchases, or other means. Food utilization refers to households or individuals' ability to make good use of the food they access through sufficient access to safe water and sanitation, appropriate practices of food storage, processing, and preparation. The final pillar refers to the stability of the other three factors over time. Although food availability is often evaluated by national-, subnational-, or community-level analysis, household- or individual-level analysis is essential for understanding food access, food utilization, and stability [4, 5].

To achieve food security, "a population, household or individual must have access to adequate food *at all time*" [6] (the italicized text has been added for emphasis by the author). In this sense of stability, seasonality is an important aspect of food security for households of subsistence farmers in developing countries [7–10]. They can harvest their crops following the regular patterns of the annual agricultural cycle. Their previous year's harvest stocks gradually dwindle, and some households run out of their food before the next harvest. These households need to buy their food with cash, but food prices are usually high immediately before the next harvest [11, 12]. Households who run out of food and buy their food when prices are high cannot buy an adequate amount of food. Most malnutrition and death among young children occur in those periods (e.g., [7]), as do famines (e.g., [8]).

The gravity of the issue has led to the emergence of a growing literature that addresses these cyclic patterns of the state of food security, which can be termed seasonal food insecurity [13]. Utilizing a food access indicator, such as per capita food expenditure, the household food insecurity access scale (HFIAS), household dietary diversity score (HDDS) and household food consumption score (HFCS), the decline in food security during the lean season (preharvest) has been detected [14–21], and the determinants of seasonal food insecurity have been investigated. Such studies have identified the demographic features of households that are more likely to be food secure across seasons [16–24]. In particular, the diversity of foods produced on smallholder farms [19–21, 25], access to the local food market [17, 26], and opportunities to generate cash income [26] are key aspects of improving food security across seasons. However, as mentioned in the policy brief by the Food and Agriculture Organization [6], households should not risk losing access to food because of sudden shocks such as an economic or climate crisis, which have not been addressed in the seasonal food insecurity literature. To fill this research gap, this paper addresses how unexpected negative harvest shocks affect the seasonal food consumption of households. This is particularly important because, with the increasing threat of climate change, the frequency of extreme weather events such as droughts and floods is expected to increase, adversely affecting crop yields [27, 28].

Description of the study area

Survey outline

Zambia is a landlocked country in sub-Saharan Africa. It has a population of approximately 20 million people, of whom 32.1% were undernourished from 2020 to 2022 and in 2021, 90.0% were unable to afford a healthy diet [2]. Thus, food insecurity and malnutrition are major concerns in Zambia. Moreover, Zambia is considered vulnerable to climate change because approximately 75% of the total population is smallholder farmers [29], and the increase in extreme climate events such as droughts and floods caused by climate change would have a large negative impact due to the rain-fed nature of their production [30]. In particular, the southern part of Zambia is considered more vulnerable to the effects of climate change than other parts of Zambia [30, 31].

The study area is in the "Sinazongwe area" of the Southern Province of Zambia, covering the shore of Lake Kariba (altitude 500 m) to the upper plain area (altitude 1050 m). Villages in this area are distributed with different annual rainfall within a radius of 15 km. Based on annual rainfall and topographical differences (on the flat or on the slope), our study area was divided into the lower flat zone near Lake Kariba (hereafter Site A), the middle slope zone (hereafter Site B), and the upper land zone on the plateau (hereafter Site C). These three sites are diverse in terms of agricultural ecosystems due to the differences in annual rainfall and topography. However, there are few differences in terms of social condition, such as access to markets and ethnic cultures [32, 33]

The villages here are spontaneous villages, not administrative villages. For this reason, there was no database that systematically compiled the names and locations of the villages. Therefore, in April 2007, a rapid extensive survey over the three zones was carried out, and a group interview was conducted in 17 intentionally selected villages to gather village-level information. Out of the 17 villages surveyed, 5 villages that represent the diversity of the study site were chosen (2 from Site A, 2 from Site B, and 1 from Site C). Administratively, sites A and B belong to the Sinazongwe district, while site C belongs to the Choma district.

Then, population censuses for 5 villages at the three sites were carried out in July and August 2007. Based on the results of the population census, 16 households were randomly chosen from each site, and the total number of sampled household was 47.[1] For these 47 households, a household survey was conducted every week from November 2007 to December 2011, collecting detailed consumption data. In this study, we utilized household panel data spanning three crop years.[2]

In September 2010, additional retrospective data were collected on the crop yields in the harvest seasons (April or May) of 2008, 2009 and 2010. For each plot, household members were also asked about planted crops for each year and asked to rate their crop yields using three categories: above average, average, and below average. To evaluate the relative value of each plot, they were asked about each plot's rental cost. In addition, in March 2011, they were interviewed to collect data on their maize purchases from the beginning of the research period, and those who purchased maize were asked when, how often, and the amounts they purchased at each time.

Typical income and consumption in the study area

According to the results of the weekly household survey [34], all 47 sampled households are found to be subsistence farmers whose main income source is agricultural production. The household members plant seeds once it starts raining, typically in November, and harvest crops from March to May. This period is the rainy season. After harvest, the dry season starts, and there is almost no rain. Throughout the year, but mainly during the dry season, there are various types of on-farm or off-farm work available to earn cash.

For consumption, Table 1 shows the average composition of values of consumption per week per adult equivalent[3] over the three years of data collection, calculated based on the weekly household survey data. Food consumption accounts for 83.3% of their consumption, almost half of which is for staple foods, primarily maize. The other half of food consumption is for vegetables and fruits, animal products, and processed food products, mainly for side dishes. Agricultural inputs such as fertilizers or seeds are excluded from these estimates of household consumption.

Table 1 Average composition of values of weekly consumption over 3 years (real terms)

	Values (ZMK)	%
Staples	3129	38.5
Vegetables	1698	20.9
Meat and fish	1152	14.2
Processed	795	9.8
Nonfood	1357	16.7
Total	8132	100.0

(Source) Household Survey Data. Resilience Project. ※ Percentages are based on average total consumption per week per adult-equivalent, which are in ZMK deflated by a monthly price index (= 1 for November 2007 at site A)

Seasonal price changes and the way households trade maize

All the sample households grow their maize for self-consumption. If their harvests exceed their annual consumption, they sell maize. If their maize production is insufficient for their annual consumption, they buy maize with cash. Figure 1 shows the average maize prices per bucket[4] for the three crop years. In each crop year, maize prices are lowest after the harvest season and gradually increase until the next harvest season. Compared to the lowest prices in May, peak prices increased by 58% on average.[5] Given these seasonal price changes, it is profitable for households to buy maize when maize prices are low and sell when maize prices are higher. However, only a few villagers sell maize in the hunger season when maize prices are high,[6] which may occur in our study site

[1] One household was dropped because it moved away.

[2] The data used are from May 2008 to April 2011. We define the crop year 08/09 as the 12 months from May 2008 to April 2009, the crop year 09/10 from May 2009 to April 2010, and the crop year 10/11 from May 2010 to April 2011. The data from November 2007 to April 2008 are not used because there are no data on crop harvest for that year. The data from May 2011 to December 2011 are not used because there are no data regarding maize trading patterns in that period.

[3] Adult-equivalent scales are adopted from the Living Conditions Monitoring Survey reports published by the Central Statistics Office, Zambia. For each household, the number of adult equivalents is defined as (number of adult males) + (number of adult females) + (number of children (10–12 years)) * 0.76 + (number of children (7–9 years)) * 0.78 + (number of children (4–6 years)) * 0.62 + (number of children (0–3 years)) * 0.36. Adults are defined as above 12 years old.

[4] In the study area, a bucket is a standard unit in the market. One bucket of maize is a bucket filled with maize (approximately 15.5 kg), and the bucket size is standardized in the study area.

[5] Note that this number is in real terms, that is, deflated by the GDP deflater, which is approximately 12% per year. Peak prices highly depend on crop situations around the study area in each year.

[6] As far as we know, in our study area, only one villager, who obviously had a large amount of capital, practiced such intertemporal price arbitrage, and he was not in one of our sample households. There are some outside intervillage traders, called briefcase businessman, who practice such intertemporal price arbitrage.

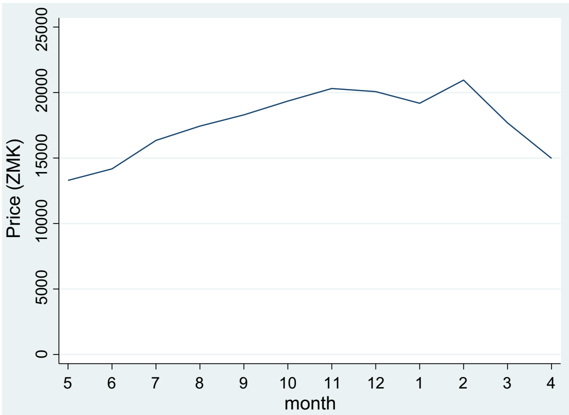

Fig. 1 Seasonal patterns of average maize price per bucket over 3 years. (Source) Household Survey Data. Resilience Project. ※ Numbers in ZMK deflated by a monthly price index (= 1 for November 2007 at site A)

due to high transaction costs for selling maize in the hunger season. Important sources of such transaction costs in our study area include social pressure to share surplus maize with neighboring households in difficult situations and additional storage capacity for intertemporal price arbitrage.

On the maize purchasing side, Table 2 presents data on households by their purchase patterns for maize. Over three crop years, slightly less than half (68) of the 141 household-year observations had purchases of maize, and there are two distinct patterns for these maize purchases. One is purchases of maize from May to December; almost all these observations consist of only one or two purchases. These are situations where households bought maize relatively soon after the harvest, when maize prices were low, and stored them for the hunger season. In this paper, these households are referred to as not buy high (NBH) households. The other group of observations is households that purchased maize from January to April (many of whom also purchased maize before January); almost all of them bought maize more than three times. They bought maize frequently because they repeated a cycle in which they worked until they had enough money to buy some units of maize (for example, one bucket of maize) purchased the maize, and this was repeated several times. This is likely to be a cycle of every week, every 15 days, or every month. In this paper, these households are referred to as buy high (BH) households.

Seasonal price changes of staple foods that are cheapest after the harvest season and that gradually increase until the next harvest season are commonly observed in broad areas of sub-Saharan Africa [11], and the patterns of trade of staple foods observed in our study are not specific to our study area. For example, a broader survey conducted at approximately the same survey period by Simtowe and De Groote [35], which used survey data from 1128 households drawn from 35 districts of five provinces in Zambia from May 2010 to April 2011, observed similar patterns of maize trade to those in our survey. For the maize selling side, the authors observed that only 4% of the total sample households sold maize from November to April. For the maize purchasing side, they reported that 33% of the total sample households purchased maize from November to April, while 26% of the sample households of this study purchased maize after December. Moreover, similar seasonal patterns of trading staple foods are reported not only in Zambia [35, 36], but also in broader rural areas of sub-Saharan Africa [37–40]. Although our data set is collected from a limited area and seems somewhat outdated, the arguments in this paper are still active in broader areas.

Analytical framework

Vulnerability as exposure to risk

When households of farmers face harvest shocks and decrease agricultural income during the harvest season, they smooth their consumption by relying on borrowing or savings (e.g., [41]) or by entering informal risk sharing

Table 2 Number of households by maize purchase pattern

		Over 3 years		08/09		09/10		10/11	
		Number	%	Number	%	Number	%	Number	%
Purchase		68	48	27	57	25	53	16	34
Purchase only until December ("buy low")	One or two times	30	21	15	32	8	17	7	15
	More than two times	2	1	0	0	0	0	2	4
Purchase after December ("buy high")	One or two times	1	1	0	0	0	0	1	2
	More than two times	35	25	12	26	17	36	6	13
Does not purchase		73	52	20	43	22	47	31	66
Total		141	100	47	100	47	100	47	100

Source Household Survey Data. Resilience Project arrangements (e.g., [42]). However, when such mechanisms do not function well (due to incomplete credit markets or insufficient risk sharing networks), they are unable to achieve perfect consumption smoothing and may reduce their food consumption during the time just before they receive their harvest income.[7] Thus, their sensitivity of consumption to negative harvest shocks could be interpreted as their inability to smooth consumption [45, 46].

Although a sizable body of literature has addressed the ability to smooth consumption across years (e.g., [41, 42, 47–50]), literature addressing households' ability to smooth consumption within a year is scarce, and the results are somewhat mixed. Paxson [51] and Chaudhuri and Paxon [52] found no evidence that seasonal consumption tracks seasonal income patterns in Thailand and India, respectively, while Dercon and Krishnan [53] and Khandker [54] showed that seasonal income affects seasonal consumption in Ethiopia and Bangladesh, respectively. These studies implicitly assumed that each household's ability to smooth consumption is identical. However, incomplete credit markets and high transaction costs of maize selling in the hunger season, combined with seasonal price changes of maize, affect seasonal consumption differently for households who did not buy maize at higher prices during the crop year (NBH households) relative to households who bought maize at higher prices (BH households). This is because high prices of staple food just before harvest can be viewed as a (potentially) high return to savings for BH households or, more accurately, a high opportunity cost of not saving, but not for NBH households[8] In particular, the ability of households to smooth consumption is likely to be different for BH and NBH households because, using cash income from off-farm labor, BH households have no choice but to buy maize at higher prices than NBH households. Thus, this paper estimates seasonal consumption separately for NBH and BH households. A more rigorous discussion that utilizes a theoretical model is illustrated in Appendix A of the Online (Additional file 1).

To test the impact of negative harvest shocks on consumption, the following regression model is estimated:

$$C_{iymw} = \sum_{y=1}^{3}\sum_{m=1}^{12}\alpha_{ym}D_{ym} + \sum_{m=1}^{12}\beta_m TI_{iy}d_m + \gamma X_{iy} + \delta X_{iy} + \xi_{vy} + \upsilon_i + u_{iymw}, \quad (1)$$

where subscript i denotes household, y denotes year,[9] m denotes month, w denotes week, and v denotes village. C_{iymw} is an average weekly consumption per adult equivalent of household i in week w of month m of year y, D_{ym} is a dummy variable that equals one if the year is y and the month is m and 0 otherwise, and the term α_{ym} captures average seasonal consumption patterns in each year. Note that, the sequence of maize prices in each year affects seasonal consumption patterns in that year; these seasonal price effects are captured by α_{ym} for $m=1\ldots,12$.[10] TI_{iy} is the harvest shock that household i suffered at the beginning of crop year y, and d_m is a dummy variable that equals one if the month is m and 0 otherwise. The construction of the variable, TI_{iy}, is discussed in the following subsection. X_{iy} is a vector of year variant household variables for household i, X_{iym} is a vector of monthly variant household variables for household i, ξ_{vy} is unobserved year-varying village fixed effects, υ_i is household fixed effects, and u_{iymw} is an error term that has an expected value of zero. Error terms are clustered at the household level and are robust to heteroscedasticity of unknown form. Equation (1) is estimated separately for BH households and for NBH households. Note that household-specific factors, such as household attributes or the unobserved ability of household members, are absorbed into household fixed effects. Note also that sample selection bias arising from any household-specific factor, such as the assets and borrowing abilities of households, is controlled in this model because the predicted inverse Mills ratio constructed from a selection equation to determine BH and NBH, which are commonly used in Heckman-type corrections of sample selection (e.g., [56–58]), are absorbed into household fixed effects. Equation (1) is estimated by a within-estimator to cancel out fixed effects.

The coefficients β_m capture the impact of harvest shocks on consumption in each month and are the parameters of interest. If the household successfully smooths consumption both across years and within a crop year, all the β_m coefficients should be zero. If the household cannot smooth consumption across years but can smooth consumption within a crop year, then the

[7] Fafchamps [43] and Dercon [44] provide comprehensive surveys of this literature.

[8] High prices of the staple food just before harvest cannot be viewed as a high return to savings for NBH households because they save enough maize for self-consumption and need to pay high transaction costs if they want to sell maize at high prices. See Kitsuki [55] for more detailed discussion.

[9] Year 1 is the crop year 08/09, year 2 is the crop year 09/10, and year 3 is the crop year 10/11.

[10] Since the study villages are located within a radius of 15 km, maize prices are assumed to be identical for all the sample households.

β_m coefficients will be negative but will be equal across months. If the farmer is unable to smooth consumption within a crop year, then some β_m coefficients will be negative. In this case, this paper will discuss how households adjust their consumption during the year by decomposing total consumption into staple foods, other foods, and nonfood items.

Considering exposure to risk as the key element of vulnerability, this kind of analytical approach is categorized as a "vulnerability as exposure to risk" approach [45, 46, 59]. In this approach, households are considered vulnerable to poverty (or food insecurity) when they are at risk of being poor (or food insecure) given their inability to smooth consumption over time [46]. Note that the estimated coefficients β_m's by themselves do not allow us to determine whether households are vulnerable because it is possible that those people who are always food secure could also decrease their consumption in response to negative harvest shocks. However, considering the situation in Zambia in which 90.0% of the population was unable to afford a healthy diet [2], the inability to smooth consumption could be understood as vulnerability to poverty (or food security). In this sense, this approach is useful compensation for the vulnerable approach[11]

Variable definitions

The main dependent variable is the value of total consumption per week per adult equivalent in real terms, which is normalized by dividing the value by its simple averages across the households over three years. Moreover, total consumption is divided into staple foods, other foods (almost always corresponding to side dishes of the diets, such as vegetables, fish, and meats, which are the most important source of many micronutrients.) and nonfood items, and Eq. (1) for each set of goods are estimated. Households that buy maize at higher prices are defined as households that bought maize after December because distinctive patterns for their maize purchases can be observed, as shown in Table 2.

The TI_{iy} variable, which represents harvest shocks, is carefully constructed so as not to correlate with unobservable factors u_{iymw}. As a proxy for this variable, rainfall data are commonly used. However, we cannot use such data because precipitation is almost identical among all households due to the narrowness of study area. Instead, the survey data collected in September 2010, which include retrospective data on negative harvest shocks, are used in this assessment. For each plot in each year, households were asked whether each plot was fallow in that year. When the plot was not fallow, a general indicator of crop yield was requested for each plot using a simple scale of "above average", "average" or "below average". The reasons for being "below average" are classified into the following categories: (1) heavy rain; (2) lack of seed; (3) lack of fertilizer; or (4) other reasons. In addition, household members were asked about rental costs for each plot to evaluate their relative values. Note that since the land market is incomplete, rental costs are subjective. From these data, the fraction of the value of plots that are below average for other reasons, divided by the total value of the land, was calculated for each household in each year to use as a proxy for harvest shocks. For example, if a household has three plots with rental costs of 300ZMK, 500ZMK, and 200ZMK and the respective crop situations are below average due to insects (which would be included as "other reasons" in the data), average, and below average due to the lack of fertilizer, the value of the proxy is $0.3 = 300/(300 + 500 + 200)$. The fraction of "below average due to lack of seed or lack of fertilizer" is excluded from the proxy because these phenomena could reflect farm management decisions in the previous year, which could be correlated with other decisions in the previous year that affect consumption in the following year (e.g., off-farm labor supply). As for time-varying household variables, number of cattle are included, because cattle are the most important household asset in our study area [62]. In addition, number of household members are controlled on a monthly basis, because it can change due to births, deaths, schooling, or seasonal work. Summary statistics of the variables used to estimate Eq. (1) are reported in Appendix B of the Online (Additional file 1).

Estimation results

Tables 3, 4, 5 report estimated parameters β_m^j in Eq. (1), in which the dependent variable is total consumption (Table 3) and its components, that is, staple food, other food, and nonfood (Table 4 for NBH households, and Table 5 for BH households)[12] The coefficients can be interpreted as the changes in the value of consumption per week per adult equivalent (compared to the sample average over all households over three years) that would occur if all of their plots were "below average".[13] In addition, to determine how sensitivity to negative

[11] The concept of vulnerability differs in various disciplines. Adger [60] and Paul [61] provide comprehensive surveys of this literature.

[12] The estimated results, including all other control variables, are reported in Appendix C of the Online (Additional file 1). Tables C.1, C.2., and C.3 report all coefficients of Tables 3, 4, and 5, respectively.

[13] For example, consider the BH group in May. The coefficient for total consumption is -0.363. This implies that if 10% of the plots of the BH farmer are below average, the total consumption per week per adult equivalent decreases by 3.63% (=36.3%*0.1) of the sample average of total consumption.

Table 3 Estimation results (total consumption) with HH fixed effects

Variables	Full sample	NBH	BH	NBH	BH
(i) Income shock * month dummy					
May	− 0.275 (0.185)	− 0.198 (0.236)	− 0.363** (0.160)	− 0.237 (0.350)	− 0.361** (0.158)
June	− 0.193 (0.139)	− 0.142 (0.200)	− 0.450*** (0.118)	− 0.022 (0.254)	− 0.459*** (0.119)
July	− 0.193 (0.152)	− 0.130 (0.198)	− 0.334*** (0.087)	− 0.001 (0.209)	− 0.340*** (0.072)
August	− 0.037 (0.134)	0.066–0.142	− 0.321*** (0.106)	0.104 (0.181)	− 0.333*** (0.097)
September	− 0.143 (0.185)	− 0.020 (0.272)	− 0.399** (0.183)	− 0.184 (0.313)	− 0.404** (0.172)
October	− 0.062 (0.131)	0.016 (0.176)	− 0.232 (0.151)	0.035 (0.244)	− 0.237 (0.159)
November	− 0.277* (0.153)	− 0.152 (0.150)	− 0.840 (0.492)	− 0.142 (0.202)	− 0.806* (0.459)
December	− 0.189 (0.179)	− 0.072 (0.245)	− 0.180 (0.121)	− 0.172 (0.283)	− 0.200 (0.126)
January	− 0.046 (0.174)	0.008 (0.277)	− 0.096 (0.105)	0.074 (0.345)	− 0.100 (0.113)
February	− 0.071 (0.144)	− 0.023 (0.207)	− 0.271* (0.144)	− 0.134 (0.281)	− 0.393*** (0.093)
March	− 0.056 (0.119)	0.028 (0.180)	− 0.418*** (0.116)	0.057 (0.243)	− 0.529*** (0.145)
April	− 0.272 (0.182)	− 0.016 (0.233)	− 1.483 (0.869)	− 0.149 (0.303)	− 1.367* (0.793)
(ii) Income shock * month dummy * cattle					
May				0.010 (0.034)	0.004 (0.105)
June				− 0.035 (0.027)	0.035 (0.165)
July				− 0.032* (0.018)	− 0.051 (0.171)
August				− 0.010 (0.023)	0.098 (0.156)
September				0.043 (0.027)	0.050 (0.121)
October				− 0.006 (0.023)	0.050 (0.135)
November				− 0.003 (0.023)	− 0.011 (0.153)
December				0.027 (0.022)	0.093 (0.098)
January				− 0.019 (0.030)	0.053 (0.112)
February				0.030 (0.026)	0.277*** (0.096)
March				− 0.009 (0.025)	0.242** (0.107)
April				0.033 (0.025)	− 0.131 (0.189)
Fixed effect					
Period * village	Yes	Yes	Yes	Yes	Yes
Household	Yes	Yes	Yes	Yes	Yes
Period * Household	No	No	No	No	No
(i) F-statistics	F(12,46)	F(12,43)	F(12,20)	F(12,43)	F(12,20)
(Income Shock * Month Dummy)	0.84	0.84	21.42	0.54	17.45
p value	0.6079	0.6092	0.0000	0.8746	0.0000
(ii) F-statistics				F(12,43)	F(12,20)
(Income shock * month dummy * cattle)				3.58	19.53
p value				0.0010	0.0000
Observations	6813	5132	1681	5132	1681
R-squared	0.178	0.203	0.182	0.204	0.187

Robust standard errors are in parentheses

*** $p < 0.01$

** $p < 0.05$

* $p < 0.1$

harvest shocks differs depending on asset holdings, interaction terms of harvest shocks and the number of cattle were added in each month. In this case, coefficients of the intersection terms of harvest shocks and month dummy are interpreted as income sensitivities for households with no cattle, and coefficients on the intersection terms for harvest shocks, the month dummy, and the number of cattle are interpreted as the marginal impact of one cattle on income sensitivities. Test results for the null hypothesis that (i) all the β coefficients of intersection terms of the income shock and the month dummies are zero and (ii) all the

Table 4 Estimation results (staple food, other food, nonfood) with HH fixed effects: NBH households

Variables	Staple food	Other food	Nonfood	Staple food	Other food	Nonfood
(i) Income shock * month dummy						
May	0.016 (0.173)	– 0.200 (0.235)	– 0.689 (0.714)	–0.130 (0.242)	– 0.117 (0.342)	– 0.807 (1.042)
June	0.017 (0.158)	0.003 (0.173)	– 0.901 (0.715)	0.118 (0.211)	0.098 (0.220)	– 0.670 (0.980)
July	– 0.147 (0.165)	0.041 (0.162)	– 0.553 (0.721)	– 0.013 (0.227)	0.135 (0.191)	– 0.341 (0.770)
August	0.031 (0.127)	– 0.152 (0.154)	0.734 (0.599)	0.043 (0.186)	– 0.119 (0.167)	0.847 (0.697)
September	0.176 (0.169)	– 0.090 (0.173)	– 0.283 (1.332)	0.071 (0.190)	– 0.096 (0.218)	– 1.009 (1.344)
October	0.101 (0.121)	– 0.002 (0.163)	– 0.132 (0.639)	0.100 (0.155)	0.051 (0.211)	– 0.155 (0.831)
November	0.024 (0.187)	– 0.253 (0.160)	– 0.288 (0.571)	0.094 (0.212)	– 0.228 (0.205)	– 0.455 (0.736)
December	0.144 (0.157)	0.035 (0.220)	– 0.859 (0.936)	0.224 (0.207)	– 0.188 (0.192)	– 1.040 (1.163)
January	– 0.017 (0.186)	0.030 (0.378)	0.006 (0.755)	0.013 (0.225)	0.235 (0.469)	– 0.220 (0.886)
February	0.126 (0.175)	0.187 (0.178)	– 0.935 (0.849)	0.058 (0.227)	0.094 (0.216)	– 1.191 (1.048)
March	– 0.011 (0.186)	0.019 (0.188)	0.143 (0.567)	0.066 (0.231)	0.056 (0.227)	0.039 (0.725)
April	0.174 (0.169)	0.003 (0.262)	– 0.503 (0.632)	0.027 (0.209)	– 0.041 (0.307)	– 0.845 (0.855)
(ii) Income shock * month dummy * cattle						
May				0.038 (0.027)	– 0.020 (0.037)	0.025 (0.093)
June				– 0.029 (0.027)	– 0.026 (0.025)	– 0.075 (0.139)
July				– 0.032 (0.026)	– 0.022 (0.022)	– 0.055 (0.050)
August				– 0.003 (0.020)	– 0.008 (0.021)	– 0.034 (0.108)
September				0.028 (0.028)	0.003 (0.027)	0.186 (0.163)
October				0.001 (0.021)	– 0.014 (0.024)	– 0.001 (0.063)
November				– 0.018 (0.027)	– 0.006 (0.033)	0.037 (0.057)
December				– 0.022 (0.021)	0.062* (0.032)	0.043 (0.072)
January				– 0.008 (0.025)	– 0.055 (0.046)	0.054 (0.078)
February				0.019 (0.027)	0.027 (0.025)	0.062 (0.077)
March				– 0.022 (0.031)	– 0.009 (0.026)	0.022 (0.060)
April				0.037* (0.021)	0.012 (0.026)	0.080 (0.071)
Fixed effect						
Period * village	Yes	Yes	Yes	Yes	Yes	Yes
Household	Yes	Yes	Yes	Yes	Yes	Yes
Period * household	No	No	No	No	No	No
(i) F-statistics						
(Income shock * month dummy)	0.80	0.83	1.14	0.59	0.64	1.01
p value	0.6454	0.6209	0.3545	0.8340	0.8003	0.4573
(ii) F-statistics						
(Income shock * month dummy * cattle)	4.24	3.21	0.77			
p value				0.0002	0.0024	0.6744
Observations	5132	5132	5132	5132	5132	5132
R-squared	0.189	0.246	0.086	0.191	0.248	0.086

Robust standard errors are in parentheses

*** $p < 0.01$

** $p < 0.05$

* $p < 0.1$

coefficients of intersection terms of the income shock, the month dummies, and the number of cattle are zero are reported at the bottom of Tables 3, 4.

The first column of Table 3 shows the results using all sample households together. The null hypothesis that all the coefficients on the interaction terms of income shock and month dummy are zero cannot be rejected. To see how such income sensitivities differ for NBH households and BH households, all other columns in Tables 3, 4, 5 report the results of separate estimations for NBH households and BH households. The robustness of the results of this section is discussed in Appendix D of the Online (Additional file 1).

Table 5 Estimation results (staple food, other food, nonfood) with HH fixed effects: BH households

Variables	Staple food	Other food	Nonfood	Staple food	Other food	Nonfood
(i) Income shock * month dummy						
May	0.070 (0.173)	− 0.516* (0.252)	− 0.951 (0.795)	0.034 (0.186)	− 0.536* (0.259)	− 0.803 (0.771)
June	0.030 (0.145)	− 0.744*** (0.180)	− 0.765** (0.331)	0.022 (0.128)	− 0.785*** (0.196)	− 0.696** (0.327)
July	− 0.044 (0.141)	− 0.301*** (0.096)	− 1.094*** (0.316)	− 0.055 (0.117)	− 0.323*** (0.091)	− 1.043*** (0.313)
August	− 0.121 (0.137)	− 0.309 (0.221)	− 0.817** (0.380)	− 0.135 (0.133)	− 0.307 (0.209)	− 0.861** (0.390)
September	− 0.136 (0.184)	− 0.280 (0.173)	− 1.325 (1.007)	− 0.212 (0.194)	− 0.281 (0.179)	− 1.175 (0.904)
October	0.055 (0.151)	− 0.388* (0.204)	− 0.476 (0.385)	− 0.005 (0.149)	− 0.377 (0.228)	− 0.394 (0.370)
November	0.030 (0.194)	− 0.578* (0.292)	− 3.547 (2.384)	− 0.044 (0.165)	− 0.579* (0.316)	− 3.172 (2.128)
December	− 0.104 (0.147)	− 0.383* (0.193)	0.194 (0.365)	− 0.087 (0.145)	− 0.416* (0.201)	0.122 (0.331)
January	0.020 (0.117)	− 0.209* (0.110)	− 0.058 (0.281)	0.056 (0.126)	− 0.216* (0.119)	− 0.146 (0.274)
February	− 0.238** (0.084)	− 0.167 (0.185)	− 0.631 (0.479)	− 0.375*** (0.126)	− 0.280* (0.153)	− 0.738 (0.444)
March	− 0.185 (0.133)	− 0.683*** (0.192)	− 0.241 (0.403)	− 0.218 (0.143)	− 0.840*** (0.276)	− 0.409 (0.357)
April	− 0.278 (0.165)	− 1.489* (0.786)	− 4.245 (3.059)	− 0.172 (0.122)	− 1.456* (0.744)	− 3.882 (2.787)
(ii) Income shock * month dummy * cattle						
May				0.100 (0.087)	0.140 (0.131)	− 0.583* (0.295)
June				− 0.052 (0.204)	0.268* (0.131)	− 0.390 (0.398)
July				− 0.032 (0.198)	0.045 (0.186)	− 0.354 (0.401)
August				0.090 (0.106)	0.111 (0.198)	0.080 (0.396)
September				0.217** (0.098)	0.150 (0.150)	− 0.603 (0.392)
October				0.141* (0.081)	0.146 (0.175)	− 0.417 (0.298)
November				0.160* (0.089)	0.166 (0.149)	− 0.882 (0.525)
December				0.001 (0.125)	0.247** (0.113)	− 0.105 (0.333)
January				− 0.015 (0.080)	0.178 (0.116)	− 0.128 (0.350)
February				0.303*** (0.079)	0.383*** (0.112)	− 0.067 (0.355)
March				0.097 (0.077)	0.442*** (0.137)	0.036 (0.340)
April				− 0.115 (0.103)	0.119 (0.210)	− 0.836 (0.661)
Fixed effect						
Period * village	Yes	Yes	Yes	Yes	Yes	Yes
Household	Yes	Yes	Yes	Yes	Yes	Yes
Period * household	No	No	No	No	No	No
(i) F-statistics						
(Income shock * month dummy)	5.68	7.08	14.57	5.61	13.13	16.29
p value	0.0003	0.0001	0.0000	0.0004	0.0000	0.0000
(ii) F-statistics						
(Income shock * month dummy * cattle)				32.58	7.58	2.84
p value				0.0000	0.0000	0.0190
Observations	1,681	1,681	1,681	1,681	1,681	1,681
R-squared	0.314	0.229	0.097	0.324	0.234	0.100

Robust standard errors are in parentheses

*** $p < 0.01$

** $p < 0.05$

* $p < 0.1$

NBH households: the household who does not buy maize at higher prices

The second column of Table 3 presents the results for the seasons when households did not "buy high" (NBH households). None of the coefficients is significant, and they are not jointly significant. In addition, looking at the fourth column of Table 3, even NBH households with no cattle did not decrease their consumption in response to harvest shocks.[14] These results indicate that households that did not buy maize at higher prices successfully smoothed their consumption during a crop year regardless of their wealth status. Furthermore, there is no evidence that they smoothed total consumption by adjusting the composition of their consumption. This is shown in Table 4; no coefficients of the interaction terms between the income shock and the month dummy variable are significant.

BH households: households who buy maize at higher prices

The third column of Table 3 shows that BH households reduce total consumption throughout the crop year in response to negative harvest shocks, especially just after the harvest and during the "hunger season" just before the next harvest. In addition, the fifth column of Table 3 exhibits a role of household assets in smoothing consumption; the coefficients of the interaction terms of the income shock, the month dummies, and the number of cattle are significant in February and March. These results indicate that households that buy maize at higher prices are unable to achieve perfect consumption smoothing regardless of their wealth status, but they can mitigate the impacts of negative harvest shocks in the hunger season as household assets increase. Note, also, that the size of the impact of harvest shocks is not negligible. For example, the coefficient of harvest shocks in March is -0.418, which is significant at the 1% level. This means that if 10% of these households' land suffers from a below-average harvest, they decrease their consumption by 4.2% of the sample average of total consumption.

Although the households in the BH group decrease their total consumption in response to harvest shocks, they almost smooth their consumption of staple foods despite the seasonal price hike for maize. This is seen in the first column of Table 5; only the coefficient for February is significant.[15] In addition, the fourth column of Table 5 shows that the negative coefficient in February is mitigated as household assets increase. In contrast, these households reduced the consumption of *other food* at a non-negligible level just after harvest (June and July) and before harvest (November to April). For example, the coefficient of harvest shocks in March is -0.683 in the second column of Table 5, which is significant at the 1% level. This means that if 10% of these households' land suffers from a below-average harvest, they decrease their consumption of other food by 6.83% of the sample average. Note that these other foods generally correspond to the side dishes of their diet, which are important sources of micronutrients, such as vitamin A, zinc, and protein. These results show that even if the households in this group suffer negative harvest shocks, they sustain their consumption of staple foods by purchasing maize at higher prices. To do so, they decrease their consumption of other foods, such as vegetables and meats. Thus, one dimension of negative harvest shocks that should not be overlooked is the intake of micronutrients, which could change over time with a crop year due to seasonal price changes of the staple food. Last, the fifth column of Table 5 shows that for BH households with more assets, these shocks are mitigated mainly during the latter half of the crop year.

Finally, consider nonfood items. According to the third and sixth columns of Table 5, BH households significantly decrease their consumption in June, July, and August but do not decrease their consumption after August. These results are reasonable considering that households in the study area tend to purchase nonfood household goods such as clothes and kitchen utensils just after harvest and that most of these other goods consist of daily necessities that can be stored over the crop year, such as candles or soap.

Discussion and conclusions

Using three years of weekly household panel data collected from the Choma and Sinazongwe Districts in the southern province of Zambia, this paper has analyzed the households' ability to smooth consumption by identifying the impact of negative harvest shocks on consumption. When faced with seasonal price changes of a staple food, some households buy it when prices are low and store enough for consumption during the hunger season (NBH households), while others do not store enough and run out of the staple food; therefore, they buy it when prices are high (BH households). This paper tests the ability of seasonal consumption smoothing separately for NBH and BH households.

While previous studies have assumed an equal ability to smooth consumption across all households and have yielded mixed results [51–54], this paper identifies heterogeneity within the two groups of households. Our results show that NBH households successfully smooth their consumption over the 12 months of the crop year. In contrast, BH households, especially for households with few assets, reduce total consumption in response to harvest shocks, just after the harvest and during the "hunger season" just before the next harvest. However, in

[14] The coefficients of the intersection terms of the income shock, the month dummies, and the number of cattle are jointly significant, but almost all the coefficients are insignificant, and they are not very large.

[15] The coefficients of intersection terms of the income shock and the month dummies are jointly significant. In addition, the coefficients in March and in April are negative with relatively small standard errors, although these are insignificant. These results indicate that BH households may also slightly decrease their consumption of staple foods throughout the hunger season.

spite of this, the consumption of staple foods is generally insensitive to harvest shocks. Instead, they reduce consumption only of non-staple food items, such as vegetables and meats.

Their inelastic demands for staple foods and elastic demands for other foods reveal their strong preferences for staple foods compared to non-staple food items. This emphasizes the need for policies that raise public awareness about the significance of non-staple foods for their health. Furthermore, our results align with frequently observed patterns of seasonal food insecurity in rural areas of sub-Saharan Africa. These patterns include no seasonal variation in grain consumption [40] but a reduction in food diversity during agricultural lean seasons [14, 16, 18, 21, 22, 25]. Our estimation results indicate that seasonal food insecurity is exacerbated by negative harvest shocks. This implies that an increase in negative agricultural harvest shocks resulting from heightened climate change threats could worsen the current state of seasonal food insecurity, unless households and their surrounding social-ecological systems adapt to accommodate such shocks. The significance of policies addressing seasonal food insecurity should also be underscored in preparation for the escalating threat of climate change.

Our estimation results also indicate that BH households should be a target for policies aimed at reducing seasonal food insecurity. In this sense, interventions designed to prevent households from purchasing staples when prices are high should be promoted. These interventions could include offering access to credit markets [36, 37, 39, 63], providing effective storage solutions to minimize harvest losses [63, 64], and implementing agricultural input subsidies [35]. However, it is important to consider production diversity. Theoretically, households that are less likely to fall into the BH households are those that focus on cultivating their staple foods [24]. This implies that, in the face of seasonal price fluctuations, households have an incentive to reduce production diversification and concentrate on growing staple foods. Nevertheless, studies have shown that this approach tends to decrease seasonal food security [65, 66]. Thus, in order to diminish such incentives, it is important not only to make efforts to reduce the number of BH households, but also to address seasonal price gaps through measures like market integration [67, 68].

We conclude this paper by highlighting three limitations of the study and proposing areas for future research. First, our data were collected weekly for 3 years from each household, but the total number of sampled households is 47. While this data is suitable for analyzing seasonal variations *within* each group of households (NBH households and BH households), exploiting variations *across* these groups is not possible. As a result, we cannot empirically analyze why some households buy maize at higher prices in certain years while others do not. Thus, collecting seasonal household data on a larger scale in the future is essential. Second, this paper examined the stability of food access at the household level. However, due to traditional gender roles, cultural norms, household bargaining power, or other factors, the allocation of food within households might not be based solely on the needs of individual household members. Specific groups within households, such as children or women of childbearing age, could experience food insecurity [69, 70]. Future analyses should delve into food utilization at the individual level. Lastly, the definition of vulnerability in this paper is narrow, limiting our analysis to only certain aspects of vulnerability. For instance, we do not consider adaptive capacity, which refers to the ability of a system to evolve in order to accommodate environmental hazards or policy change and to expand the range of variability with which it can cope [60]. Insufficient adaptive capacity could prolong the negative effects of adverse harvest shocks on food security, potentially hampering the ability to cope with subsequent shocks. The scope of this paper does not encompass the analysis of such dynamics. Given the various concepts of vulnerability [60, 61, 71], it is necessary for future studies to construct a new framework for analyzing such dynamics.

Abbreviations

BH households	Buy high households
NBH households	Not buy high households

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40066-023-00442-4.

Additional file 1: Appendix A: Theoretical Model, **Appendix B:** Summary Statistics, **Appendix C:** Estimation Results (Full version), **Appendix D:** Robustness of the results.

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Author contributions
AK designed and executed the survey and wrote the manuscript. TS designed and executed the survey and helped to write the manuscript. Both authors read and approved the final manuscript.

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Availability of data and materials

The data sets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The Zambia Agricultural Institute has the legal authority to conduct research in their local communities and engage with households, and they were contacted to request permission to carry out the questionnaire survey in the areas under their respective research jurisdiction. On the day of the exercise, every participant's respondent gave their consent to take part in the survey.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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