

Supplementary Material

Characteristics and socioeconomic performance of neglected and underutilized plant species (NUS) production systems in Burkina Faso

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Box S1: Economy and agriculture in Burkina Faso.

Burkina Faso is one of the poorest and most food insecure countries in the world. The average annual per capita income stands at USD 874.1 (187th out of 192 countries globally) and the Human Development Index at 0.449 (184th) in the world (The World Bank 2024). Approximately 21.2% of the population can be considered as food insecure, with high prevalence of child stunting (22.6%) (The World Bank 2024). Poverty and food insecurity rates are higher in many rural areas, particularly those that experience challenging climatic conditions (Tankari 2020).

The national economy is heavily reliant on the agricultural sector, which occupies approximately 80% of the population and accounts for 16.3% of the national Gross Domestic Product (GDP) (Bilali 2020, The World Bank 2024). Cotton is an important commodity crop that dominates the economic output of the agricultural sector (Bilali 2020). However, the majority of arable land is under food crops, with >50% of total cultivated land dedicated to cereal production, including crops such as sorghum, pearl millet, maize, and rice (Bilali 2020).

A large proportion of the national food crop production comes from small-scale food production systems, which are characterized by small plot sizes, use of unimproved production technologies, low market orientation, and high levels of food self-consumption (Bunclark *et al* 2018). Although agricultural areas expanded rapidly in the past decades (91% increase between 2001-2014), this was through the expansion of small-scale farms. As a result the agricultural output cannot meet the domestic demand due to fast population growth (56% increase between 2000-2015) and low agricultural productivity (Knauer *et al* 2017).

Box S2: Methodological challenges and mitigation.***Selection of study areas and participants***

Expert consultation and participatory processes have been used extensively for site selection in many studies due to their ability to tap into rich local knowledge (Porcuna-Ferrer *et al* 2023), but the fact remains that they could introduce certain biases and uncertainties. Participant selection in the specific study sites also was constrained by the lack of comprehensive lists of NUS producers to enable their randomized selection. Furthermore, it was not possible for the research team to pre-record all NUS producers in the selected regions, as this was beyond the scope of the study and would have required prohibitively extensive resource. For this reason, we used the transect walks to randomize to the extent possible participant selection. Although several studies and protocols have used such approaches in the absence of producer lists (Gasparatos *et al* 2018), the fact remains that perfect randomization is challenging and possible selection biases cannot be entirely ruled out.

Variable recollection

Key variables such as NUS production, consumption and income were recorded using a 12-month recall period, which may pose challenges in terms of respondent recollection and could lead to underestimation (Beegle *et al* 2012, Wang *et al* 2024). To minimize to the extent possible these effects, we meticulously designed the survey and trained the enumerators. In terms of design, the survey structure sought to facilitate respondent recollection and data precision by asking questions about income generation and consumption immediately following harvest inquiries. Each set of questions formed a loop for individual NUS and coded into tablets to detect discrepancies if totals for collection/production, sales, and consumption did not align. In terms of training, enumerators were instructed to devote extra time to these loop questions during interviews to ensure accuracy in data collection. Additionally, collected data was uploaded daily and checked by the first author, allowing daily consistency checks and the provision timely feedback to enumerators on these sensitive variables.

Box S3: Estimation of analytical variables.

Experience of climatic events (months)

Respondents were asked to indicate which months (from January to December 2022) their household experienced challenging climatic conditions.

NUS collection and harvest (months)

Respondents were asked to indicate which months (from January to December 2022) their household collected and/or harvested each species of NUS.

Food insufficiency (months)

Respondents were asked to indicate which months (from January to December 2022) their household did not have adequate food.

Energy intake from NUS (kcal/adult equivalent/day)

Respondents were asked to indicate how much (in terms of mass) of each NUS collected/harvested was used for consumption within their household (in kg/year). This was transformed in energy equivalents (kcal/day) using the edible portion of each plant species, based on their energy composition sourced from a food composition table for Western Africa (Table S5, Supplementary Material) (Vincent *et al* 2020). Finally, energy intake from all collected and cultivated NUS was aggregated at the household level and expressed it in adult equivalents (kcal/adult equivalent/day). For adult equivalence, we use the OECD-modified equivalence scale, assigning a value of 1 to the household head, 0.5 to each additional adult, and 0.3 to each child.

NUS income (USD/household/year)

Respondents were asked to indicate the income received from selling each NUS collected/harvested in the previous 12 months (from January to December 2022). On-farm income was estimated by adding all these income streams selling collected or produced NUS.

On-farm income (USD/household/year)

Respondents were asked to indicate the income received from all farm-related activities, including selling crops, livestock and other farm products (incl. NUS), in the previous 12 months (from January to December 2022). On-farm income was estimated by adding all these individual income streams.

Total household income (USD/household/year)

Respondents were asked to indicate the income received from all on-farm (see above) and off-farm

income activities (e.g. salaried employment, side-business), in the previous 12 months (from January to December 2022). Total household income was estimated by adding all minor and major income streams.

Food consumption score (FCS)

The FCS is a composite measure of diet diversity developed by the World Food Programme that is a proxy of household food security (WFP 2008). Respondents were asked to report the frequency of consumption of eight food groups within their household over the seven days before the survey. The frequency was weighted by the relative nutritional value of each group and aggregated across all groups. Table S4 (Supplementary Material) provides more information about the food items and estimation of the FCS.

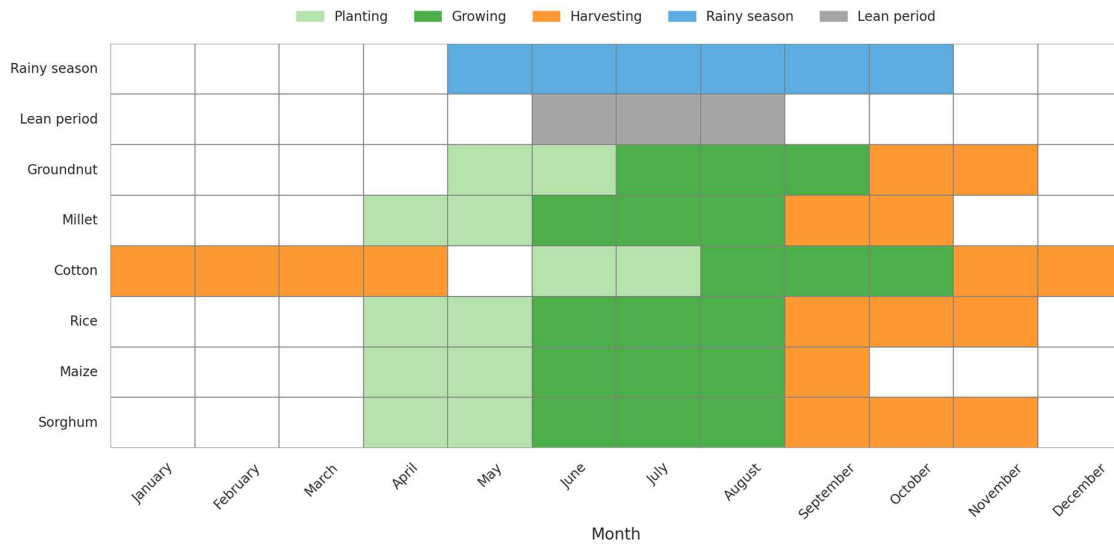


Fig. S1 Agricultural calendar in Burkina Faso. Data were sourced from a crop calendar created by FAO (2023) and USDA (2025).

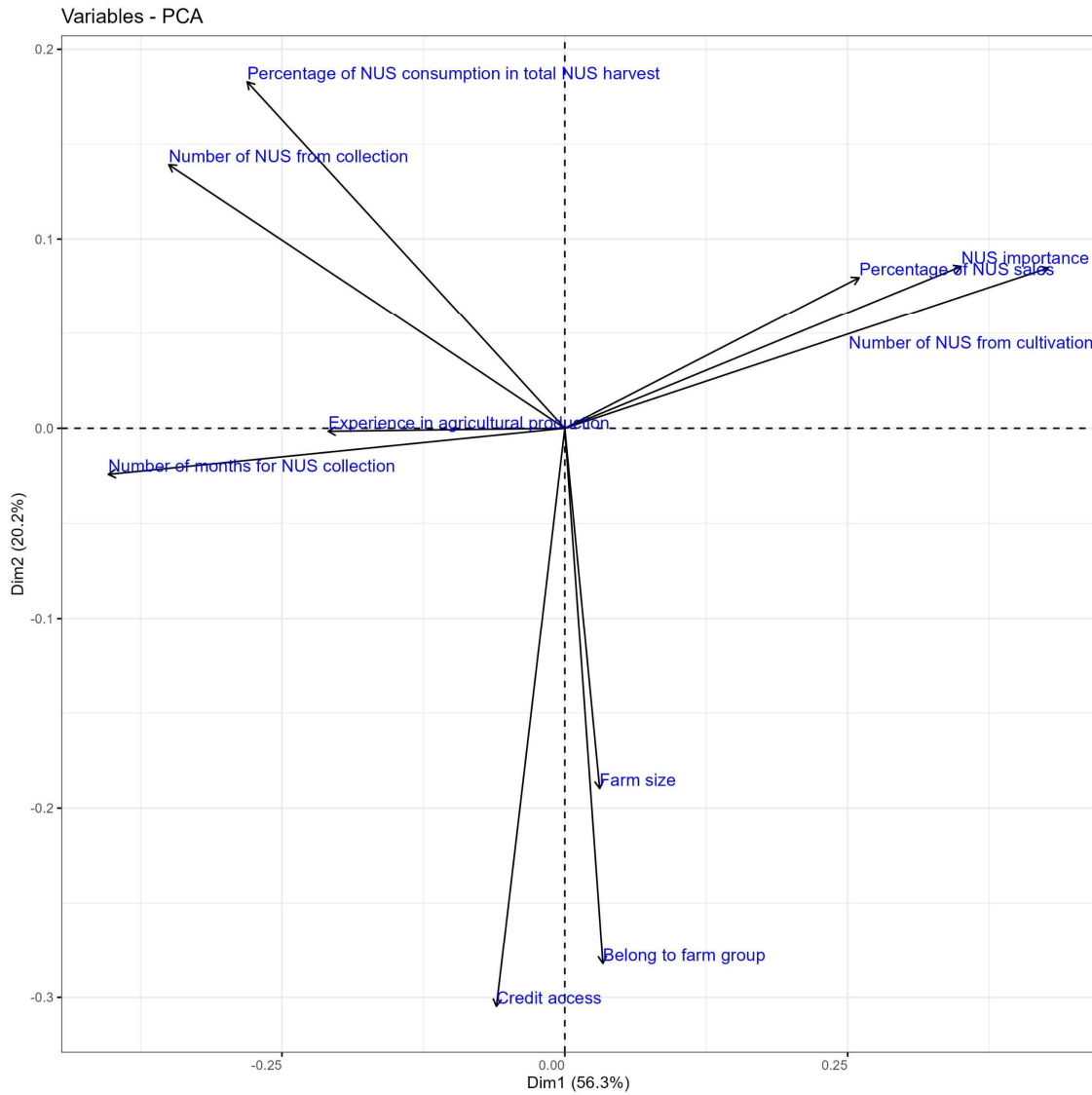


Fig. S2 The results of Principal Component Analysis.

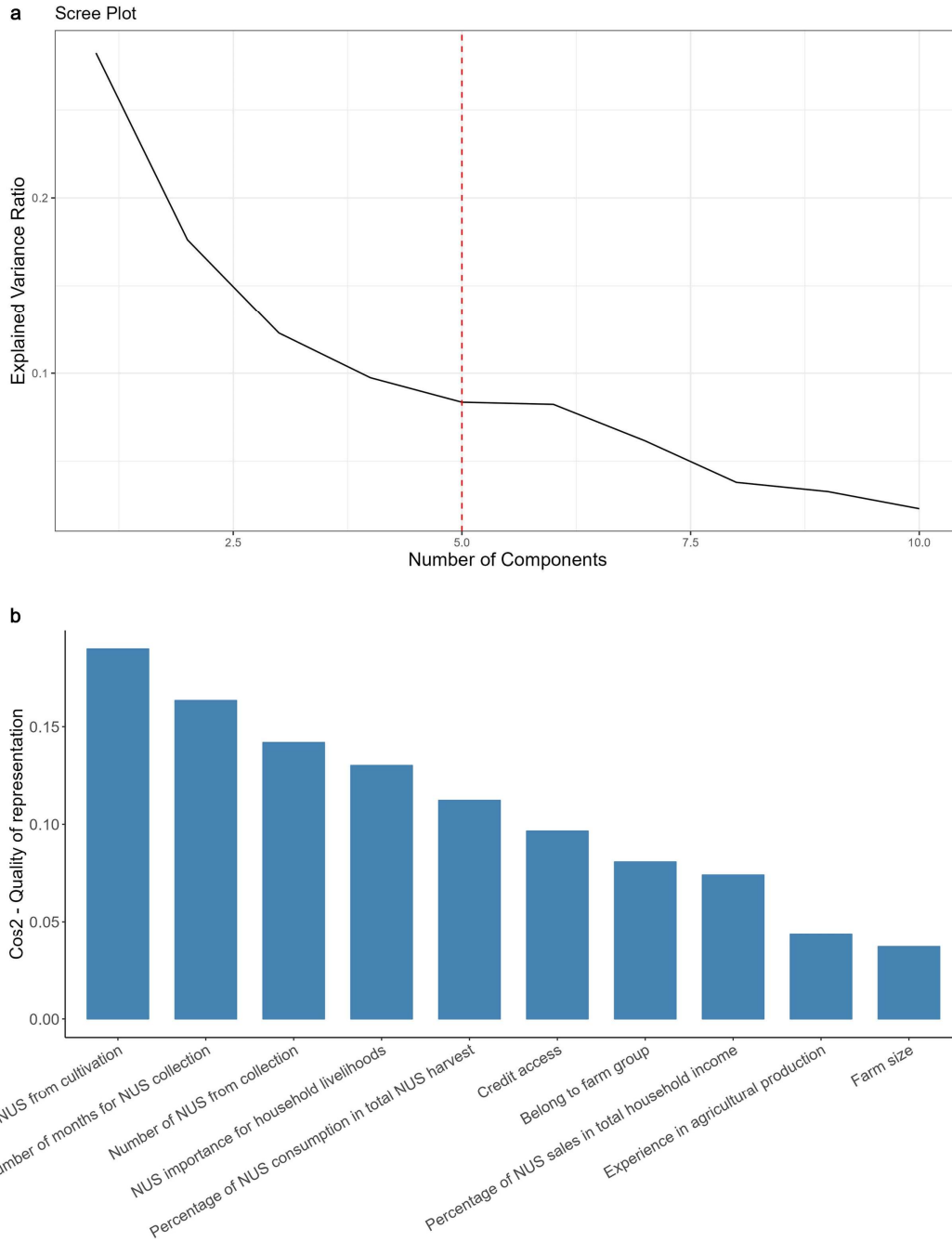


Fig. S3 The identification of optimal number of principal components (a), and the quality of representation of variables (b). An abrupt change in the slope can be identified, often referred to as the ‘elbow point,’ and select the number of principal components occurring before that point. The optimal number of principal components is five (a), and the five variables with the highest quality of representation ($\text{Cos}^2 > 0.1$) were identified (b).

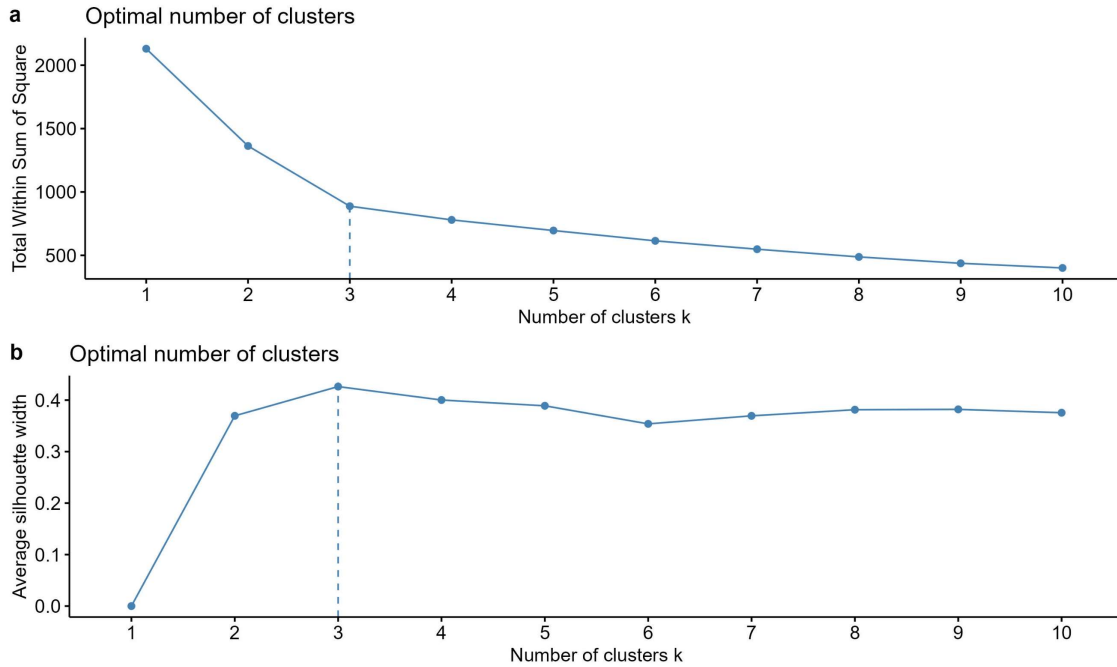


Fig. S4 The identification of optimal number of clusters in the HCA. The elbow method (a) and average silhouette method (b) were applied to identify the optimal number of clusters. The elbow method involves plotting the variance explained by different numbers of clusters and identifying the “elbow” point, where the rate of variance decreases sharply levels off, suggesting an appropriate cluster count for analysis or model training. The average silhouette method computes the average silhouette of observations for different values of k . The optimal number of clusters k is the one that maximizes the average silhouette over a range of possible values for k . In total, 3 is the optimal number of clusters for both techniques.

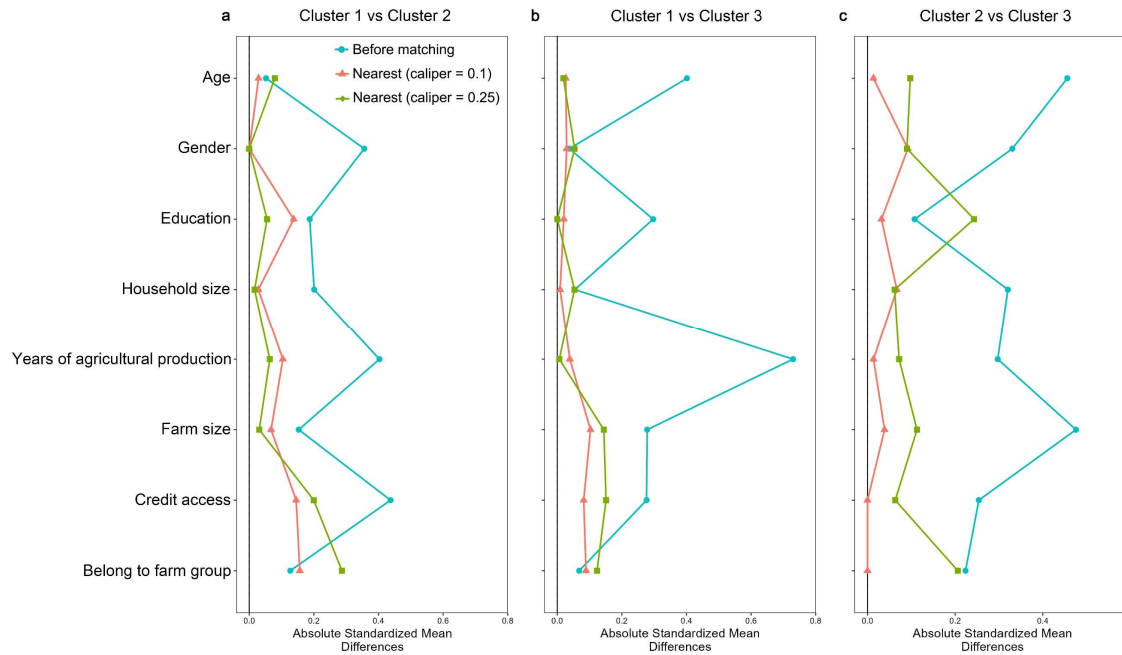


Fig. S5 Absolute standardized mean difference across different matching techniques. An absolute standardized mean difference of less than 0.1 is considered indicative of better matching between groups.

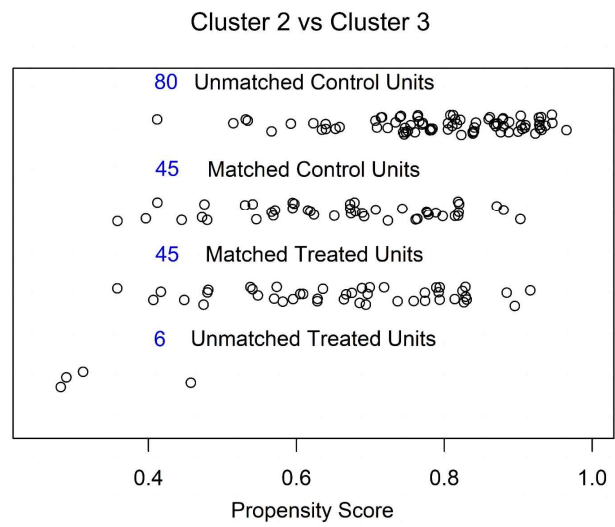
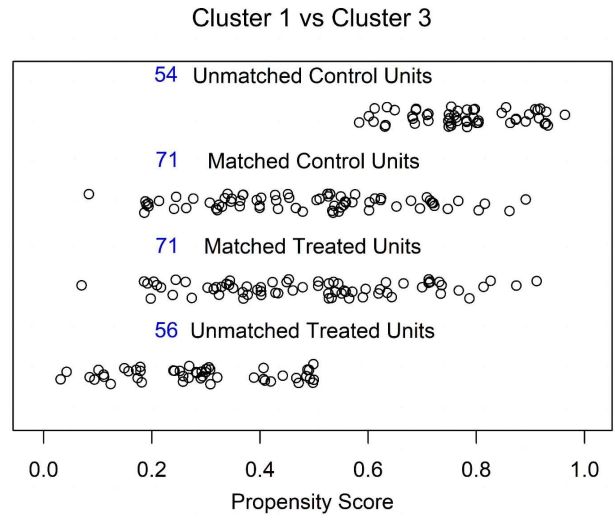
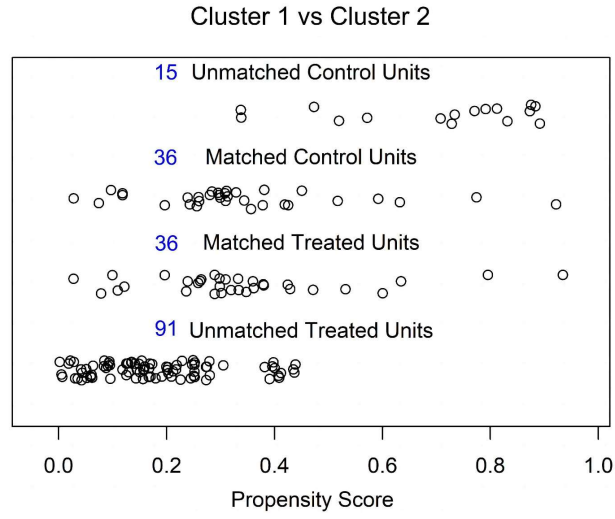


Fig. S6 Distribution of propensity score and sample size for different comparison groups.

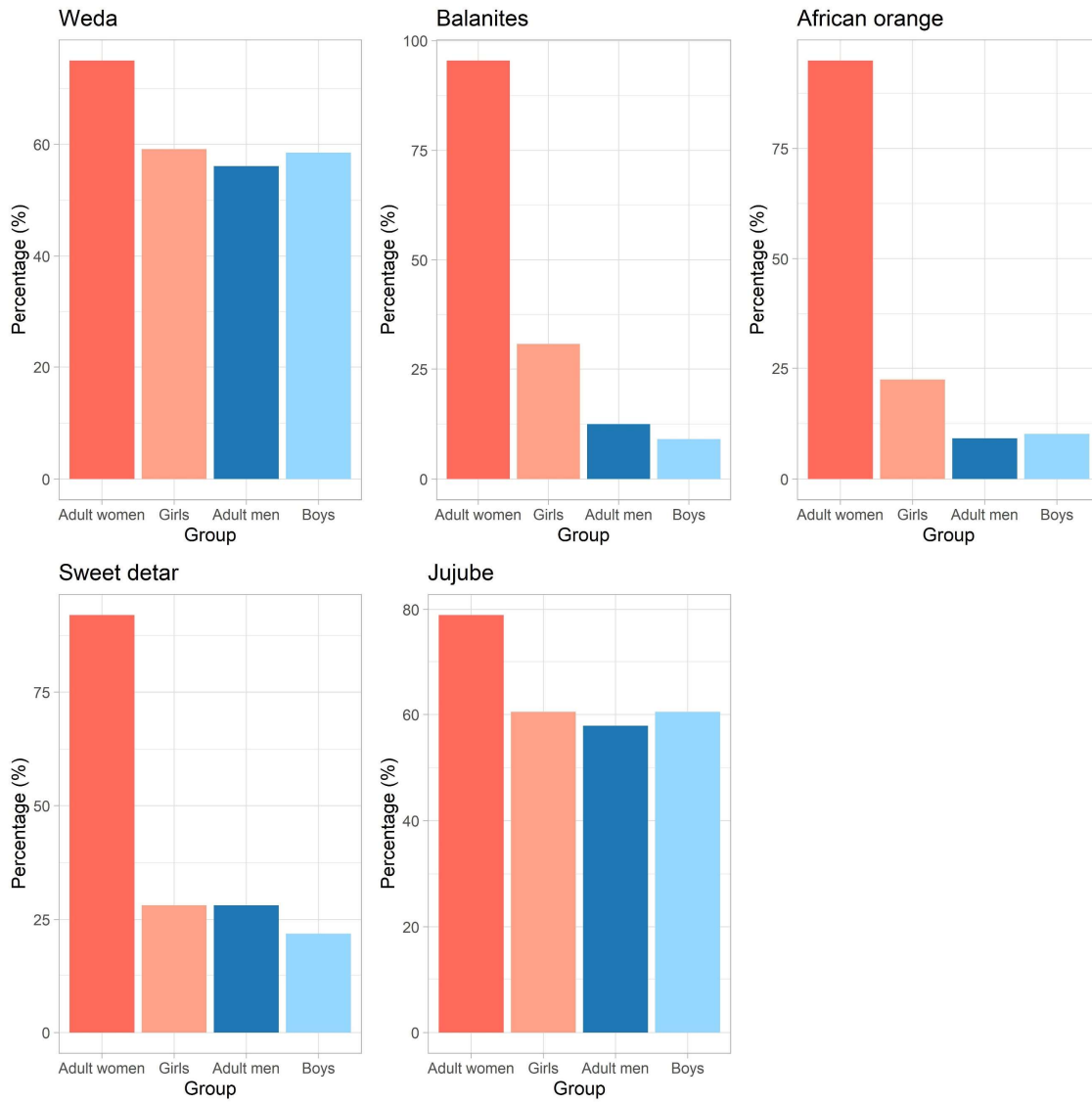


Fig. S7 Distribution of gender groups involved in collecting NUS across individual species.

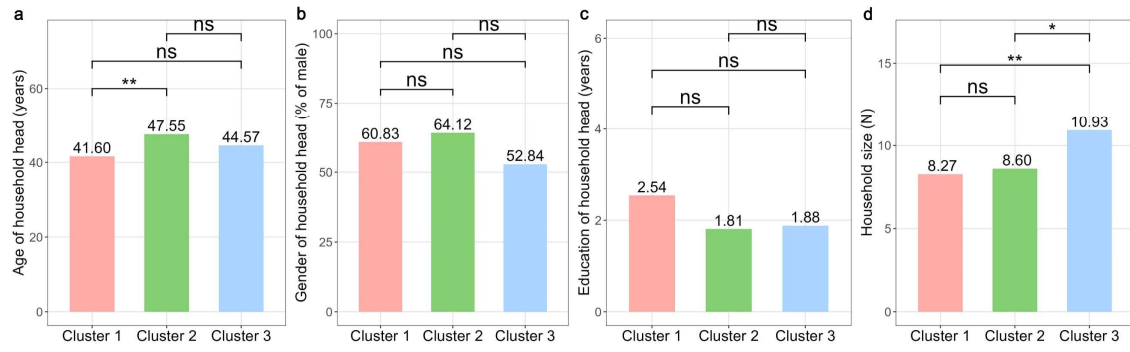


Fig. S8 Differences in household characteristics between clusters. '*' $P < 0.05$, '**' $P < 0.01$, '***' $P < 0.001$, and 'ns' not significant.

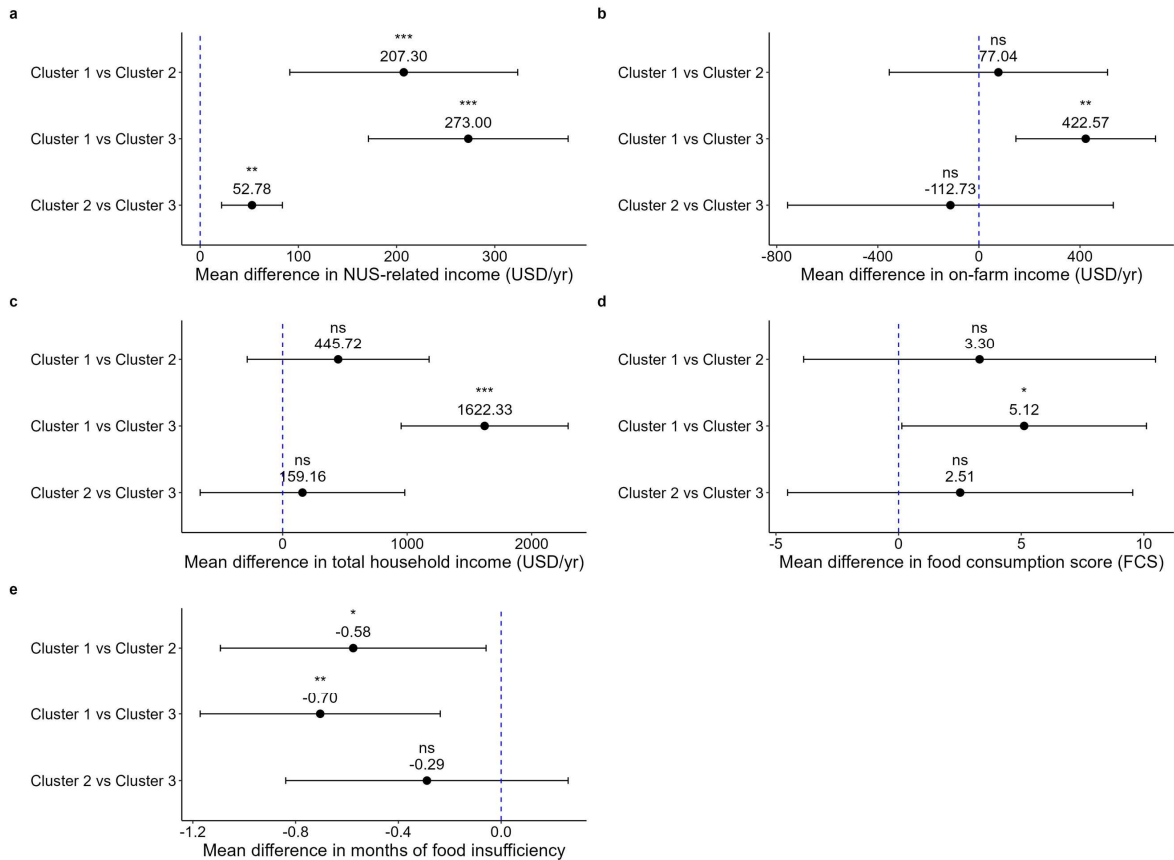


Fig. S9. Mean differences in economic and food security performance between clusters based on PSM analysis. Numbers above bars provide the mean difference between the respective clusters for the respective variable in each panel. Bars around the means denote the 95% Confidence Intervals (95% CIs). If a bar falls in the positive side and does not intersect with zero we interpret that the first cluster in the specific comparison performs better for the variable than the second. If the bar intersects with zero then the difference between the two clusters for this specific variable is not considered statistically insignificant. Significance levels: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, ns = not significant.

Table S1. Average farm sizes for Burkina Faso and the study regions.

Areas	Living Standards Measurement Study		Our study	
	Sample size (N)	Average farm size (ha)	Sample size (N)	Average farm size (ha)
Burkina Faso	4,347	3.19 (0.06)	-	-
Centre-Ouest	323	2.48 (0.15)	176	3.76 (0.22)
Hauts-Bassins	323	5.64 (0.31)	87	3.66 (0.41)
Cascades	382	5.84 (0.31)	40	3.09 (0.37)
Average study regions	1,028	4.72 (0.16)	303	3.65 (0.18)

Note: Number in the parentheses indicates standard error (SE). Source data from the Living Standards Measurement Study (LSMS) were extracted from The World Bank (INSD 2024).

Table S2. Socio-economic status of regions in Burkina Faso.

Region	Poverty rate (%)	Human development index (2022)
Sahel	59.7	0.305
Est	70.4	0.375
Centre-Nord	45.2	0.390
Nord	47.0	0.413
Plateau-Central	34.4	0.417
Centre	9.6	0.540
Centre-Est	41.5	0.400
Centre-Sud	22.6	0.429
Boucle du Mouhoun	50.1	0.400
Sud-Ouest	41.5	0.365
Centre-Ouest	36.1	0.429
Hauts-Bassins	20.6	0.469
Cascades	22.6	0.453
Burkina Faso	40.1	0.438

Note: Data were sourced from MCC, (2022) and UNDP, (2023). Study regions in bold.

Table S3. Household perceptions for NUS collection and cultivation.

Category	Perception	1	2	3	4	5
Crop characteristics	Nutritious					
	Good taste					
	Filling					
	Diversifies diet					
	Medicinal uses					
	Integral to local culture					
Collection/Production characteristics	Tolerates extreme weather					
	Improves soil fertility (only for NUS production)					
	Time-consuming to collect/produce					
	Easy to collect/produce					
	Increased scarcity					
	Easy to prepare for own food consumption					
	Easy to prepare for selling					
Food security	Important food source year-round					
	Important food source only during period					
	Important food source during food insecurity periods					
	Consumed only due to lack of other food during collection/harvesting period					
	Unwilling to collect/produce if farm food is sufficient year-round					
Livelihoods	Important income source year-round					
	Important income source only during collection/harvesting period					
	Important income source during low-income periods					
	Satisfied with income from sales					
	Unwilling to collect/produce if farm income is sufficient year-round					
Support mechanisms	Existing markets					
	Existing policy support					
	Strong advocacy					

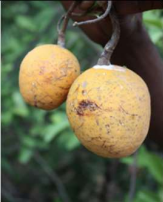



Note: These perceptions were elicited through 5-level Likert Scale Response Options, including ‘1 - strongly disagree’, ‘2 - disagree’, ‘3 - neither agree nor disagree’, ‘4 - agree’, ‘5 - strongly agree’.





Table S4. Food groups and weights in the calculation of food consumption score (FCS).

Food group	Food item	Weight
Main staples	e.g., rice, wheat, maize, and other items food made from these cereals	2
Pulses	e.g., bean, chickpea, groundnut	3
Vegetables	e.g., potato, tomato, brinjal, okra, bitter gourd, cauliflower, cabbages, and leafy vegetables	1
Fruits	e.g., mango, banana, watermelon, pineapple, guava	1
Meat/fish	e.g., beef, mutton, poultry, pork, eggs, fish	4
Milk and diary	e.g., cow milk, buffalo milk, goat milk, yogurt, cheese, milk powder	4
Sugar/honey	e.g., sugar and sugar products	0.5
Oil	e.g., oil, fat, butter	0.5

Note: Data were sourced from WFP (WFP 2008).

Table S5. Characteristics of NUS in the study area.

Common name	Latin name	Energy (kcal / 100g edible portion, EP)	Edible Portion (%)	Classification	Edible parts	Main uses	Pictures	Picture sources (Photographer)
Weda	<i>Saba senegalensis</i>	75	32	Fruits	Fruits	Fresh consumption, traditional medicine		Marco Schmidt
Balanites	<i>Balanites aegyptiaca</i>	212	50	Fruits / Oilseeds	Fruits, kernel	Fresh consumption, kernel for oil, traditional medicine		Marco Schmidt
African orange	<i>Strychnos spinosa</i>	43	73	Fruits	Fruits	Fresh consumption, processed into juice		Ralf Biechele
Sweet detar	<i>Detarium senegalense</i>	125	47	Fruits	Fruits	Fresh consumption, condiments, traditional medicine		Wilma Dijkstra

Jujube	<i>Ziziphus spp</i>	29	93	Fruits	Fruits	Fresh consumption, dried snacks, traditional medicine		Blandine M. I. Nacoulma
Fonio	<i>Digitaria exilis</i>	356	90	Cereals	Grains	Staple grain, festive dishes, gluten-free diets		Arne Erpenbach
Taro	<i>Colocasia esculenta</i>	39	86	Sugars and starches	Tuber, leaves	Tuber for staple, leaves also edible		Paul Latham
Souchet	<i>Cyperus esculentus</i>	344	90	Nuts / Oilseeds	Tuber (nut-like)	Snack, beverage (e.g. horchata), oil		Meike Piepenbring

Note: The characteristics of NUS were source from a food composition table for Western Africa (Moustapha *et al* 2014, Vincent *et al* 2020, FAO 1988). NUS pictures were sourced from the West African Plants - A Photo Guide (Brunken *et al* 2008).

Table S6. Contribution of individual NUS on energy intake and household income for each cluster.

	Energy intake (% daily energy requirement)			Income generation (% total household income)		
	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
Weda	0.01	0.04	1.20	0.00	6.25	1.05
Balanites	0.00	0.55	4.83	0.05	1.63	2.75
African orange	0.04	0.43	1.71	0.17	2.97	0.61
Sweet detar	0.00	0.09	0.18	0.09	6.74	0.05
Jujube	0.00	0.00	0.07	0.00	0.84	0.07
Fonio	24.59	0.00	0.00	10.05	0.00	0.00
Taro	0.48	0.00	0.00	11.78	0.00	0.00
Souchet	0.39	0.00	0.00	2.76	0.00	0.00

Note: According to the WFP Food and Nutrition Handbook, 2,100 kcal/day/adult is the initial reference value for calculating energy requirements and designing food aid rations (WFP 2018).

Table S7. Cluster distribution across regions.

	Cluster 1	Cluster 2	Cluster 3	Overall
Centre-Ouest	10	50	116	176
Hauts-Bassins	78	1	8	87
Cascades	39	0	1	40
Overall	127	51	125	303

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