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Livelihood diversification as coping strategy under climate risk : Evidence from rural farm household in Cameroon

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Abstract

This study aims at highlighting the role of livelihood diversification and identifying the optimal portfolio of farm household's activities under climate risk in the rural Cameroon. Data used comes from a survey on the perception and adaptation to climate change from November 2022 to July 2023. Climatic data on rainfall and temperature were collected from meteorological stations. Markowitz portfolio model has been applied to identify the optimal portfolio. It's found that to reduce climate risk related vulnerability, farm households adopt income diversification choosing a portfolio consisting of wild mango kernels and ngnetum africanum on one hand, and cassava sticks and maize on the other. The results have also unveiled that, whatever the value of the risk-aversion coefficient, the optimal portfolio should contain gnetum africanum, maize, wild mango kernels and cassava sticks. Therefore this study aims to equip rural farmers knowledge and principles of combining income-generating activities to maintain and improve their livelihoods, in order to effectively fight against poverty in the rural area. Policy makers should implement measures to support production of gnetum africanum, maize, wild mango kernels and cassava sticks. These measures may be combined with equipping them with necessary skills, market access and storage infrastructure to fully benefit from income diversification.

N/A

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1. Introduction

Agricultural production in Sub-Saharan Africa in general is affected by climate change through changes in normal sowing and harvesting dates, the spatio-temporal distribution of rainfall and the increase in rainfall deficits and droughts. This inevitably leads to an uncertainty which may hamper agricultural productivity, food security and increase incidences of rural poverty, given that majority of the population reside in rural areas and are primarily dependent on agriculture as the main source of livelihood (Ochieng et al., 2020). According to Hossain et al. (2019) and Azzarri and Signorelli (2020), the extreme climatic events are likely to affect the ability of farm households to maintain their livelihood levels. Indeed, these extreme weather events inevitably lead to risk of loss of productive assets and crops, with spillover effects, a reduction in farm household's income likewise the erosion of food chains in urban and rural areas due to the significant drop in the supply of food products in the central region. The threat of climatic stresses induces rural smallholders to diversify their livelihood strategies which rely primarily on crop production in agriculture or aquaculture, particularly in countries of the Global South (Tsusaka et al., 2022 ; Bernzen et al., 2023). Rural communities are then forced to seek alternate sources of income in order to cope with climate shocks and increase farm resilience (Mondal, 2023). Theoritically, the concept of diversification dates back to the pioneering work of Markowitz (1952), according to whom a judicious combination of many assets in a portfolio reduces the total risk incurred for a given expected rate of return. The main lesson of Markowitz's theory is the diversification's fondamental role in reducing risk and improving portfolio quality. In this study, a portfolio is a combination of activities characterized by the weight of fraction of income invested in each activity. The founding idea of modern portfolio theory is that activities should no longer be chosen solely on the basis of their individual characteristics, but rather to examine the potentialities linked to dependencies that may exist between them. This calls for diversification, which is synonymous with risk reduction. Diversification refers to the growth of diversity as the dynamic economic and social process of the farm household (Ellis 2000a, b). According to Ellis (1997), livelihood diversification is defined as the process through which rural families build a diverse portfolio of activities and social support capacities in their struggle for survival and improving their living standards. As one of the coping mechanisms, livelihood diversification is a strategy that involves developing a large portfolio of earnings to cope with potential shocks or stress (Scoones, 1998). Livelihood diversification is an adaptive mechanism in wich new practices are added, some practices are maintained while others are withdrawn (Admiral, 2012). According to Katun and Roy(2012), livelihood diversification refers to the attempts by individual and households to find new ways to raise incomes and reduce vulnerability to different livelihood shocks.

Risk is imperfect knowledge of the occurrence of an event to which a probability can be attached (Knight, 1921). To this end, Francis and Kim(2013) specify that dispersion of outcomes around the expected value could be substituted for the word risk. Accordingly, Markowitz(1952) defined risk as the variance of the portfolio, in the sense that the deviation from the expectation measured by the variance is considered a risk. In the Markowitz model, individuals are by nature risk-averse and are characterized by quadratic utility functions and base their decisions on the first two moments of random distribution of their wealth namely the mathematical expectation and the variance. According to Markowitz model, the activities that make up a portfolio must be chosen according to their level of interdependence or correlation. This idea implies the notion of portfolio diversification. The optimal portfolio must be fully diversified to significantly reduce risk.

Empirically, applying the portfolio model, Werners et al. (2007) identified combinations of agricultural products that reduce current and future climate related risks in the Guadiana River Bassin. The results showed that cropping pattern with barley and sunflower is a combination that has the lowest variance in crop revenue and likely to reduce climate risk. Moreover, the authors found that climate will have modest effects on average crop yields, but will significantly reduce the variance of yields and modify the yield correlation. Werners et al. (2011), in assessing agricultural land use diversification as a climate risk adaptation strategy in the Tisza river basin in Hungary, showed that the portfolio of activities containing wheat, maize and sunflower is on the efficient frontier, as far as the region of intensive agriculture is concerned. Kumar et al. (2020) by using panel data from 256 smallholders households from 2006 to 2014 in three semi-arid regions India, found that diversification in on-farm enterprises and off-farm income sources contribute in reducing climate risk. Then, livelihood diversification plays, at farmer's level, a major role in reducing hunger and mitigating the adverse impacts of climate change as shown by Shah et al. (2021). The authors indicated that 50% of the total sampled households have used off-farm livelihood diversification, whereas 40% have used on-farm livelihood diversification to cope with catastrophic risks in the selected study areas. On a total of 432 farm households selected through a multi-stage sampling procedure and usage of livelihood vulnerability index with equal and unequal weighting through principal component analysis, Adzawla and Baumuler (2021) found that livelihood diversification has the potential of reducing climate vulnerability among male heads, female spouse and female heads by 2.6-5.7%, 2.2-5.9% and 2.1-4.7% respectively.

In the central region of Cameroon, livelihood diversification appears as the most utilized coping strategy in the the face of uncertainty related to climate change. The challenges posed by climate change have led to renewed interest in the adaptation strategies such as diversification implemented by farm households. Furthermore, current adaptation strategies in Sub-Saharian Africa (SSA) are insufficient to ensure agricultural systems'resilience to climate change-related stress and risks (Intergovernmental Panel on Climate Change, 2014). Yet there, particularly in Cameroon where 11% of the population faces acute food insecurity, it is vital to explore strategies for improving livelihood adaptations and resilience among highly vulnerable populations across the country and particularly in the central region where the population is beginning to be severely affected by food insecurity (Ministry of Agriculture and Rural Development, 2023). Hence, the focus of the analysis is put on the questions what is the role of livelihood diversification ? What is the optimal combination of income-generating activities that farm households should choose under climate risk, since all activities are risky ?

This study aims at highlighting the role of livelihood diversification in reducing risk and identifying the optimal portfolio of rural farm household's activities under climate risk in the central region of Cameroon. This paper contributes to the contemporary literature on three points. First, although there is extensive research on diversification as a risk-coping strategy, relatively few studies have employed the Markowitz portfolio model (Wenners et al., 2007; Crowe & Parker, 2008; Nalley & Barkley, 2010; Witt & Waibel, 2009; Bodin et al., 2014), which is nonetheless well-suited for describing the behavior of economic agents under risk. In determining the optimal portfolio, prior studies often overlook farmers' attitudes toward risk, even though agricultural activities are inherently risky and farmers' behavior varies according to their degree of risk aversion. To address this gap, the present study incorporates a risk-aversion coefficient to more accurately examine the impact of climate risk on livelihood diversification decisions. Most of the studies aim at assessing levels of livelihood diversification by computing indices such as Herfndahl Index, Simpson Index(Habib et al., 2022), Entropy Index, Ogive index, Herfindahl–Hirschman index and the Composite Entropy Inde ; to identify the factors of adopting diversification, using econometric methods(Nguyen et al., 2018 ; Sardar et al., 2020 ; Shah et al., 2021 ; Yang et al., 2021 ; Sardar et al., 2022 ; Habib et al., 2022 ; Musyoka and Onjala, 2023). This study contributes to the literature by empirically examining producer behaviour under uncertainty. Such a study is crucial in the context of climate risk because it provides empirical evidence of the role of livelihood diversification in the face of consequences of climate change. In this study, applying modern portfolio theory to agricultural economics is a major contribution, providing a tool for analyzing rural farm household behaviour under uncertainty. More specifically, this study contributes to the validation of a decision model for agricultural production which permits to identify the optimal portfolio of activities in an uncertain world. Finally, to the best of our knowledge, this is the first study conducted in Cameroon to apply Markowitz's modern portfolio theory in determining the optimal mix of income-generating activities based on farm households' risk attitudes in the face of systemic threats from increasingly adverse weather conditions. The interest in livelihood diversification is driven by the fact that since the frequency and severity of extreme weather events are expected to increase globally, there is an urgent need to strengthen the research on livelihood adaptation strategies of rural household who are most exposed. Furthermore, beyond analyzing the role of livelihood diversification, this research also identifies the optimal portfolio of activities that should be held by the farm household to reduce vulnerability in the face to climate change. This analysis makes it possible to identify combination of income generating activities that are most suitable and appropriate for rural farm household under climate risk, and formulate relevant recommendations.

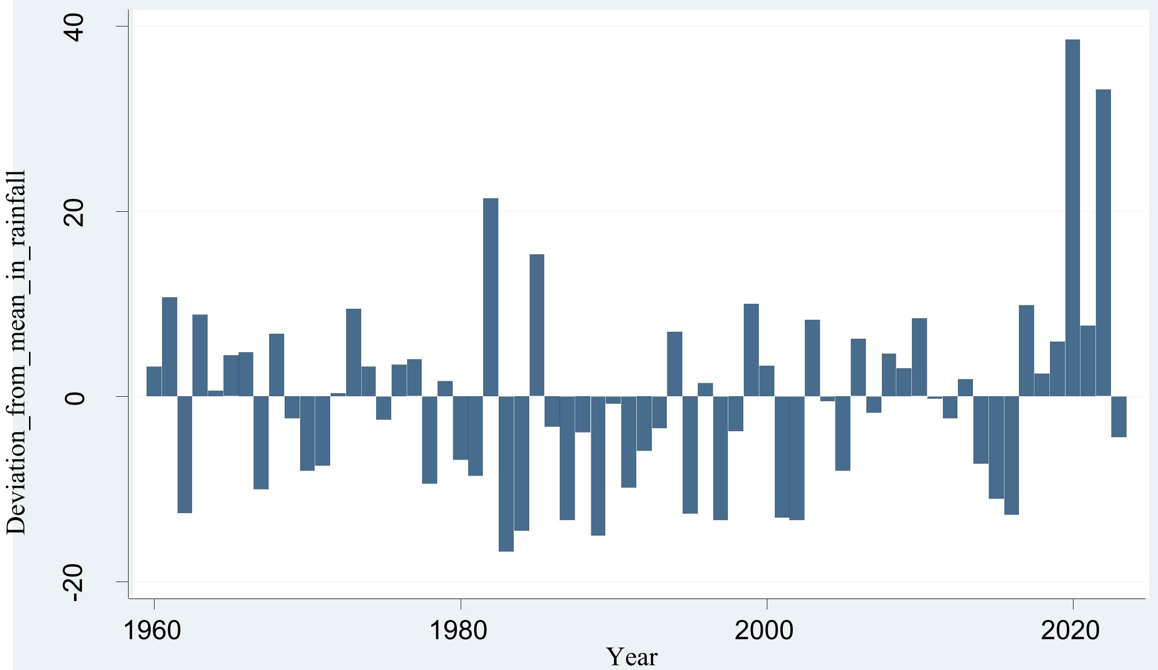
The rest of the article is organized as follows: section 2 is devoted on analysis of the the frequency and severity of climatic risks. While section 3 describes methodology, results are presented and discussed in section 4 and section 5 concludes.

2. Analysis of the frequency and severity of climatic risks in Cameroon

The Lékié division is located at the North West of Yaounde-Cameroon, with a surface area of 2989Km^2, and remains a strategic locality in terms of food security in Cameroon. The study area is characterized by the bimodal forest zone and two rainy seasons, the first or short season running from mid-March to mid-June, with a maximum rainfall of 200 mm per month; and the second or long season generally from September to the mid-November, with heavier rainfall reaching almost 300 mm/month. Between these rainy periods are dry seasons, one of which is short and the other long, with very low rainfall (less than 150 mm/month) and slightly higher temperatures. However, as can be seen in the figures below, climate change has significantly impacted these characteristics.

For agricultural purpose, climate change analysis involves examining the risk of insufficient or excessive rainfall (flooding) on the one hand, and high and low temperatures on the other. As can be seen in Figure 1, total annual precipitation volumes vary significantly from year to year over the past 65 years in the Center region of Cameroon. Data on rainfall show that the greatest rainfall deficit was recorded in 1983 at -16.76 mm while the highest rainfall surplus was observed in 2020 at +38.56 mm. The period 1986-1994 shows recurring deficits, whereas 1997-2022 recorded episodes of heavy rainfall. Three distinct rainfall peaks stand out: 1982, 2020 (the highest), and 2022, indicating the wettest years in the period studied.

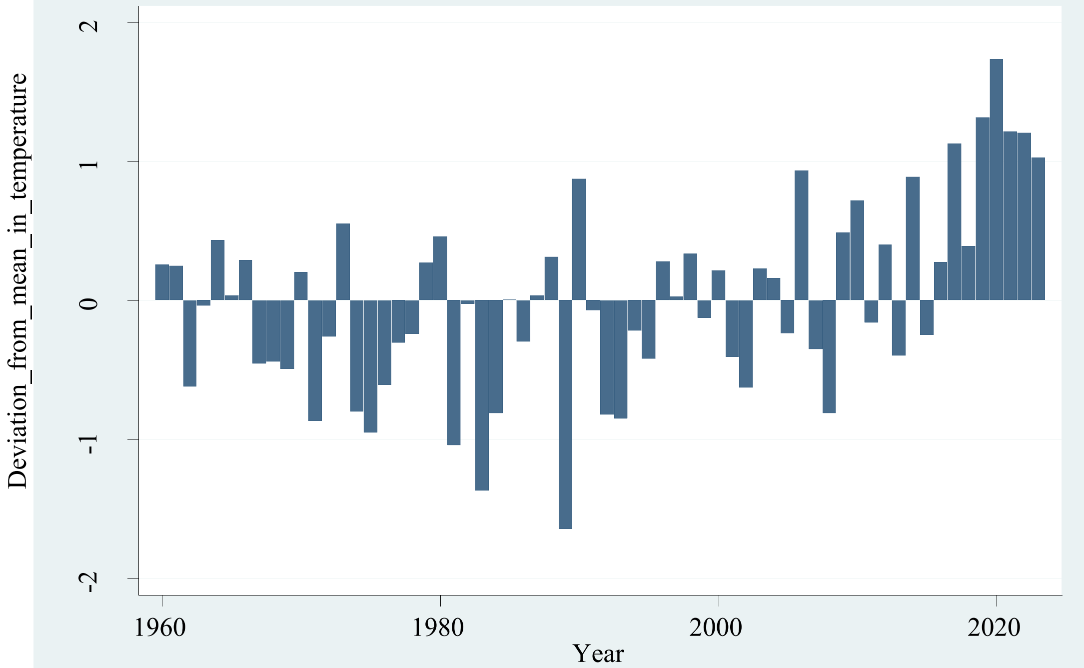
Figure 1: inter-annual variation in rainfall



Source : author from Ministry of Environment, Nature Protection and Sustainable Development of Cameroon and Minitry of transports (2023).

Fitting a trend is of considerable analytical importance, as it provides empirical evidence regarding the presence or absence of long-term global warming. In terms of temperature dynamics, Figure 2 reveals a pronounced decline commencing in 1962, which intensified in 1972 and persisted until approximately 1983, culminating in a further marked drop in 1989. This trajectory underscores the magnitude of climatic risk in the region. Such abrupt thermal declines are likely to induce substantial variability in agricultural output. Conversely, from 2016 onward, temperatures exhibited a pronounced upward trajectory, peaking in 2020, a year characterized by anomalously high warmth, before continuing to rise through 2023.

Figure 2: inter-annual variation in temperature



Source : author from Ministry of Environment, Nature Protection and Sustainable Development of Cameroon and Minitry of transports (2023).

3. Methodology

3.1. Data collection

The data for this study were obtained from a survey conducted between November 2022 and July 2023, focusing on how farm households in the central region of Cameroon perceive and respond to climate change. In rural areas, the perceived effects of climate change are among the main factors shaping farmers' responses (Mohammed et al., 2021). The survey collected both quantitative and qualitative data. Quantitative data covered socio-demographic characteristics such as gender, age, education level, and income, while qualitative information was obtained from two focus group discussions (FGDs) exploring farmers' perceptions of agricultural risks, climate change resilience, adaptive capacity, and perceived resilience. Each FGD lasted approximately 45 minutes. To test the suitability of the questionnaire, a pilot survey involving 10 local farmers in each sub-division was conducted prior to the main data collection. The final survey was implemented in 21 villages across three selected sub-divisions: Saa, Obala, and Okola. Grouping farm households was deemed necessary, as the allocation of significant resources to particular activities varies not only between households but also between villages.

In the Lékié Division, the main agricultural activities include cocoa, coffee, plantain, banana, peanut, cassava, egusi, yam, mango kernel, taro, Gnetum africanum, tomato, pepper, poultry, fishery, and pig farming. Within the scope of this study, it is important to note that certain agricultural activities such as cocoa, Gnetum africanum, maize, and wild mango kernel are primarily produced for sale, with less than 50% consumed by the producers themselves. The survey gathered information on demographics, livelihood assets, livelihood activities, income sources, a timeline of climate-related disasters (including droughts, landslides, and floods), coping mechanisms in the Lékié Division, and perceived changes in climate variables. Population estimates for each village were derived from demographic maps provided by the National Institute of Statistics(2022) and the Central Bureau of the Census and Population Studies (2005).

The quota sampling method was used to select participants. While this non-probability method has two main limitations: (i) results cannot be generalized to the entire population, and (ii) it may introduce representativeness bias by excluding individuals who meet the selection criteria but are not chosen, it was selected for three main reasons. First, it is well-suited to contexts where no sampling frame is available.

Second, it is cost-effective and does not require a large budget. Third, it does not necessitate the inclusion of specific individuals in the sample.

Table I : population distribution by gender identity

Sub-divisions	Male	Female
Obala	30158	36010
Okola	37500	27500
Sa'a	40806	52307
Total	**108464**	**115817**

Sources : author's computation from data provided by the National Institute of Statistics(2022).

In this study, non-proportional quota sampling was applied to select 300 farm households from among those available. Because only gender-disaggregated data were available, the sample was stratified by gender (Table 1). This resulted in the selection of 145 men and 155 women. Following data entry, cleaning, and the removal of 96 outlier households, the final sample comprised 204 farm households.

3.2. Model

Making use of the modern portfolio theory, through its risk mitigation principle for a given level of return rate, provides a suitable analytical framework to analyse the system of livelihood strategies (Tasfahun, 2017). In the setting of this study, we assume that agricultural households are rational, that is, they choose a portfolio of maximum utility which is optimally diversified.

Mathematical model

Let R_p be the return of the portfolio made up of n return activities $R_1, R_2, \ldots, R_n$. It is assumed that each activity enters a proportion X_i in the composition of the portfolio as follows:

$$R_p = \sum_{i=1}^{n} X_i R_i \tag{1}$$

Since the returns R_i are normally distributed, the traditional parameters of the normal distribution used are expectation and variance of the portfolio's return:

$$E(R_p) = E\left(\sum_{i=1}^{n} X_i R_i\right) = \sum_{i=1}^{n} X_i E\left(R_i\right) \tag{2}$$

$$V\left(R_p\right) = \sum_{i=1}^{n} \sum_{j=1}^{n} X_i X_j \operatorname{cov}\left(X_i, X_j\right) \tag{3}$$

The portfolio's return is determined by the weighted sum of returns for each activity, while the volatility is a function of the correlations between the components of the entire portfolio.

It assumes that farmers are rational, risk-averse and maximize utility. Therefore, the optimal portfolio is the one whose total variance of return is minimal. Four conditions are necessary to apply the modern portfolio theory: there is more than a single activity in each given period, all activities are subject to risk, there is information on past and/or anticipated income activities and the same external conditions do not also affect all activities. Thus, applying the Markowitz model in this study requires, beforehand, to draw up a number of hypothesis among which:

H1-farm households have a rational behaviour: income is allocated to various income generating activities in order to maximize revenues for a given risk level or to minimize risk for given return levels.

H2-The weight of each activity is represented by the share of income allocated to an activity the farmer is involved in.

H3-For a given farmer household, income is completely allocated among the various activities which make up his portfolio.

H4-All activities in the portfolio are carried out during the same period. This means that all farmers have the same decision-making horizon.
H5-The income of the portfolio of activities are correlated and low but with a non-zero covariance.
H6-The behaviour of all the farmers is characterized by a higher or lower risk aversion level.
The basic principles of this model are:

- Given equal risk, portfolio with the highest expected return is selected
- With equal expectation of return, portfolio with the lowest risk is selected. Equation 4 below reflects the fact that the farm household is faced with two objectives: maximizing income and minimizing risk, under the constraint that the sum of allocated income shares ϕ_i to each activity that make up its portfolio, is equal to one. We then have a double optimization program as follows:

$$\begin{cases} MaxE(R_p) \\ MinV(R_p) \end{cases} \tag{4}$$

$$s/b\sum_{i=1}^{n}\phi_i = 1 \tag{5}$$

But both of the objective functions in equation 4 above can be combined as follows:

$$Z = E(R_p) - \alpha V\left(R_p\right) \tag{6}$$

Farm household is supposed to make decisions according to his or her income expectation, that is he or she wishes the highest possible and the variance of the income that it desires at the lowest possible rate: the Expectation-Variance (EV) criterion. On the basis of this criterion, the farm household thus maximizes a function $Z(E(R_p), V(R_p))$, where R_p is portfolio income. This theory predicts which combinations should be selected in order to reduce the total variance of the portfolio's return.
So that the farm household's objective is to maximize the difference between expected income and the associated risk :

$$\max Z = E(R_p) - \alpha V\left(R_p\right) \tag{7}$$

$$s/b\sum_{i=1}^{n}\phi_i = 1 \tag{8}$$

ϕ_i stands for the share income allocated to each activity, while α is a measure of the climate risk aversion of farming households. It expresses the rate at which the farm household agrees to take an increased risk in favour of an increase in the expected return. Indeed, a risk-averse farm household is willing to sacrifice some amount of his or her expected income in order to keep the risk of loss at a minimum. The amount of income a farmer is willing to sacrifice to reduce his or her exposure to risk tells us about his or her degree of risk aversion. In rural area, risk aversion is revealed by the diversification of income generating activities. Some authors have estimated relative aversion coefficient values between 2 and 4 (Nicholson, 1997). Myers (1989) estimated a relative aversion coefficient between 1 and 3 for a given American farmer. Other studies have estimated it between 0 and 4, where the value 0 stands for the neutral risk preferences. Since in the Markowitz model, individuals are by nature risk-averse, that is why in this study, a quantitative method is used and involves assigning values ranging from 1 to 4. The number 1 represents the minimum risk aversion value, while 4 is the maximum risk aversion value. We then consider a relative aversion coefficient varying between 1 and 4 on the basis of our sixth hypothesis below. This makes it possible to observe the behaviour of farmers towards climate risk. The solution to the program defined above lies in the definition of the Lagrange function. Thus, the Lagrangian gives:

$$L_a(\lambda, \phi_1, \phi_2, ..., \phi_n) = \alpha\sum_{i=1}^{n}\phi_i E(R_i) - \sum_i \sum_j \phi_i\phi_j \operatorname{cov}(R_i, R_j) + \lambda(1 - \sum_{i=1}^{n}\phi_i) \tag{9}$$

Applying the first order conditions, we have:

$$\frac{\partial L_a}{\partial \phi_1} = \alpha E(R_1) - 2\phi_1 \operatorname{cov}(R_1, R_1) - 2\phi_1 \operatorname{cov}(R_1, R_2) -$$
$$.... - 2\phi_1 \operatorname{cov}(R_1, R_n) \tag{10}$$
$$\frac{\partial L_a}{\partial \phi_2} = \alpha E(R_2) - 2\phi_1 \operatorname{cov}(R_2, R_1) - 2\phi_2 \operatorname{cov}(R_2, R_2) -$$
$$.... - 2\phi_n \operatorname{cov}(R_2, R_n) \tag{11}$$

$$\frac{\partial L_a}{\partial \phi_n} = \alpha E(R_n) - 2\phi_1 \operatorname{cov}(R_n, R_1) - 2\phi_1 \operatorname{cov}(R_n, R_2) -$$
$$.... - 2\phi_1 \operatorname{cov}(R_n, R_n) \tag{12}$$
$$\frac{\partial L_a}{\partial \lambda} = 1 - \phi_1 - \phi_2 ... - \phi_n = 0 \tag{13}$$

By posing:
$\operatorname{cov}(R_i, R_j) = \sigma_{ij}$
R_i is the revenue from activity i.
We have :

$$2\phi_1\sigma_{11} + 2\phi_2\sigma_{12} + ... + 2\phi_n\sigma_{1n} + \lambda = \alpha E(R_1) \tag{14}$$
$$2\phi_1\sigma_{21} + 2\phi_2\sigma_{22} + ... + 2\phi_n\sigma_{2n} + \lambda = \alpha E(R_1) \tag{15}$$

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$$2\phi_n\sigma_{n1} + 2\phi_2\sigma_{n2} + ... + 2\phi_n\sigma_{nn} + \lambda = \alpha E(R_1) \tag{16}$$
$$\phi_1 + \phi_2 + ... + \phi_n = 1 \tag{17}$$

$$\begin{pmatrix} 2\sigma_{11} & 2\sigma_{12} & . & . & . & 2\sigma_{1n} & 1 \\ 2\sigma_{21} & 2\sigma_{22} & . & . & . & 2\sigma_{2n} & 1 \\ . & & & & & & . \\ . & & & & & & . \\ . & & & & & & . \\ 2\sigma_{n1} & 2\sigma_{n2} & . & . & . & 2\sigma_{nn} & 1 \end{pmatrix} \begin{pmatrix} \phi_1 \\ \phi_2 \\ . \\ . \\ . \\ \phi_n \\ \lambda \end{pmatrix} = \begin{pmatrix} \alpha E(R_1) \\ \alpha E(R_2) \\ . \\ . \\ . \\ \alpha E(R_n) \end{pmatrix} \tag{18}$$

Since five activities have been selected, the matrix form is then

$$\begin{pmatrix} 2\sigma_{11} & 2\sigma_{12} & 2\sigma_{13} & 2\sigma_{14} & 2\sigma_{15} & 1 \\ 2\sigma_{21} & 2\sigma_{22} & 2\sigma_{23} & 2\sigma_{24} & 2\sigma_{25} & 1 \\ 2\sigma_{31} & 2\sigma_{32} & 2\sigma_{33} & 2\sigma_{34} & 2\sigma_{35} & 1 \\ 2\sigma_{41} & 2\sigma_{42} & 2\sigma_{43} & 2\sigma_{44} & 2\sigma_{45} & 1 \\ 2\sigma_{51} & 2\sigma_{52} & 2\sigma_{53} & 2\sigma_{54} & 2\sigma_{55} & 1 \\ & & & & & \end{pmatrix} \begin{pmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \\ \phi_4 \\ \phi_5 \\ \lambda \end{pmatrix} = \begin{pmatrix} \alpha E(R_1) \\ \alpha E(R_2) \\ \alpha E(R_3) \\ \alpha E(R_4) \\ \alpha E(R_5) \\ \end{pmatrix}$$

$$A\Phi = B \Leftrightarrow \Phi = A^{-1}B \tag{19}$$

Where A is the variance-covariance matrix, Φ is the column matrix of the share ϕ_i of income allocated to each activity, and $\sigma_{ij} = \text{cov}\left(R_i, R_j\right)$ covariance between incomes from activities i and j. This matrix is used to compute variance and covariance of the portfolio.

The results showed that cropping pattern with barley and sunflower is a combination that has the lowest variance in crop revenue and likely to reduce climate risk.

4-Results and discussion

Diversification is underscored by the results presented in the correlation matrix in Table 2. According to Markowitz (1952), holding several assets that are not positively correlated reduces overall risk compared to relying on a single asset. In the MPT framework, the net incomes from each on-farm activity are additive, while their associated risks can offset one another. Thus, selecting a combination of activities whose incomes are weakly or negatively correlated is an effective strategy to lower the overall income risk. Furthermore, crops differ in their exposure to drought, waterlogging and frost. These differing tolerances imply that livelihood diversification can reduce overall production risk since a single climate shock is unlikely to affect all crops equally. Constructing such a diversified portfolio requires knowledge of the correlations between all activities considered (Francis & Kim, 2013).

Similarly, Birthal and Hazrana (2019) highlight that, because crops respond differently to climatic shocks, risk-averse farm households tend to select combinations with low-correlated returns to spread climate-related risks. If adverse weather reduces the yield of one crop, the loss may be offset by gains from another crop that withstands the shock better. A negative correlation between two activities therefore implies that diversification based on these activities reduces the variance of total household income and helps stabilize earnings.

Our results indicate that all correlation coefficients, in absolute value, are less than one. Consequently, the total risk of a farmer's portfolio is lower than the weighted sum of the standard deviations of individual activity incomes. Portfolio volatility decreases as correlation coefficients approach their lower bound, and increases as they approach their upper bound. The findings also show that the activities in the portfolio are not perfectly correlated, meaning portfolio risk declines as the number of activities increases. In particular, low correlation coefficients enhance risk reduction through diversification, allowing the elimination of activity-specific risks.

According to Riaz (2002), high negative-correlation activities are prioritized for selection and later replaced with low negative-correlation activities as farmers' risk aversion decreases. Based on our correlation matrix, a rational farm household would choose a portfolio consisting of activity pairs with low or negative correlations. The optimal combinations identified are: Wild mango and Gnetum africanum; cassava sticks and maize; cassava sticks and cocoa; cocoa and maize; cassava sticks and Gnetum africanum; wild mango kernels and maize; cassava sticks and wild mango kernels; wild mango kernels and cocoa; cocoa and Gnetum africanum; and maize and Gnetum africanum.

Table II: correlation matrix

	Gnetum africanum	**Maize**	**Cocoa**	**Wild mango Kernel**	**Cassava sticks**
Gnetum africanum	1.0000				
Maize	0.1642	1.0000			
Cocoa	0.1453	0.0372	1.0000		
Wild mango Kernels	-0.0761	0.0455	0.1075	1.0000	
Cassava sticks	0.0404	-0.0300	0.0220	0.0752	1.0000

Source: authors from the survey data.

Following Burbano-Figueroa et al. (2022), for a portfolio manager, the decision is about which crops must be included in the portfolio to provide an expected outcome with acceptable risk. For this purpose, by providing the optimal portfolio, the results presented in table 3 complete those previouly obtained on matrix correlation.

Climate risk is measured by the variance (which indicates the portfolio variability) of the expected income. Portfolio variability is calculated from Equation 3 above which shows the results from optimization problem set equations in equations 7 and 8. It's found that although the composition of portfolio at the optimal level remains unchanged, the shares of income allocated to each activity change according to the risk-aversion coefficient as it also can be seen in table 3, but this variation is not monotonic because it is a non-linear variation. Kussaiynov et al. (2023) corroborates this, suggesting that the degree of climate risk-aversion of the farmer affects the optimal farming plan.

Table III: optimal income allocation

		Risk-aversion coefficient		
	1	**2**	**3**	**4**
Gnetum africanum	0.14058682	0.28829257	0.26129246	0.22351488
Maize	0.182114417	0.236903358	0.178339456	0.136616908
Cocoa	0	0	0	0
Wild mango kernels	0.206122836	0.104521211	0.464868284	0.205766403
Cassava sticks	0.47117593	0.37028286	0.0954998	0.43410181
Proportion sum	1	1	1	1
Z	-2517261173	-12013664926	-12716540764	-15019175021

Source: author from the survey data.

The results in the above table indicate that, at the optimum, cocoa production receives no allocation, regardless of the risk-aversion coefficient. In contrast, when the risk-aversion coefficient equals 1, the optimal investment strategy for a farm household allocates 14.05% of total revenue to Gnetum africanum production, 18.21% to maize, 20.61% to wild mango, and 47.11% to cassava sticks. Thus, to mitigate climate risk, the optimal portfolio should consist of four key crops: Gnetum africanum, maize, wild mango kernels, and cassava sticks.
It appears that, except when the risk-aversion coefficient equals 3, where wild mango receives the highest share of household income allocation, farm households should channel a substantial proportion of their income into cassava stick production. This finding confirms that cassava sticks are, if not the primary, then at least one of the most important income-generating activities for farm households in the study area. Focus group discussions further revealed that several Common Initiative Groups (CIGs) have been established and legally registered specifically for cassava stick production.

So it is found that in the Lékié division, in the face of climate risk, farm households adopt diversification of income generating activities as an adaptation strategy, so that the optimal portfolio of activities contains the above four crops. The role of livelihood diversification in the face of the consequences of climate change is thus highlighted in this study. Livelihood diversification appears to be an essential risks spreading strategy in rural area of Cameroon. Since the potential to stabilize farm income through diversification is a function of the proportion of mean income contributed by each activity(Hansen et al., 2019), there are ways of diversifying activities: a farm can increase the diversity of its income sources by assigning a higher amount income in complementary activities or by increasing the number of complementary activities carried out by each household member. In addition to on-farm diversification, access to markets and storage infrastructure can play significant roles in smoothing farmers' income over time. In the Lékié division, limited access to markets may force farmers to sell immediately after harvest even when prices are lowest, while lack of storage prevents intertemporal optimization of both consumption and income. As such, these constraints can exacerbate the income instability that arises from weather shocks, particularly for crops with high perishability or limited market channels. Hence, to fully benefit from income diversification, market access and storage infratsurure should be improved.

5-Conclusion and policy implications

Livelihood diversifiction is a coping strategy adopted by rural farm households which is likely to open up great prospects for poverty reduction, increases compensatory mechanisms in the event of crop yield problems or price instability, and strengthens food security and the protection of livelihoods. By applying modern portfolio theory , this study therefore aimed at highlighting the role of livelihood diversification and identifying the optimal portfolio of farm household's activities under climate risk in the central region of Cameroon. The study show that income generating activities can be combined to reduce climate change related risks. This study sheds light on relationship between the farmer's income and risk of individual income-generating activity on the one hand, and the relationship between the revenue and risk of a famer's portfolio on the other. The results of the study unveiled that modern portfolio theory can help in determining the optimal portfolio that generates the highest revenue under climate risk such as gentum africanum, maize, wild mango kernels and cassava. As a result, related risk of each activity can be eliminated through diversification. On the basis of this study findings, to build rural livelihoods' resilience against climate change related uncertainty, policy makers should reduce the adaptation deficit gap by implementing measures to support production of the income generating activities identified in the optimal portfolio. To decrease rural households' vulnerability to climate change, these measures may include equipping farm households with necessary skills, reliable infrastructure storage and building or improving physical infrastructure to improve market access.

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Appendix

Table IV: optimal income allocation with outliers

	Risk-aversion coefficient			
	1	**2**	**3**	**4**
Gnetum africanum	0.161132018	0.279597612	0.248845671	0.219986982
Maize	0.173833782	0.240007201	0.170003442	0.130237201
Cocoa	0	0	0	0
Wild mango kernels	0.199800952	0.114921716	0.471113265	0.228102929
Cassava sticks	0.465233243	0.38001301	0.110037626	0.421672892
Proportion sum	1	1	1	1
Z	-2541142309	-1200032871	-1262981172	-1510022010

Source: author from the survey data.