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Maternal Characteristics and Newborn Birth Weight: A Comprehensive Statistical Analysis

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ABSTRACT: This report presents a statistical analysis of the impact of key maternal characteristics, including age, smoking status, parity, height, weight, and gestation period, on newborn birth weight. A real-world dataset comprising 1,236 observations was utilized for this investigation. The methodology involved comprehensive data cleaning, exploratory data analysis (EDA), and a series of parametric statistical tests, specifically the One-Sample t-test, Two-Sample t-test, Chi-Square tests, and Analysis of Variance (ANOVA). All analyses were conducted within the SAS programming environment.

The study's findings indicate a statistically significant negative impact of maternal smoking on birth weight, a finding consistent with broader public health literature. Gestation period emerged as the strongest positive predictor of birth weight within this dataset. While the analyses using broad categories of maternal age and parity did not reveal significant differences in mean birth weight, a review of existing literature suggests more intricate, potentially non-linear relationships and nuanced effects of these factors. Similarly, maternal pre-pregnancy weight, though showing a weak linear correlation in this dataset, is widely recognized as a critical determinant of birth weight outcomes, particularly at its extremes. These results emphasize the importance of targeted prenatal care interventions, especially those focused on smoking cessation. The study reinforces the utility of data-driven insights in informing public health policies aimed at improving maternal and child health outcomes. Future research should explore non-linear relationships and potential interactions among various maternal factors.

KEYWORDS: birth weight, maternal characteristics, smoking during pregnancy, gestational age, statistical analysis.

1 INTRODUCTION

Birth weight serves as a critical indicator of neonatal health and is a robust predictor of infant survival, growth, and long-term developmental trajectories. Low birth weight (LBW), conventionally defined as less than 2,500 grams (approximately 88 ounces), is consistently associated with heightened risks of infant mortality, developmental delays, and the onset of chronic health conditions later in life. Beyond LBW, abnormal birth weights, encompassing macrosomia (excessively large birth weight), small for gestational age (SGA), and large for gestational age (LGA), are linked to both immediate and enduring health challenges, such as stunted growth, cognitive impairments, increased childhood mortality, and an elevated susceptibility to chronic diseases like hypertension and diabetes in adulthood. Consequently, a profound understanding of the maternal factors that influence birth weight is indispensable for enhancing prenatal care practices and fostering healthy birth outcomes.

LITERATURE REVIEW ON INFLUENCING FACTORS

Extensive research has identified numerous maternal characteristics that play a role in determining newborn birth weight. This study focuses on several key demographic and behavioral factors.

MATERNAL SMOKING

Maternal smoking during pregnancy is consistently and causally associated with significant reductions in birth weight, an increased risk of LBW, fetal growth restriction, stillbirth, preterm birth, placental abruption, and sudden infant death syndrome (SIDS). The detrimental effects of smoking extend beyond birth weight, impacting almost every facet of fetal development and long-term child health. For instance, smoking can impair in utero airway development, alter lung elastic properties, and reduce the functional residual capacity (FRC) in infants. Furthermore, it increases the risks of childhood overweight, certain cancers (e.g., non-Hodgkin lymphoma, acute

lymphoblastic leukemia, Wilms' tumor), cleft lip/palate, and adverse respiratory function. The pervasive and multi-faceted adverse effects of maternal smoking underscore its status as a critical, modifiable risk factor. This broad impact on child health suggests that public health interventions targeting smoking cessation during pregnancy offer wide-ranging benefits, making such efforts a high priority for improving population health.

MATERNAL AGE

Maternal age is recognized as a significant determinant of birth outcomes, with advanced maternal age (typically defined as over 35 years) being a known risk factor for adverse events such as premature birth and LBW. However, the relationship between maternal age and birth weight is often non-linear, with risks concentrated at both the younger and older extremes of the age spectrum. Adolescent mothers, aged 10-19 years, face higher risks of LBW, preterm birth, and severe neonatal conditions. Conversely, advanced maternal age can increase the risk for LGA and preterm birth, and has been associated with higher rates of C-sections, mortality, sepsis, and asphyxia in very low birth weight infants. This complex, non-linear relationship implies that a simple grouping or linear model might not fully capture the critical nuances of how maternal age influences birth weight. A more detailed analysis, potentially considering age as a continuous variable or using more refined age categories, would be necessary to fully understand these effects, especially given that gestational weeks can have a masking effect on the association between maternal age and birth weight.

PARITY

Parity, indicating whether a mother has had previous children, also influences birth outcomes. Previous studies suggest that multiparous mothers may have children with higher fetal growth (e.g., head circumference, length, and weight) and lower risks of preterm birth and SGA, though potentially a higher risk of LGA compared to nulliparous mothers. Children born to multiparous mothers have also been observed to show lower rates of accelerated infant growth and lower childhood BMI. However, some studies present conflicting findings, with one indicating that maternal multiparas had higher rates of LBW, preterm birth, and LGA. This suggests that the relationship between parity and birth weight is more intricate than a simple binary comparison. The presence of other confounding factors or the specific definitions of parity employed in different studies might contribute to these varying observations.

MATERNAL HEIGHT AND PRE-PREGNANCY WEIGHT/BMI

Maternal height is generally considered a factor influencing fetal growth, with taller mothers often having larger babies. More critically, maternal pre-pregnancy weight or Body Mass Index (BMI) has a significant and direct impact on neonatal birth weight. Pre-pregnancy underweight increases the risk of SGA and LBW. Conversely, pre-pregnancy overweight or obesity significantly increases the risk of LGA, high birth weight (HBW), and macrosomia, as well as the subsequent risk of offspring overweight or obesity. Obese mothers also face a higher prevalence of gestational diabetes mellitus, hypertension, and a lower likelihood of completing full-term gestation. While a linear correlation with continuous maternal weight might appear weak, the categorization of maternal weight (underweight, normal, overweight, obese) and its extremes are highly influential on birth weight outcomes, indicating a non-linear or threshold effect. This makes maternal pre-pregnancy weight a modifiable risk factor with substantial implications for interventions.

GESTATION PERIOD

Gestation duration is a critical and strong predictor of birth weight, with longer pregnancy durations generally associated with higher birth weights. Babies born after longer gestation periods, closer to full term, typically exhibit higher birth weights, reinforcing the biological principle that fetal development progresses with time in utero. It is also observed that outliers and variability in birth weight are more prominent at lower gestation periods, particularly in premature births, highlighting the elevated risk of adverse birth weight outcomes associated with early delivery.

RESEARCH PROBLEM AND OBJECTIVES

Despite extensive research into individual maternal factors, the complex interplay of these variables on newborn birth weight within specific populations warrants continuous investigation to refine public health strategies and clinical guidelines. This study aims to analyze a real-world dataset to identify key demographic and behavioral factors influencing birth weight, specifically focusing on maternal age, smoking status, parity, height, weight, and gestation period. The specific objectives of this research are:

- To explore the relationship between birth weight and various maternal attributes using appropriate statistical techniques.
- To evaluate differences in birth weight across maternal factors such as smoking status, age groups, and parity.
- To identify maternal attributes that exhibit statistically significant effects on newborn birth weight through hypothesis testing.
- To provide actionable insights for healthcare providers and policymakers, thereby facilitating the design of targeted interventions and contributing to the improvement of maternal-child health outcomes.

2 MATERIALS AND METHODS

2.1 DATA SOURCE AND DESCRIPTION

The dataset utilized for this study, titled "Birthweight and Maternal Factors Dataset," was sourced from Kaggle. It comprises 1,236 unique observations, each representing a distinct pregnancy case. The dataset includes seven variables, encompassing both quantitative and categorical information pertinent to maternal health and behavior.

The primary outcome variable for this analysis is bwt, representing the birth weight of the baby in ounces. The predictor variables include:

- gestation: Duration of pregnancy in days (continuous).
- parity: Whether the mother had previous children (encoded as 0 for "No" and 1 for "Yes," a binary categorical variable).
- age: Mother's age in years (continuous).
- height: Mother's height in inches (continuous).
- weight: Mother's pre-pregnancy weight in pounds (continuous).
- smoke: Whether the mother smoked during pregnancy (encoded as 0 for "No" and 1 for "Yes," a binary categorical variable).

All variables were stored as numeric types within the SAS environment, with categorical variables (smoke and parity) numerically encoded to ensure compatibility with statistical procedures. Table 1 provides a comprehensive overview of the dataset's features and their descriptions.

Table 1. Dataset Features and Descriptions

Variable Name	Description	Data Type (SAS)	Role
bwt	Birth weight of the baby in ounces	Numeric	Target
gestation	Duration of pregnancy in days	Numeric	Predictor
parity	Mother had previous children (0=No, 1=Yes)	Numeric	Predictor
age	Mother's age in years	Numeric	Predictor
height	Mother's height in inches	Numeric	Predictor
weight	Mother's pre-pregnancy weight in pounds	Numeric	Predictor
smoke	Mother smoked during pregnancy (0=No, 1=Yes)	Numeric	Predictor

2.2 DATA PREPROCESSING

Effective data analysis necessitates a clean and complete dataset. Prior to conducting statistical tests and exploratory data analysis, the dataset underwent a thorough preprocessing phase to address missing values and ensure data integrity.

INITIAL MISSING VALUE CHECK

The dataset was initially examined for missing values across all variables using PROC FORMAT and PROC FREQ in SAS. The initial assessment revealed the following counts of missing observations:

bwt: 0, gestation: 13, parity: 0, age: 2, height: 22, weight: 36, and smoke: 10.

HANDLING MISSING NUMERICAL VALUES (IMPUTATION)

Missing values in the numerical columns (age, height, weight, and gestation) were imputed using the median value of each respective variable. The median was selected over the mean for imputation to minimize the influence of potential outliers and skewed distributions, thereby ensuring that the imputed values remained representative of the original data's central tendency. The specific imputed median values were:

age = 26, height = 64, weight = 2000, and gestation = 280.

HANDLING MISSING CATEGORICAL VALUES (IMPUTATION)

The categorical variable smoke, which indicates maternal smoking status during pregnancy, contained 10 missing values. These missing entries were replaced with the mode of the variable, which was determined to be 0 (Non-smoker). This category accounted for

60.03% of the valid observations within the smoke variable. Imputing with the mode, representing the majority class, was based on the assumption that this approach best reflects the underlying distribution of the binary variable and helps to mitigate potential bias that might arise from other imputation methods or from simply removing records with missing data.

DATA TRANSFORMATION

The initial data loading from the CSV file (babies.csv) into the SAS environment was performed using FILENAME and PROC IMPORT. Subsequently, a DATA Step was employed for various transformations, including type conversions (e.g., converting character variables to numeric if needed, though all were already numeric in this dataset), unit standardization (e.g., ensuring bwt was in ounces and weight in pounds as specified), and renaming variables for clarity.

PROC CONTENTS was utilized to verify variable types, structure, and metadata following these transformations, confirming the integrity of the processed dataset.

Table 2 summarizes the missing value counts and the imputation strategies applied to each variable.

Table 2. Missing Value Summary and Imputation Strategy

Variable Name	Initial Missing Count	Imputation Method	Imputed Value (Median/Mode)
bwt	0	N/A	N/A
gestation	13	Median	280
parity	0	N/A	N/A
age	2	Median	26
height	22	Median	64
weight	36	Median	2000
smoke	10	Mode	0

2.3 EXPLORATORY DATA ANALYSIS (EDA)

Exploratory Data Analysis (EDA) was conducted to gain a deeper understanding of the dataset's underlying structure, variable distributions, and relationships, as well as to assess the suitability of variables for subsequent parametric statistical modeling.

Various SAS procedures were employed for this purpose: PROC UNIVARIATE was used to generate histograms and Q-Q plots, facilitating the assessment of distribution and normality for continuous variables such as bwt, gestation, age, height, and weight.

PROC SGPLOT was instrumental in creating visual representations, including boxplots, bar charts, and scatterplots, for a comprehensive visual analysis of both numerical and categorical variables.

PROC FREQ provided summaries of the distributions for categorical variables like smoke and parity. Finally, PROC CORR was utilized to perform Pearson correlation analysis among the numerical variables, enabling the detection of linear relationships.

Key observations from the EDA, to be detailed in the Results section, included the approximate normal distribution of bwt and gestation, which supported the use of parametric tests. Age and height also exhibited approximate normality, despite a slight right skew in age. In contrast, weight was found to be highly right-skewed with numerous extreme outliers, suggesting that caution or transformation might be necessary for parametric tests involving this variable. The parity variable displayed a significant class imbalance, with approximately 74.51% of mothers being first-time mothers. The smoke variable, while moderately imbalanced (60.84% non-smokers vs. 39.16% smokers), maintained adequate sample sizes for meaningful statistical comparisons. Preliminary correlation analysis indicated that gestation had the strongest positive correlation with bwt ($r = 0.40577$). Visualizations, particularly boxplots, also suggested a lower median birth weight for babies born to smoking mothers.

2.4 STATISTICAL ANALYSIS

All statistical analyses were meticulously implemented using the SAS programming environment. A series of hypothesis tests were performed to investigate the relationships between maternal characteristics and newborn birth weight.

ONE-SAMPLE T-TEST

A One-Sample t-test was conducted to determine whether the mean birth weight of babies in the sample statistically differed from the national average birth weight of 118 ounces. The null hypothesis (H_0) posited that the sample mean birth weight (μ) was equal to the national average ($\mu = 118$ ounces), while the alternative hypothesis (H_a) stated that it was not equal ($\mu \neq 118$ ounces). Assumptions

for this test included random sampling (assumed due to lack of contrary indication), independence of observations (naturally satisfied as each observation represents a different baby), and approximate normality of the data. The normality assumption was considered justified due to the large sample size ($n = 1236$), invoking the Central Limit Theorem, and was further supported by the Q-Q plot from the EDA.

PROC TTEST in SAS was used for this analysis.

TWO-SAMPLE T-TEST

A Two-Sample t-test was performed to ascertain whether the mean birth weight of babies differed significantly between smoking and non-smoking mothers. The null hypothesis (H_0) stated that the mean birth weight of babies born to non-smoking mothers (μ_0) was equal to that of babies born to smoking mothers (μ_1) ($\mu_0 = \mu_1$). The alternative hypothesis (H_a) proposed that these means were different ($\mu_0 \neq \mu_1$). Key assumptions for this test included independence of observations (satisfied) and homogeneity of variances between the two groups. The homogeneity of variances was assessed using the Folded F test, which yielded a p-value of 0.3730, greater than 0.05, thereby supporting the assumption of equal variances. Normality for each group was justified by their respective large sample sizes ($n=752$ for non-smokers and $n=484$ for smokers), again relying on the Central Limit Theorem.

PROC TTEST was employed for this analysis.

CHI-SQUARE TEST OF INDEPENDENCE (SMOKING STATUS VS. PARITY)

To investigate whether there was an association between maternal smoking status and parity, a Chi-Square Test of Independence was conducted. The null hypothesis (H_0) was that smoking status and parity were independent, while the alternative hypothesis (H_a) proposed that they were not independent. The assumptions for this test included that both variables were categorical (satisfied, as smoke and parity are binary categorical variables) and that the expected frequency in each cell of the contingency table was at least 5. This assumption was met, with observed cell counts of 558, 194, 363, and 121, all well above the minimum threshold.

PROC FREQ with the CHISQ option in SAS was used for this analysis.

ONE-WAY ANALYSIS OF VARIANCE (ANOVA) (MATERNAL AGE GROUPS)

A One-Way Analysis of Variance (ANOVA) was performed to test whether the average birth weight differed across predefined maternal age groups (<20 years, 20-30 years, and >30 years). The null hypothesis (H_0) stated that the mean birth weight was the same across all three maternal age groups ($\mu_1 = \mu_2 = \mu_3$). The alternative hypothesis (H_a) posited that at least one maternal age group had a different mean birth weight. Assumptions for ANOVA included independence of observations (satisfied), homogeneity of variances (checked using Levene's Test, with a p-value greater than 0.05, supporting the equal variances assumption), and normality of residuals (justified by the large overall sample size via the Central Limit Theorem).

PROC ANOVA in SAS was utilized for this statistical test.

3 RESULTS

3.1 DESCRIPTIVE STATISTICS AND DATA CHARACTERISTICS

The exploratory data analysis provided a comprehensive overview of the dataset's characteristics, including the central tendency, dispersion, and distribution of both numerical and categorical variables.

SUMMARY OF NUMERICAL VARIABLES

Table 3 presents the summary statistics for the continuous numerical variables after the imputation of missing values.

Table 3. Summary Statistics of Numerical Variables (Post-Imputation)

Variable Name	N	Mean	Median	Standard Deviation	Skewness	Kurtosis
bwt	1236	119.6	N/A	18.2365	Slight Left	N/A
gestation	1236	N/A	280	N/A	Slight Left	Moderate
age	1236	N/A	26	N/A	Moderate Right	N/A
height	1236	N/A	64	N/A	Negligible	N/A
weight	1236	N/A	2000	N/A	1.29	>3

Note: Specific mean, standard deviation, and range values for all variables were not explicitly provided in the source material beyond what is listed, but their distributional characteristics were described

DISTRIBUTIONAL CHARACTERISTICS

- **Birth Weight (bwt):** The target variable exhibited an approximately normal distribution, characterized by a bell-shaped histogram centered around a mean of approximately 119.6 ounces. A slight left skew was observed, along with a few mild outliers on both the lower and higher ends of the distribution. This near-normality supported the use of parametric statistical tests in subsequent analyses.
- **Gestation (gestation):** The duration of pregnancy in days also showed an approximately normal, unimodal distribution, centered around 279 days. While generally aligned with the normal line in the Q-Q plot, some deviation was observed in the tails, and the boxplot indicated a few moderate outliers at both extremes. Despite these characteristics, the distribution was considered sufficiently well-behaved for parametric statistical tests.
- **Age (age):** Maternal age displayed a moderately right-skewed distribution, with a higher concentration of observations in the early to mid-twenties. The Q-Q plot showed mild deviation in the upper tail, consistent with this skewness, and a few mild outliers were identified, predominantly in the higher age spectrum. However, given the large sample size (N = 1236), the Central Limit Theorem suggests that the sampling distribution of the mean would still be approximately normal, thus justifying the application of parametric tests.
- **Height (height):** Maternal height was found to be approximately normally distributed, with a bell-curved histogram and points well-aligned with the reference line in the Q-Q plot. Only a few mild outliers were detected, and the overall distribution remained symmetric and within reasonable bounds. The low coefficient of variation (3.92%) further indicated a stable and tightly spread dataset, making height well-suited for parametric statistical analysis.
- **Weight (weight):** Maternal pre-pregnancy weight exhibited a strong right skew, with the majority of data concentrated around 2000 pounds and a long tail extending towards higher values. The Q-Q plot showed significant deviation from the normal line in the upper tail, confirming non-normality and the presence of numerous extreme outliers, particularly above 3000–4000 pounds. This non-normal distribution, coupled with a high skewness value of 1.29 and kurtosis greater than 3, suggested that parametric tests involving weight should be applied with caution. Transformation techniques or non-parametric tests might be more appropriate for variables with such characteristics.

Table 4. Frequencies of Categorical Variables

Variable Name	Category	Count	Percentage
parity	0 (First-time mother)	N/A	74.51%
	1 (Experienced mother)	N/A	25.49%
smoke	0 (Non-smoker)	N/A	60.84%
	1 (Smoker)	N/A	39.16%

Note: Exact counts were not provided in the source material, but percentages are given.

CATEGORICAL VARIABLE DISTRIBUTIONS

Table 4 presents the frequencies and percentages for the categorical variables parity and smoke.

The parity variable showed a significant class imbalance, with approximately three-fourths (74.51%) of the mothers being first-time mothers (parity = 0). This skewed distribution requires careful consideration when performing stratified statistical testing or developing classification models. The smoke variable, indicating maternal smoking status, was moderately imbalanced, with non-smokers (60.84%)

slightly outnumbering smokers (39.16%). Despite this imbalance, both categories possessed adequate sample sizes for reliable statistical comparison and subgroup analysis.

Table 5. Pearson Correlation Matrix of Numerical Variables

Variable	bwt	gestation	age	height	weight
bwt	1.0000	0.40577 (p<.0001)	Weak (N/A)	0.19726 (p<.0001)	0.15198 (p<.0001)
gestation	0.40577 (p<.0001)	1.0000	Weak (N/A)	Weak (N/A)	Weak (N/A)
age	Weak (N/A)	Weak (N/A)	1.0000	0.00341 (p=0.9121)	Weak (N/A)
height	0.19726 (p<.0001)	Weak (N/A)	0.00341 (p=0.9121)	1.0000	0.43223 (p<.0001)
weight	0.15198 (p<.0001)	Weak (N/A)	Weak (N/A)	0.43223 (p<.0001)	1.0000

Note: "Weak (N/A)" indicates correlations described as very weak or not explicitly detailed with specific r-values and p-values in the source material's correlation analysis summary beyond the key insights provided.

3.2 CORRELATION ANALYSIS

A Pearson correlation analysis was conducted to assess the linear interdependence among the continuous numerical variables: bwt, age, height, weight, and gestation. Table 5 presents the correlation coefficients and associated p-values.

The correlation analysis yielded several key findings:

- **Birth Weight (bwt) and Gestation (gestation):** A moderate positive correlation was observed ($r = 0.40577$, $p < 0.0001$). This indicates that longer pregnancy durations are associated with higher birth weights, a biologically expected relationship.
- **Maternal Height and Weight:** The height and pre-pregnancy weight of the mothers showed a moderate positive correlation ($r = 0.43223$, $p < 0.0001$), which is also a biologically intuitive relationship.
- **Birth Weight and Maternal Anthropometrics:** bwt exhibited weak positive correlations with both maternal height ($r = 0.19726$, $p < 0.0001$) and weight ($r = 0.15198$, $p < 0.0001$). While these correlations were statistically significant due to the large sample size, their practical strength was limited.
- **Maternal Age:** age demonstrated very weak correlations with all other variables. For instance, the correlation between age and height was almost negligible ($r \approx 0.00341$, $p = 0.9121$), suggesting no substantial linear relationship with other factors in this dataset.
- **Overall Predictor:** Among all numerical variables analyzed, gestation emerged as the strongest individual linear predictor of Birth Weight.

3.3 HYPOTHESIS TESTING OUTCOMES

The results from the various hypothesis tests are summarized below and in Table 6.

3.3.1 ONE-SAMPLE T-TEST (BIRTH WEIGHT VS. NATIONAL AVERAGE)

The One-Sample t-test, comparing the sample mean birth weight to a national average of 118 ounces, yielded a sample mean of 119.6 ounces, a t-value of 3.04, and a p-value of 0.0024, with 1235 degrees of freedom. The 95% Confidence Interval for the mean birth weight was (118.6, 120.6) ounces.

At the 5% level of significance, since the p-value (0.0024) was less than 0.05, the null hypothesis ($\mu = 118$) was rejected. This indicates statistically significant evidence that the mean birth weight in the sample (119.6 ounces) is different from the national average of 118 ounces. This divergence may reflect distinct characteristics or health factors within the sampled population.

3.3.2 TWO-SAMPLE T-TEST (BIRTH WEIGHT BY SMOKING STATUS)

The Two-Sample t-test investigated differences in mean birth weight between babies born to smoking and non-smoking mothers. The mean birth weight for non-smokers (smoke = 0) was 123.1 ounces, while for smokers (smoke = 1), it was 114.1 ounces. The test produced a t-value of 8.64, with 1003 degrees of freedom, and a p-value of less than 0.0001.

At the 5% level of significance, as the p-value (<0.0001) was less than 0.05, the null hypothesis ($\mu_0 = \mu_1$) was rejected. This provides strong statistical evidence that the mean birth weight of babies born to smoking mothers is significantly lower than that of babies born to non-smoking mothers.

3.3.3 CHI-SQUARE TEST OF INDEPENDENCE (SMOKING STATUS VS. PARITY)

The Chi-Square Test of Independence examined the association between maternal smoking status and parity. The test statistic was 0.0987, with 1 degree of freedom, and a p-value of 0.7534.

At the 5% level of significance, since the p-value (0.7534) was greater than 0.05, the null hypothesis of independence was failed to be rejected. This indicates that there is no statistically significant association between maternal smoking status and parity in this dataset.

3.3.4 ONE-WAY ANOVA (BIRTH WEIGHT BY MATERNAL AGE GROUPS)

The One-Way ANOVA assessed differences in mean birth weights across three maternal age groups (<20, 20-30, >30 years). The analysis yielded an F-value of 0.62, with 2 degrees of freedom between groups and 1233 within groups, and a p-value of 0.5387. At the 5% level of significance, as the p-value (0.5387) was greater than 0.05, the null hypothesis (equal means across age groups) was failed to be rejected. This suggests that there is no statistically significant difference in the mean birth weights across these three broad maternal age groups in the dataset.

Table 6. Summary of Hypothesis Test Results

Test Name	Hypotheses (H0, Test Ha)	Test Statistic	Degrees of Freedom	p-value	Statistical Conclusion	Interpretation
One-Sample t-Test	H0: $\mu = 118$; Ha: $\mu \neq 118$	$t = 3.04$	1235	0.0024	Reject H0	Mean birth weight in sample is significantly different from national average.
Two-Sample Test	H0: $\mu_0 = \mu_1$; Ha: $\mu_0 \neq \mu_1$	$t = 8.64$	1003	<0.0001	Reject H0	Mean birth weight of babies from smoking mothers is significantly lower.
Chi-Square (Smoke vs Parity)	H0: Independent; Ha: Not Independent	$\chi^2 = 0.0987$	1	0.7534	Fail to Reject H0	No significant association between smoking status and parity.
One-Way ANOVA (BWT by Age)	H0: $\mu_1 = \mu_2 = \mu_3$; Ha: At least one μ differs	$F = 0.62$	2, 1233	0.5387	Fail to Reject H0	No significant difference in mean birth weights across age groups.

4 DISCUSSION

The comprehensive statistical analysis of maternal characteristics and newborn birth weight has yielded several important findings, some of which align with established literature, while others highlight the complexities and nuances that warrant further investigation.

INTERPRETATION OF KEY FINDINGS

MATERNAL SMOKING AND BIRTH WEIGHT

The study's finding of a significantly lower mean birth weight for babies born to smoking mothers (114.1 oz compared to 123.1 oz for non-smokers, with a p-value <0.0001) is a robust and critical result. This observation strongly aligns with extensive existing literature that consistently demonstrates a causal link between maternal smoking during pregnancy and adverse fetal growth outcomes. The consistency of this finding across multiple studies, including the present one, underscores maternal smoking as a crucial and, importantly, a modifiable risk factor. This reinforces the imperative for public health interventions that prioritize smoking cessation during pregnancy, as such efforts have a direct and substantial positive impact on newborn health.

GESTATION PERIOD AS A PRIMARY PREDICTOR

The moderate positive correlation observed between gestation duration and birth weight ($r = 0.40577$) confirms that gestation period is the strongest linear predictor of birth weight within this dataset. This relationship is biologically intuitive, as fetal development and growth naturally progress throughout the duration of pregnancy. The strong predictive power of gestation emphasizes the profound importance of preventing preterm births. Shorter gestation periods inherently lead to lower birth weights and are associated with a range of health risks for the newborn. Therefore, interventions aimed at prolonging healthy gestation, where medically appropriate, would have a direct and beneficial impact on birth weight outcomes.

MATERNAL AGE AND BIRTH WEIGHT: A NUANCED RELATIONSHIP

The ANOVA conducted in this study indicated no statistically significant difference in mean birth weights across the broad maternal age groups (under 20, 20-30, and over 30 years). This finding, however, appears to contrast with a significant body of literature that identifies maternal age as a key factor influencing birth outcomes. Existing research frequently highlights non-linear associations, where increased risks are concentrated at the extremes of maternal age, specifically among adolescent mothers and those of advanced maternal age. For example, adolescent mothers face higher risks of low birth weight and preterm birth, while advanced maternal age has been linked to large for gestational age infants, preterm birth, and other adverse neonatal outcomes such as higher rates of C-sections, mortality, sepsis, and asphyxia in very low birth weight infants. The discrepancy between the current study's findings and the broader literature suggests that the broad categorization of maternal age employed here may have masked a more complex, non-linear relationship. A simple ANOVA might not be sensitive enough to capture the nuanced effects present at the tails of the age distribution. This points to a limitation in the current analysis and suggests that future investigations could benefit from analyzing age as a continuous variable in regression models, or by creating more refined age categories, and potentially controlling for confounding factors such as gestational weeks, which can obscure the true association between maternal age and birth weight.

MATERNAL PARITY AND BIRTH WEIGHT: LIMITED EVIDENCE IN THIS STUDY

The Chi-Square test revealed no statistically significant association between smoking status and parity in this dataset. Furthermore, the exploratory grouped boxplot showed only a slight difference in median birth weight by parity, with a higher incidence of outliers among first-time mothers. The lack of a significant difference in mean birth weights across parity groups in this study appears to diverge from some external research. For instance, studies have shown that multiparous mothers may have children with higher fetal growth and lower risks of preterm birth and small for gestational age. However, it is also important to note that other studies present conflicting evidence, with some indicating that maternal multiparas had higher rates of LBW, preterm birth, and LGA. This suggests that the binary nature of the parity variable (0 or 1) in this dataset might oversimplify the complex biological and physiological changes associated with multiple pregnancies. The observed discrepancy could be due to unmeasured confounding factors or the need for a more granular definition of parity (e.g., the exact number of previous births) to fully capture its effects on birth weight.

MATERNAL PRE-PREGNANCY WEIGHT/BMI AND BIRTH WEIGHT: UNDERESTIMATED IMPACT

This study found only a weak positive correlation between continuous maternal pre-pregnancy weight and bwt ($r = 0.15198$). This weak linear correlation, however, potentially underestimates the significant impact of maternal pre-pregnancy weight, particularly when it is categorized into Body Mass Index (BMI) groups (underweight, normal, overweight, obese). Extensive literature consistently demonstrates that pre-pregnancy underweight status significantly increases the risk of low birth weight and small for gestational age infants, while pre-pregnancy overweight or obesity significantly increases the risk of large for gestational age, high birth weight, and macrosomia. This indicates that the effect of maternal weight on birth weight is likely non-linear, with critical thresholds at the extremes of BMI. Analyzing maternal weight solely as a continuous variable in a simple correlation might not fully capture its clinical significance or its profound implications for fetal development, as highlighted by the "fetal programming" hypothesis.

PRACTICAL IMPLICATIONS

The robust finding regarding the negative impact of maternal smoking on birth weight provides clear and actionable insights for healthcare providers and policymakers. Targeted prenatal care programs should continue to prioritize and emphasize smoking cessation, offering comprehensive support and resources to pregnant individuals. The ability to identify at-risk pregnancies early, based on factors such as smoking status and gestation period, can facilitate the efficient allocation of medical resources and enable the provision of specialized care to those who need it most. The insights derived from this study contribute to the expanding field of statistical health analytics, reinforcing the crucial role of data in shaping informed public health policies aimed at improving maternal and child health outcomes.

LIMITATIONS

This study, while providing valuable insights, is subject to several limitations. First, its observational nature means that it can establish associations but cannot definitively prove causality between maternal factors and birth weight outcomes. Second, the dataset's scope is confined to a specific set of maternal characteristics. Other crucial factors known to influence birth weight, such as detailed maternal nutrition and dietary patterns, specific medical conditions (e.g., gestational diabetes, hypertension), socioeconomic factors, and paternal smoking status, were not included in the analysis. The absence of these variables means their potential confounding or modifying effects could not be assessed.

Furthermore, the granularity of certain variables, such as the categorization of maternal age into broad groups and parity as a simple binary variable, might have obscured more complex, non-linear, or nuanced relationships that have been identified in the broader scientific literature. Similarly, the analysis of continuous weight in a linear correlation might not fully capture the significant impact of maternal weight when considered in clinically relevant categories, such as BMI classifications. Finally, while median and mode imputation methods were employed for missing data, these methods assume that data are missing at random (MAR) and may not perfectly represent the true underlying values, potentially introducing some level of bias into the results. The current analysis primarily focused on univariate and bivariate relationships, which means more advanced multivariate models could reveal confounding effects or important interaction terms, such as the masking effect of gestational weeks on maternal age's association with birth weight.

5 CONCLUSION

This project successfully applied various statistical techniques to analyze the impact of key maternal characteristics on newborn birth weight using a real-world dataset. The study confirmed a statistically significant negative impact of maternal smoking on birth weight, a finding that is consistent with extensive public health research and underscores the importance of smoking cessation interventions. Gestation period was identified as the strongest positive predictor of birth weight within the dataset, reinforcing the biological principle that longer in-utero development leads to higher birth weights.

While the initial analyses did not find significant differences in birth weight across the broad maternal age or parity groups, a comprehensive review of the existing literature highlights the complex, often non-linear, effects of these factors. For maternal age, risks are particularly pronounced at the extremes (adolescent and advanced maternal age), a nuance that broad categorization might not capture. Similarly, maternal pre-pregnancy weight, though showing only a weak linear correlation as a continuous variable, is a critical determinant of birth weight outcomes when considered in clinically relevant categories, such as BMI, which significantly influence the likelihood of low or high birth weights.

By identifying key risk factors and highlighting areas where further detailed investigation is warranted, this study provides valuable insights for healthcare providers to enhance prenatal care strategies. Furthermore, the findings contribute to the evidence base for policymakers to design targeted public health interventions aimed at reducing the incidence of low birth weight cases and improving overall maternal-child health outcomes.

6 FUTURE WORK

To build upon the findings of this study and address its limitations, several avenues for future research are recommended:

- **Expand Dataset Scope:** Future studies should incorporate additional maternal variables known to influence birth weight. These could include detailed nutritional intake and dietary patterns, specific measures of prenatal care quality, various socioeconomic factors, and pre-existing maternal medical conditions such as gestational diabetes or hypertension. Furthermore, including paternal factors, particularly paternal smoking status, would allow for the investigation of potential combined effects on birth outcomes. Consideration should also be given to including the sex of the baby as a covariate, given evidence of sex-based differences in birth weight and gestational age.
- **Advanced Statistical Modeling:** The application of more advanced statistical models is crucial for a deeper understanding of these complex relationships. Techniques such as multiple linear regression or generalized linear models could be employed to better predict birth weight while simultaneously controlling for confounding variables and exploring potential interaction effects. This approach would be particularly valuable for disentangling complex relationships, such as the masking effect of gestational weeks on maternal age's association with birth weight. Additionally, investigating non-linear relationships, especially for maternal age and weight, could involve using polynomial terms, spline functions, or by categorizing these variables into more refined groups (e.g., specific age ranges, BMI categories for weight).
- **Machine Learning Approaches:** Incorporating machine learning models, such as Random Forest, XGBoost, or Neural Networks, could help capture intricate non-linear relationships and complex interactions between maternal factors and birth outcomes that

traditional linear models might overlook. These models offer powerful predictive capabilities and can identify subtle patterns in large datasets.

- **Longitudinal Studies:** Conducting longitudinal studies that track maternal health throughout pregnancy and observe dynamic changes affecting birth weight would provide a more nuanced understanding of these relationships over time. Such studies could also shed light on the long-term child health outcomes, further exploring the concept of "fetal programming".
- **Replication and External Validation:** To enhance the generalizability and robustness of the findings, it is important to replicate this analysis using different datasets from diverse populations. This would help validate the observed associations and confirm their applicability across various demographic and geographical contexts.

REFERENCES

- [1] Andriani, L., & Kuo, S. (2014). The effect of maternal and paternal smoking on birth outcomes. *International Journal of Epidemiology*, 43 (5), 1355–1364.
- [2] Campbell, N. A., Urry, L. A., Cain, M. L., Wasserman, S. A., Minorsky, P. V., & Reece, J. B. (2020). *Biology* (12th ed.). Pearson.
- [3] Cnattingius, S., Haglund, B., & Meirik, O. (1988). Cigarette smoking as a risk factor for stillbirth. *British Medical Journal*, 297 (6654), 1019–1021.
- [4] Cnattingius, S., & Haglund, B. (1990). The association between maternal smoking during pregnancy and fetal growth restriction. *American Journal of Public Health*, 80 (6), 682–686.
- [5] Gul, R., Iqbal, S., Anwar, Z., Ahdi, S. G., Ali, S. H., & Pirzada, S. (2020). Pre-pregnancy maternal BMI as predictor of neonatal birth weight. *PLoS ONE*, 15 (10), e0240748. <https://doi.org/10.1371/journal.pone.0240748>.
- [6] Howe, L. D., Tilling, K., & Smith, G. D. (2012). Maternal smoking during pregnancy and offspring growth and adiposity: a systematic review and meta-analysis. *Obesity Reviews*, 13 (12), 1079–1092.
- [7] Iñiguez, C., Ballester, F., Costa, T., Murcia, M., Llop, S., & Esplugues, A. (2007). Maternal smoking during pregnancy and fetal growth: a dose-response relationship. *Environmental Health Perspectives*, 115 (10), 1461–1466.
- [8] Kaggle Dataset: Birthweight and Maternal Factors Dataset. Source: <https://www.kaggle.com/datasets/baby-dataset>.
- [9] Kramer, M. S., & Olivier, M. (1999). The effect of maternal smoking on fetal growth. *Journal of Public Health*, 21 (1), 1–11.
- [10] Li, Y., Chen, Y., Yu, X., Li, X., Wu, Y., & Zhang, Y. (2023). Maternal age and birth weight relationship: A retrospective study from south-central China. *Frontiers in Pediatrics*, 11780902. <https://pmc.ncbi.nlm.nih.gov/articles/PMC11780902/>.
- [11] Liu, P., & Li, G. (2014). Pre-pregnancy body mass index and adverse pregnancy outcomes: a systematic review and meta-analysis. *PLoS ONE*, 9 (4), e61627. <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0061627>.
- [12] Melo, A. C., & Barros, H. (2017). Maternal smoking and birth outcomes: a systematic review and meta-analysis. *Journal of Public Health*, 39 (3), 1-10. <https://academic.oup.com/jpubhealth/article/39/3/1/3002976>.
- [13] Morken, N. H., & Kallen, B. (2008). Maternal smoking during pregnancy and fetal growth. *Acta Obstetrica et Gynecologica Scandinavica*, 87 (6), 652–658.
- [14] Nanning People's Hospital. (2024). In vitro fertilization and dichorionic diamniotic twin pregnancies in advanced maternal age nulliparous women: A retrospective study. *International Journal of Women's Health*, 16, 119–128. <https://www.dovepress.com/in-vitro-fertilization-and-dichorionic-diamniotic-twin-pregnancies-in-peer-reviewed-fulltext-article-IJWH>.
- [15] Pediatrics. (1992). Maternal smoking during pregnancy and risk of sudden infant death syndrome. *Pediatrics*, 905–908.
- [16] Placental weight and function in vivo. *ResearchGate*. (https://www.researchgate.net/post/What_is_the_association_between_maternal_dietary_patterns_and_birth_weight).
- [17] Ramirez, A., & Eng, R. (2000). Maternal cigarette smoking during pregnancy and cleft lip/palate. *Plastic and Reconstructive Surgery*, 105 (2), 522–526.
- [18] SAS Institute Inc. (2022). *SAS 9.4 Procedures Guide*. Cary, NC: SAS Institute Inc. Available at: <https://documentation.sas.com>
- [19] SAS Support: Resources on PROC TTEST, PROC ANOVA, PROC FREQ, PROC UNIVARIATE, and PROC CORR for statistical analysis.
- [20] Stack Overflow: Community-driven solutions for R coding issues and statistical modeling best practices.
- [21] WHO. (n.d.). Adolescent pregnancy. *World Health Organization*. Retrieved from <https://www.who.int/news-room/fact-sheets/detail/adolescent-pregnancy>.
- [22] Xiong, X., Fraser, W. D., & Niu, L. (2009). Maternal age and adverse pregnancy outcomes: a meta-analysis. *American Journal of Obstetrics & Gynecology*, 201 (4), 382.e1-382.e14.
- [23] Yang, Y., Wang, L., & Zhang, Y. (2025). Maternal age and adverse outcomes of singleton very low birth weight neonates. *Frontiers in Pediatrics*, 13, 1444471. <https://www.frontiersin.org/journals/pediatrics/articles/10.3389/fped.2025.1444471/full>.
- [24] Zhu, Y., & Li, G. (2015). Maternal parity and offspring cardiometabolic risk factors: a prospective cohort study. *Hypertension*, 65 (4), 819–825. <https://www.ahajournals.org/doi/10.1161/hypertensionaha.114.03492>.
- [25] Zhu, Y., & Li, G. (2015). Maternal and offspring birth weight and gestational age: A cross-generational study. *Annals of Human Biology*, 42 (5), 458-464. <https://www.tandfonline.com/doi/pdf/10.1080/03014469300002662>.

Gouvernance et identité sociale des syndicalistes: Cas des dockers des Entreprises de Manutention du Port Autonome d'Abidjan (SEMPA)

[Governance and Social Identity of Trade Unionists: Case of Dockworkers at the Autonomous Port Handling Companies (SEMPA) in Abidjan]

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ABSTRACT: In a work environment marked by danger and precariousness, trade union action constitutes a central lever for dockworkers at the Port of Abidjan to defend their rights. This study analyzes the social profile of dockworker trade unionists and their repertoires of action, based on a methodology combining direct observation, individual interviews, and documentary research. The findings show that union leaders generally come from among the most experienced dockworkers and possess a higher level of education than the average of their peers. Their legitimacy relies on the strategic use of narrative and symbolic resources, while, in certain situations, resorting to forms of physical violence. The article highlights the tensions between internal solidarity, power struggles, and structural constraints in a context where institutional mechanisms for worker protection remain limited.

KEYWORDS: solidarity, multiplicity, collective organization, dominant identities, social security.

RESUME: Dans un environnement de travail marqué par la dangerosité et la précarité, l'action syndicale constitue pour les dockers du Port Autonome d'Abidjan un levier central de défense de leurs droits. Cette étude analyse le profil social des syndicalistes dockers et leurs répertoires d'action, en s'appuyant sur une méthodologie combinant observation directe, entretiens individuels et recherche documentaire. Les résultats montrent que les leaders syndicaux sont généralement issus des dockers les plus expérimentés et disposent d'un niveau d'instruction supérieur à la moyenne de leurs pairs. Leur légitimité repose sur l'usage stratégique de ressources narratives et symboliques, tout en mobilisant, dans certaines situations, des formes de violence physique. L'article met en lumière les tensions entre solidarité interne, enjeux de pouvoir et contraintes structurelles, dans un contexte où les mécanismes institutionnels de protection des travailleurs restent limités.

MOTS-CLEFS: solidarité, multiplicité, organisation collective, identités dominantes, protection sociale.

1 INTRODUCTION

La Côte-D'Ivoire compte deux ports en eau profonde. Il s'agit du Port de San Pedro au Sud-Ouest et celui d'Abidjan, la capitale économique au Sud-Est. Le Port Autonome d'Abidjan est décrit comme le « poumon de l'économie ivoirienne » et une « référence » dans la sous-région ouest-africaine. Il participe à plus de 75% des échanges maritimes de la Côte-d'Ivoire (PAA, 2022). Son trafic contribue à 90% des recettes douanières du pays et à 60% du revenu de l'État. 65% des unités industrielles du pays exercent sur le port, représentant un effectif de 50 000 personnes sur le site. 70% du Produit Intérieur Brut (PIB) ivoirien passe par le port. Dans le port, transitent 70% des

échanges extérieurs des pays de l'hinterland (Koutou, 2018). Ce sont plus de 20 entreprises qui se partagent l'activité portuaire à Abidjan avec une main-d'œuvre essentiellement constituée de dockers (PAA, 2024).

Le rapport de la commission internationale de travail du BIT (2002), stipule que le docker est tout travailleur occupé tant à terre qu'à bord des navires à la manutention des marchandises dans un port. La revue de la littérature sur le milieu ouvrier docker a montré qu'ils traversent de nombreuses difficultés. Belkacem R. et Montcharmont L. (2012), explique par exemple que la sécurité est quasi inexistante dans le travail de ces ouvriers si bien que les accidents constituent une des principales causes d'invalidité temporaire et permanente dans les ports. Quant à Lanciné Bakayoko (2010), il met en lumière le vécu quotidien des ouvriers dockers au Port Autonome d'Abidjan, notamment de nombreuses entraves à leur liberté syndicale. Pourtant ils jouent un rôle important et contribuent à faire du Port Autonome d'Abidjan l'un des plus importants ports en Afrique. Aussi, Albert Agbeko (2018) affirme dans une étude similaire que les dockers ont un salaire de misère en dépit des risques encourus dans leur métier. Dans ce contexte de montée des incertitudes socio-professionnelles et la dégradation des conditions de vie d'une partie grandissante de la classe laborieuse (Castel, 2009), on peut s'interroger sur le rôle joué par les syndicats, en particulier ceux du Collectif National des Dockers et Dockers Transit (CNDD), par rapport à leur rôle de producteur de solidarités (Dufour, 2016).

S'il est vrai que les syndicats jouent un rôle crucial dans la protection des droits des ouvriers dockers, peu de travaux sont consacrés à leurs profils social et à leur répertoire d'action. Ainsi, comment les syndicalistes dockers du Port Autonome d'Abidjan interprètent-ils et expliquent leurs profils et leurs répertoires d'actions ? La présente étude réalisée au port d'Abidjan a pour double objectif de répondre à cette préoccupation.

2 METHODOLOGIE

2.1 CADRE THÉORIQUE ET MÉTHODOLOGIQUE

Cette étude, extrait d'une recherche plus large menée dans le cadre de ma thèse de doctorat s'appuie sur le modèle sociologique de Dufour et al. (2009), qui postule que les syndicalistes construisent leurs pratiques et choix à partir de normes internalisées héritées, leur permettant de développer des stratégies de résilience face aux aléas sociaux. Pour analyser ces dynamiques, une enquête qualitative a été menée entre janvier et avril 2024 auprès de 30 dockers syndicalistes du Collectif National des Dockers et Dockers Transit (CNDD) au Port Autonome d'Abidjan. L'échantillon, constitué par convenance, comprend 23 participants interrogés sur site et 7 hors site, sélectionnés pour leur disponibilité et pertinence. La collecte des données a combiné entretiens semi-directifs et observation participante et non participante afin de saisir la culture et les pratiques syndicales dans leur contexte social.

2.2 PROCEDURES D'ENQUETE ET D'ANALYSE DES DONNEES

Un guide d'entretien qui traite des questions liées au profil des leaders syndicaux ainsi que de leurs répertoires d'actions, a été élaboré et administré sous la forme d'un guide d'entretien individuel. Ces entretiens individuels et semi-structurés ont permis à tous les acteurs (dockers syndiqués ou non, leaders des syndicats) qui ont un intérêt direct et indirect à donner leurs perceptions. En plus des entretiens individuels réalisés avec le secrétaire du syndicat, d'autres dockers ont été interrogés. Ces entretiens de terrain se sont déroulés sur trois mois au Port Autonome d'Abidjan et dans les communes de la capitale. De façon pratique, il s'est agi pour chaque question posée, de dénombrer et de classer les réponses obtenues de même que les avis recueillis sur la plate-forme par groupe de réponses identiques. Ainsi, en fonction de la récurrence des idées, la perception des acteurs vis-à-vis du phénomène étudié a été ressortie.

3 RESULTATS: SYNDICALISME DOCKER, UNE ACTIVITE SOCIALE PARTICULIERE

3.1 PROFIL SOCIAL DES LEADERS SYNDICAUX DOCKER

Nous présenterons dans cette partie quelques-unes des caractéristiques des leaders syndicaux docker du Port Autonome d'Abidjan, notamment: Le charisme syndical, le niveau d'instruction et l'ancienneté. Ces caractéristiques sont essentielles pour comprendre le rôle et l'influence des leaders syndicaux. Elles conditionnent leur légitimité, leur capacité à négocier et leur expérience dans la gestion des dynamiques collectives.

3.1.1 LE NIVEAU D'INSTRUCTION, UNE CARACTERISTIQUE MAJEURE

Selon les données documentaires corroborées par l'enquête réalisée environ 57% des ouvriers dockers du Port Autonome d'Abidjan n'a jamais été scolarisé. Parmi les 43% de dockers scolarisés, la grande majorité, soit (84%) n'est pas allé au-delà du cycle primaire. Le faible taux de scolarisation des ouvriers dockers n'est cependant pas un fait isolé car cela est illustré par la littérature sur le milieu ouvrier docker. Plusieurs raisons sont avancées pour justifier cette situation sociale. Entre autres, la pauvreté, le chômage des parents, la classe sociale des familles, etc. La tâche principale du docker est le chargement et le déchargement des marchandises arrivant à bord des navires, ainsi l'activité de docker n'exigeant pas de spécialisation scolaire particulière se présente comme une voie de recours pour les

chômeurs. A contrario les leaders syndicaux sont issus de la faible proportion des dockers ayant un niveau d'étude supérieure au cycle primaire, voire ayant un diplôme du supérieur, eu égard aux exigences de l'activité syndicale. A ce propos, un leader syndical interrogé dit ceci BIS¹:

« Nous ne pouvons pas prendre un illettré pour le mettre à la tête du syndicat parce que le leader syndical doit au moins savoir lire et écrire. Quand il va aux réunions avec les employeurs ou avec les partenaires sociaux, il doit prendre la parole pour exprimer les revendications des camarades mais s'il ne peut pas se faire entendre par supérieurs comment il pourra transmettre le message... en plus de cela il doit prendre note de ce qui a été dit pour venir faire le point aux camarades. C'est une réalité donc si tu ne peux pas prendre note qu'est-ce que tu vas dire aux ouvriers à ton retour. Parmi nous, il y en a quelques-uns qui ont des diplômes et ce sont ceux-là qui peuvent faire ce travail »

En vue donc d'être plus efficient et plus fort certains individus pensent qu'il faut à la tête du syndicat des individus ayant fait des études supérieures et capables de discuter avec des interlocuteurs généralement instruits. Cette réalité est attestée par un ouvrier docker, membre du syndicat des dockers, rencontré sur la plateforme portuaire en ces termes AL:

« Moi-même j'ai plusieurs années d'expérience. Je suis ici depuis plus de 15 ans mais on m'a dit que je ne peux pas parler devant les patrons parce que je ne maîtrise pas bien le français donc il faut des gens qui ont des diplômes pour devenir leader de notre syndicat. Ce sont eux qui deviennent plus tard superviseurs et ils sont mieux payés que nous. »

Ainsi, l'activité de leader syndical demande un niveau d'instruction minimum afin de pouvoir gérer toutes les activités de représentation y afférentes. Même si la plupart des ouvriers dockers sont perçus comme des analphabètes et des individus sans qualification, l'on peut constater que l'activité syndicale, à un certain niveau requiert un niveau d'instruction minimum. Cette faible scolarisation ne signifie pas pour autant un désintérêt total pour la sécurité et les bonnes pratiques. En effet, des initiatives de sensibilisation ont permis d'améliorer la prise de conscience des dockers quant aux risques liés à leur activité. Cela est illustré par l'exemple d'un docker portant un tee-shirt sur lequel est inscrit: « J'ai conscience des risques, je m'engage à respecter les consignes », témoignant de l'importance accordée à la formation pratique et à l'engagement individuel malgré un faible niveau d'instruction



Fig. 1. Docker sensibilisé portant un tee-shirt incitant au respect des consignes de sécurité, Port Autonome d'Abidjan (Auteur, 2024).

3.1.2 LE CHARISME SYNDICAL

Le charisme est une caractéristique importante dans le milieu ouvrier docker, car les dockers sont des individus perçus comme robustes et ayant une grande endurance physique. Le leader syndical est censé jouer un rôle important, notamment mobiliser les ouvriers et en défendre leurs droits. A ce titre, sa capacité à inspirer confiance et à galvaniser les masses ouvrières est cruciale. Cette capacité du leader syndical est confirmée par cet ouvrier docker nommée BG, secrétaire général d'un syndicat en ces termes:

¹ Par souci d'anonymat, le pseudonyme des participantes n'a pas été associé à leur rôle professionnel

« Ici il y a trop de problèmes donc un leader doit pouvoir mobiliser les gens. Si tu parles que les gens n'écoutent pas comment tu peux rassembler. Les dockers sont des gens compliqués donc il n'y a pas de recrutement particulier pour devenir leader syndical. Ce sont juste des gens qui sont beaucoup écoutés et qui savent parler, car ce sont les personnes qui ont du beau monde derrière eux que les patrons écoutent. Des gens qui peuvent aller devant les patrons et parler pour tous les dockers...car certains quand ils arrivent devant nos patrons, ils sont incapables de traduire fidèlement les revendications de leurs camarades »

D'après cet enquêté, le leader syndical doit pouvoir être capable de mobiliser les ouvriers. Il doit être un homme écouté et capable de galvaniser les militants pour les causes communes. À cet effet, un leader incapable de mobiliser et d'être écouté par la majorité des ouvriers aura du mal à se maintenir à la tête d'un syndicat. En effet, celui qui mobilise le plus de personnes s'impose naturellement comme leader dans le milieu syndical, la mobilisation étant un facteur essentiel dans la lutte syndicale.



Fig. 2. Leaders syndicaux dockers en réunion de mobilisation (Auteur, 2023)

3.1.3 L'ANCIENNETÉ DANS LE MÉTIER, UN CRITÈRE DE STRATÉGIE

Les leaders syndicaux dockers du Port Autonome d'Abidjan rencontrés au cours de cette étude avaient exercé pendant plus de 20 ans pour certains et 15 ans pour d'autres avant d'occuper cette fonction. Les dockers qui totalisent plusieurs années d'expériences dans le métier sont les plus susceptibles de diriger les mouvements collectifs tels que les syndicats et les associations. Le témoignage de cet ouvrier docker, ZOM que nous avons interrogé au Port Autonome d'Abidjan illustre cette réalité:

« Tous ceux que tu vois à la tête des syndicats sont des gens qui ont duré ici au port. Nous sommes venus les trouver sur les lieux... quand je suis venu en 2010, certains avaient déjà 10 ans de service voir 15 et 20 ans pour d'autres. Ce sont nos "vieux père" (ndlr) et ce sont eux qui maîtrisent le travail et qui sont capables de parler devant les patrons de nos conditions. Si tu es un nouveau docker, qu'est-ce que tu peux dire du métier de docker ? »

En outre, cette réalité s'explique par l'expérience acquise dans le métier, leur donnant ainsi beaucoup de légitimité dans leur environnement social et aux yeux des ouvriers. En effet, ce sont ceux-là qui sont à même de connaître au mieux les réalités et les conditions de travail liées au chargement et au déchargement des navires dans le port, car depuis des années le manque de mobilité professionnelle contraint la plupart des ouvriers à exercer la même tâche jusqu'à la retraite, et cela dans les mêmes conditions.

3.2 REPERTOIRE D'ACTION DES SYNDICATS DE DOCKERS

Les actions menées par les collectifs d'actions dockers pour leurs revendications sociales sont multiples et contenues dans leurs répertoires d'actions. Elles vont d'actions pacifiques aux actions les plus violentes, selon l'idéologie proclamée par le collectif. Notamment les ressources narratives, les ressources physiques et l'ancrage dans les réseaux.

3.2.1 LES RESSOURCES NARRATIVES, MOYEN DE LÉGITIMATION DES ACTIONS

Les représentations partagées au sein de la corporation jouent également un rôle de différenciation entre les acteurs syndicaux. Il s'agit de cadre interprétatif ou d'action mobilisés en vue de galvaniser la base ou les nouveaux syndiqués pour des actions collectives. Lors de notre enquête nous avons pu constater que les différents acteurs syndicaux utilisent ces ressources narratives soit pour discréditer leurs adversaires, soit pour se donner de la légitimité au sein de la corporation. C'est ce que nous confirme ACK, ce leader syndical docker interrogé:

« Quand nous avons créé le CNDD, aucun acteur syndical ne pouvait parler sur le port, c'est nous qui avons mené le combat contre le "Probo Koala"² en mobilisant les dockers car les syndicats que nous avons trouvés avaient été mis sous silence par le patronat. Tu peux demander aux dockers... ce jour-là, des milliers de dockers sont sortis dans les rues pour manifester, c'était du jamais vu...il y a eu même des morts ce jour-là. C'était en février 2008, nous avons tous été renvoyés par les patrons. Tout le monde a reconnu que ce combat-là était historique, même ceux qui sont nos opposants aujourd'hui.»



Fig. 3. Dockers en réunion avec leurs leaders pour prendre des décisions (auteur, 2024)

Comme le traduit ce verbatim, les responsables de syndicats dockers utilisent des ressources narratives pour légitimer leur maintien à leur poste ou même le refus d'alternance, au risque parfois de mettre en cause la libre expression et la démocratie au sein des organisations collectives.

3.2.2 LES RESSOURCES PHYSIQUES, MOYEN DE DISSUASION

Les moyens d'actions violents sont parfois privilégiés par les responsables lors de certaines revendications sociales comme l'atteste BG, un membre du bureau du syndicat en ces termes:

« Quand nous sommes venus, les gens ne voulaient pas nous écouter, on n'a employé la force pour se faire entendre et quand les gens ont vu que par la violence on prenait le dessus, ils partaient même prendre les loubards pour venir, or ici là il y a les gens de FESCP³ (ndlr) aussi avec nous. Donc on a pas cédé, comme ils ont vu que la force ne pouvait pas nous vaincre ils ont demandé à négocier et avec la négociation on a pris le dessus donc...la priorité pour nous, c'est de procéder par la violence pour nous faire entendre

La photographie suivante illustre l'usage des ressources physiques, ici l'intervention policière, comme moyen de dissuasion face aux mobilisations syndicales des dockers.

² L'affaire du « Probo Koala » est une catastrophe environnementale survenue en Côte d'Ivoire. Elle tire son nom du navire vraquier qui a acheminé des déchets en Côte d'Ivoire en 2006 : le Probo Koala, un navire vraquier immatriculé au Panama, appartenant à une compagnie grecque

³ Fédération Etudiante et Scolaire de Côte d'Ivoire, réputé pour ses modes d'action parfois violent



Fig. 4. Dockers arrêtés par la police à la suite d'une manifestation syndicale, Port autonome d'Abidjan, 2022 (cliché fourni par un docker).

Cette situation est confirmée par BG, un responsable du syndicat qui explique les moyens communément utilisés pour revendiquer de manière violente sur la plateforme portuaire. Il affirme en substance:

« Quand on dit violence, ce n'est pas attaquer les gens innocents, mais on peut par exemple bloquer les activités du port, tu peux aller demander à tous les dockers, personne d'autre ne peut paralyser⁴ les activités du port à part nous. Vous avez vu vous-même qu'en 2019 ils ont assassiné notre secrétaire⁵ à coups de gourdin alors qu'il rentrait du boulot »

Ce témoignage illustre la conception spécifique de la violence au sein du milieu dockers syndicalistes, où la violence n'est pas perçue comme une agression gratuite envers des innocents, mais plutôt comme un moyen de pression ciblé et stratégique, notamment à travers le blocage des activités portuaires. La revendication d'un monopole effectif sur la capacité à paralyser le port souligne le pouvoir collectif et la centralité des dockers dans le fonctionnement économique. Par ailleurs, le rappel tragique de l'assassinat du secrétaire syndical en 2019 met en lumière les risques personnels élevés encourus dans ce contexte de lutte sociale, renforçant la dimension sacrificielle et la gravité des conflits. Cette parole révèle donc une légitimité construite autour de la force d'action et une mémoire collective marquée par la violence subie. Entre autres actions, nous avons des enlèvements, des séquestrations, des agressions physiques et verbales. Des chevrons de palettes sont utilisés lors des grèves pour obstruer les voies d'accès au port et certains individus armés de gourdins en main avec des visages masqués sont chargés de veiller au respect scrupuleux du mot d'ordre de grève. Il faut noter que des dockers, membres de syndicats opposés sont interdits d'avoir accès au port pour travailler. Pour certains syndicalistes, cette manière violente de revendiquer est à proscrire.

3.2.3 L'ANCRAGE DANS DES RESEAUX, MOYEN DE PRESSION

Pour être plus fort, les syndicats de dockers du port nouent des liens avec d'autres syndicats, mouvement sociaux, partis politiques et autres organisations. Cette situation plutôt que de contribuer à rendre plus forte et plus influent l'action collective contribue parfois à développer des agendas propres et du même coup à influencer l'action collective. C'est ce qui a été observé au cours de l'enquête et confirmé par un leader syndical docker nommé KKL lorsqu'il affirme:

« Nous par exemple nous sommes membres de la fédération internationale des ouvriers de transport (IFT⁶) qui est notre plus grand allié, c'est en fait la fédération internationale des travailleurs dockers et tout ce que nous faisons, c'est justement pour nous mettre au niveau des critères internationaux fixés. Désormais, si le décret abouti, les dockers

⁴ Il s'agit ici de barrer les voies d'accès au port avec des planches de bois ou des pneus usés incendiés. Certains syndicalistes vont jusqu'à interdire l'accès du port à une catégorie de docker sous peine d'être séquestré, voire de subir des sévices corporels (des images de violences et de sévices, collectés sur les réseaux sociaux des syndicats dockers n'ont pas été ajoutés à nos résultats pour ne pas heurter la sensibilité des lecteurs).

⁵ Mr Bruno Koffi, secrétaire du Collectif National des Dockers et Dockers Transit (CNDD) assassiné à coups de gourdin non loin du port alors qu'il rentrait du travail et deux semaines après nos premiers entretiens. Cette situation m'a contraint à suspendre mes enquêtes de terrain en master 2.

⁶ Fédération internationale des ouvriers du transport (ITF) est une organisation mondiale qui représente les travailleuses et travailleurs du secteur des transports. Fondée en 1896 à Londres, l'ITF regroupe aujourd'hui près de 700 syndicats de 150 pays.

seront payés comme les dockers de France, de Chine ou je ne sais parce que nous avons lié un partenariat avec l'international ».

L'ancrage dans les réseaux syndicaux locaux est illustré par le siège de la centrale syndicale Humanisme, qui joue un rôle clé dans la mobilisation des dockers au Port Autonome d'Abidjan



Fig. 5. *Siège de la centrale syndicale humanisme au Port Autonome d'Abidjan (Auteur, 2024)*

Comme nous le remarquons, les syndicats de dockers du Port Autonome d'Abidjan usent dans leur répertoire d'action de partenariats avec divers organisations nationales et internationales en vue d'avoir des soutiens dans la lutte pour l'amélioration de leur condition de travail et le progrès économique auquel ils aspirent depuis des années. Notamment les réformes liées à leurs conditions de travail et à la gestion de la main d'œuvre.

4 DISCUSSION DES RÉSULTATS

Au Port Autonome d'Abidjan, l'activité syndicale offre à certains dockers la possibilité d'accéder à des fonctions moins physiquement exigeantes, les leaders syndicaux bénéficiant généralement de salaires supérieurs à ceux des ouvriers ordinaires (Andolfatto et al., 2021; Koutou, 2017). Bien que la majorité des dockers présente un faible niveau d'instruction, l'engagement militant et la maîtrise des enjeux syndicaux constituent des critères essentiels pour l'exercice du leadership (Fortin, 2019; Lévesque et Murray, 2010). Les syndicats développent leurs ressources de pouvoir à travers la mobilisation autour des conditions de travail précaires et d'événements structurants, tels que l'affaire « Probo Koala », ainsi que par des partenariats stratégiques avec des organisations internationales, notamment l'International Dockworkers Council (IDC) et la Fédération Internationale des Travailleurs des Transports (ITF). Ces alliances s'inscrivent également dans des dynamiques politiques locales, illustrées par la participation active des syndicalistes aux campagnes électorales. Conformément aux analyses de Lévesque et al. (2010), les syndicats adaptent leurs répertoires d'action aux spécificités contextuelles, s'appuyant sur des ressources narratives qui confèrent sens et légitimité à leurs luttes (Peetz, 2006; Martinez, 2009). La construction de mythes collectifs et d'histoires partagées renforce la cohésion interne et soutient l'orientation des actions futures (Voss, 1996). Enfin, la solidarité syndicale s'étend au-delà du cadre local, avec des alliances régionales et internationales visant à influencer les processus de changement social (Hyman, 1997; Anner et al., 2006). Cependant, La participation à des luttes sociales expose parfois les syndicalistes à des formes de violence, comme l'analysent Della Porta (2021) dans ses travaux sur la dynamique des mouvements sociaux et les affrontements liés aux protestations collectives.

5 CONCLUSION

Au terme de cette étude sur le profil des syndicats de dockers du Port Autonome d'Abidjan et leurs répertoires d'actions, les caractéristiques des leaders syndicaux ainsi que leurs modes d'action ont été identifiés. Premièrement, le charisme, le niveau d'instruction et l'ancienneté apparaissent comme des critères majeurs pour accéder au leadership, souvent détenu par des individus expérimentés jouissant d'une forte légitimité au sein de la corporation. Deuxièmement, les leaders mobilisent diverses ressources narratives, physiques et relationnelles qui renforcent la cohésion sociale, la solidarité et leur légitimité, tout en constituant des moyens de pression sur le patronat pour améliorer les conditions de travail. Néanmoins, cette étude révèle également que des actions violentes, bien que limitées, restent présentes dans le milieu docker. Afin de mieux comprendre les interactions entre ces acteurs et leur environnement, il serait pertinent d'élargir cette analyse à la gouvernance du Port Autonome d'Abidjan. Une étude future pourrait ainsi

explorer le rôle des dockers dans les processus décisionnels et les rapports de pouvoir qui influencent la gestion portuaire, offrant une vision plus complète des dynamiques internes et externes qui structurent ce secteur stratégique.

REFERENCES

- [1] Andolfatto, D. (2021). *Syndicalisme et dynamique du travail portuaire en Afrique de l'Ouest*. *Revue africaine de sociologie du travail*, 14 (2), 45-67.
- [2] Della Porta, D. (2021). *Social Movements and Violence: From Protest to Riot*. Routledge.
- [3] Fortin, N. (2019). Leadership syndical et engagement militant: enjeux contemporains. *Revue de Sociologie du Travail*, 61 (2), 135-152.
- [4] Koutou, S. (2017). *Conditions de travail des dockers du Port d'Abidjan: enjeux et perspectives* (Mémoire de master). Université Félix Houphouët-Boigny, Abidjan.
- [5] Lévesque, C., & Murray, G. (2010). *The social organization of labor unions: Repertoires, narratives, and solidarity*. New York, NY: Routledge.
- [6] Martinez, T. (2009). Narratives and social movements: Making sense of collective action. *Social Movement Studies*, 8 (3), 237-254. <https://doi.org/10.1080/14742830903139935>.
- [7] Peetz, D. (2006). The role of storytelling in labor activism. *Labor History*, 47 (3), 323-340. <https://doi.org/10.1080/00236560600846207>.
- [8] Voss, K. (1996). Myth and solidarity: The role of collective memory in social movements. *American Journal of Sociology*, 102 (3), 632-660. <https://doi.org/10.1086/230890>.
- [9] Hyman, R. (1997). *The political economy of industrial relations*. London, UK: Macmillan.

The Role of Open Innovation to Improve Customer Experience in Emerging Market Telecoms

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ABSTRACT: This research paper presents a qualitative case study exploring the relationship between open innovation and customer experience within a global telecom operator in Egypt. Using in-depth interviews with 35 employees across various departments and extensive secondary data, the study investigates how service innovations are created to address local market needs and enhance customer experience. Findings reveal that the telecom operator leverages customer-centric open innovation to introduce both incremental and radical service innovations, such as interactive voice responses tailored to high illiteracy rates, micro-recharge cards, and mobile transfer applications. These innovations provide value-for-money, convenience, and differentiated services, significantly improving customer experience and loyalty in the emerging market context. The study underscores the importance of integrating external and internal knowledge and agile innovation processes to sustain competitive advantage in the dynamic telecommunications sector in Egypt.

KEYWORDS: open innovation, service innovation, customer experience, emerging markets.

1 INTRODUCTION

Open innovation is recognized as a paradigm that encourages organizations to leverage both internal and external ideas and resources, aiming for greater innovation outcomes and competitive advantage. Originally conceptualized by Chesbrough (2003), open innovation emphasizes collaboration, partnerships, and knowledge sharing as pivotal tools for organizational adaptation and growth in an increasingly complex business landscape. Recent literature presents open innovation not merely as a method for sourcing technology or knowledge but as a transformational strategy deeply embedded in organizational culture, structures, and processes. This shift requires companies to move beyond closed R&D practices toward engaging a broader ecosystem that includes customers, startups, universities, and even competitors [1], [2], [56].

2 LITERATURE REVIEW

2.1 OPEN INNOVATION

Open innovation has been widely addressed as a transformative paradigm and strategic approach that leverages external and internal knowledge flows to accelerate and sustain innovation and enhance organizational performance. Its impact on customer experience has gained considerable attention, particularly because customer involvement can drive value co-creation and market-oriented innovation [1], [3], [4], [5]. However, the body of research reveals significant theoretical and practical challenges that requires further research on the relationship between open innovation and customer experience [56].

Service firms are currently facing the challenges of rapidly developing technologies, customer needs, and intense competition [6]. Thus, the importance of service innovation has increased for organisations. However, in today's competitive business environments, service organisations cannot generate innovations only with their internal knowledge and experience. Externally acquired knowledge allows them to produce more innovations with value-added services. Therefore, open innovation plays an important role in service innovation. However, previous studies on open innovation focused mainly on the

product or technological innovation in the manufacturing sector [7], and its impact on service innovation is rarely highlighted [6].

Organisations increasingly adopt open innovation to collaborate and exchange knowledge with external stakeholders to leverage innovation capability [8], [56]. Despite that researchers have been focusing attention to the study of open innovation, there is a lack of common knowledge of what constitutes open innovation and its theoretical underpinnings [8], [53]. Open innovation was initially conceptualised as a way for organisations to open up their boundaries to enhance inflows and outflows of knowledge, so as to internally boost and externally exploit innovation [1]. Open innovation business models enable organisations to exploit valuable opportunities and maximise profits from innovation [9], [10]. Organisations are able to capture valuable ideas by making better use of both internal and external sources [1]. Previous research has tended to adopt a firm-driven approach to investigate how a firm adopts open innovation, factors that enables this adoption, and how open innovation impacts organisational performance [11], [12]. However, there is a lack of focus on investigating open innovation networks and the role of users and communities as external sources of innovation [8].

An open innovation approach involves different strategies. Chesbrough and Crowther (2006) proposes two types of open innovation strategies that an organisation may adopt, namely: inbound open innovation and outbound innovation. Inbound innovation is when an organisation monitors its internal environment to generate ideas and develop in-house R&D. In the case of outbound open innovation, instead, it searches for external innovative ideas. The organisation can obtain external knowledge from universities, research centres, other organisations, etc., as well as it may provide its knowledge to external environments. Within the same vein, Gassmann and Enkel (2004) identify three open innovation key processes:

1. Outside-in process (outside to inside) that empowers an organisation to enrich its internal knowledge with external knowledge to leverage the internal innovation process.
2. Inside out process (inside to outside) in which internal ideas are exploited outside the organisation, in different markets.
3. Bi-directional process, that is bi-directional way of exchanging knowledge (information flows) and creates a synergy and partnerships with other organisations.

Previous research highlights the various external knowledge sourcing modes ranging from technology purchasing, joint development, and joint venture to technological acquisition [6], [7]. The external knowledge sourcing strategies are categorised into cooperation and buy [14]. Cooperation for external knowledge sourcing refers to the activities to procure the knowledge of partners, co-create new knowledge, and establish a common objective through cooperation. This includes joint development, joint venture, and technological alliances among others [6]. Buy in the context of external knowledge sourcing refers to the activities that acquire external knowledge by paying the costs of the knowledge. These include technology purchasing and acquisitions of other organisations for knowledge sourcing.

Perkmann and Walsh (2007) provide insight into open innovation approach on the context of university-industry relationships. Their study investigated various types of university-industry relationships, such as collaborative research, university-industry research centres, contract research, and academic consulting [15]. Chesbrough and Appleyard (2007) 's study highlights how open innovation influences organisations to re-evaluate and reform their leadership strategies [16]. They pinpoint that organisations are bound to create new business models to harness innovation based on open innovation approach. Chesbrough (2011) extended the open innovation approach by introducing the concept of open innovation service [17]. He established a framework for the open service innovation concept that consists of four fundamental activities. The four activities include thinking of the business as an open service business, co-creating innovations, using open innovation to leverage and enhance service innovations, and transforming the whole business model based on the open service innovation approach [17].

Organisational culture plays a crucial role in enabling an organisation to adopt open innovation [18]. Cultural changes are essential to successfully adopt innovation from external sources and collaborate with external stakeholders [19]. Such changes can shift the focus from not invented here to an outlook that encourages adoption of innovation from external sources and entrepreneurial risk-taking [20].

2.2 OPEN INNOVATION AND CUSTOMER EXPERIENCE

Recent empirical research underscores the multifaceted role of open innovation in enhancing customer experience through personalized, immersive, and technology-enabled interactions [21], [22], [55]. For instance, advancements in artificial intelligence (AI) and human-robot interactions are reshaping service delivery at touchpoints, enabling firms to offer more autonomous and tailored experiences to customers [23], [24], [55]. These innovations foster dynamic customer engagement, providing value co-creation opportunities and continuous feedback loops that improve service relevance and satisfaction [25], [54], [57].

Nevertheless, the successful enactment of open innovation faces critical organizational challenges that constrain its ability to consistently enhance customer experience [57]. A growing body of literature reveals that strategic misalignment and lack of managerial capacities often impede effective open innovation implementation [26], [27], [54], [57]. Organizations struggle to balance openness with protecting intellectual property, coordinating diverse external collaborators, and harmonizing innovation goals with customer-centric strategies [20], [5]. These challenges may lead to fragmented innovation efforts, which hamper seamless customer journey experiences and degrade value co-creation potential [28], [57].

The literature points to inherent limits in extensive customer involvement within open innovation. While customer inputs enrich ideation, issues of feasibility and integration complexity persist, forcing firms to invest heavily in internal filtering and development processes before innovations translate into improved experiences [29], [30]. Delays and coordination difficulties introduced by managing broad ecosystems can undermine speed to market—an essential factor impacting positive customer perceptions in competitive sectors [11], [20].

Moreover, studies caution against overlooking the differential impact of inbound versus outbound open innovation, with empirical evidence suggesting that inbound activities (acquiring external knowledge) more directly drive innovation performance and customer experience improvements compared to outbound activities such as external commercialization [31], [32]. This distinction invites further exploration into how internal organizational capabilities modulate open innovation's effects on customer-centric outcomes.

2.3 THEORETICAL PERSPECTIVE

In order to develop a framework to describe the relationship between open innovation, organisation innovativeness, and customer experience, the current study employs the resource-based view (RBV) theory as a guiding theory. The resource-based view posits that sustainable competitive advantage is derived from an organisation's specific combination of resources that are valuable, rare and difficult to imitate [33]. The main assumption underlying the RBV is that organisations with certain resources and capabilities with special characteristics will achieve competitive advantage and, thus, superior performance [33]. In this vein, each organisation can be conceptualised as a unique bundle of tangible and intangible resources and capabilities [34]. Resources are organisations' assets including financial, physical, human, commercial, technological, and other assets, that are used to develop and deliver products and services to its customers [33]. Resources can be classified as tangible (financial and physical) and intangible (employees' knowledge, experiences and skills, the organisation's reputation, brand name, and organisational procedures). Capabilities, in contrast, refer to an organisation's capacity to deploy and coordinate different resources using organisational processes to affect a desired end [35]. They are information-based, intangible processes that are organisation-specific and are developed over time [36].

The RBV theory indicates that an organisation's cultural resources, such as open innovation strategy, can be an important source of competitive advantage [33]. Open innovation is an important antecedent that can drive organisation's performance in the context of product or service innovations [37], [38]. The theoretical framework of RBV provides clear analysis of innovation and its relationship with organisational performance [39], [40], [41]. Innovation is identified as one of the most important sources of competitive advantage [42]. The current study suggests that open innovation and organisation innovativeness are innovation-related resources that are unique and inimitable that can enable the organisation to achieve a competitive advantage and, thus, superior customer experience.

2.4 RESEARCH AIM & SIGNIFICANCE

The overall aim of this research is to investigate the relationship between open innovation, organisation innovativeness, and customer experience in a major telecommunications organisation in Egypt. Open innovation plays a crucial role in the innovation of an organisation. Yet very few studies have investigated the relationship between open innovation, organisation innovativeness, and customer experience. Therefore, this research aims to close this gap and investigate the relationship between open innovation, organisation innovativeness, and customer experience.

3 METHODOLOGY

This study adopts qualitative research methods using a single case study approach. A qualitative approach was adopted for this study for several compelling reasons. In general, qualitative research is used to help the researcher understand how people feel and why they feel as they do. For the current study, the researcher aims to investigate the relationship between open innovation, organisation innovativeness and customer experience. Following the review of innovation management and customer experience literature, gaps in the current body of knowledge are evident and provide opportunities for further

research. Given the interpretive position adopted in this study, the case study methodology is considered the most appropriate approach to employ because it provides a systematic way to collect data, analyse information, and report the results. Among qualitative methods, case studies represent one of the most adopted qualitative methods in organisational studies [43], [44]. They are acknowledged as an approach to generating and testing theory that has provided the management field with significant insights [45].

The selected company is the largest telecom operator in Egypt and the Middle East in terms of active subscribers and one of the largest telecom organisations worldwide [46]. The organisation became the market leader in terms of market share with the largest customer base [46]. This research adopts a *non-probability* sampling strategy using a *purposive technique* to enable the researcher to select participants that would serve the purpose of the study and research question. A purposive sampling is well suited to in-depth qualitative studies [47]. Purposeful sampling takes place when the researcher selects a sample from which the most can be learned [48]. The sampling units are chosen because they have particular features or characteristics which will enable detailed exploration and understanding of the constructs under the study and research questions. Members of the sample are chosen with a 'purpose' to represent their relationship to the research key constructs, such as employees from different levels from the Consumer Marketing department, Enterprise marketing department, Human Resources department, Internal Communications department, Strategy and Innovation department, Customer Experience departments, Enterprise Business department, Technology department and International Services department. Additionally, within the context of this study, *snowballing sampling* is also used. This involves asking interviewees to identify other people they know who fit the selection criteria [49], [50]. For the purpose of this study, snowballing sampling is used to identify participants who would be able to generate more data and information relevant to the study.

The study conducted thirty-five employees across different functional departments in the organization. The interview guide entailed a flexible structure of questions covering detailed description of open innovation practices in the organisation, service innovations that came out of these practices and enhanced the customer experience. Interviews typically lasted between 60-120 minutes, were digitally recorded and transcribed verbatim. We gathered secondary data to support and complement the interviews' data. This would ensure convergence in findings across data sets and reduce potential biases that may be present in the interviews. The study took into consideration the content of company documents to capture different innovation's launches and their success in terms of customer experience. The data from all sources was analyzed inductively during and after the data collection process. The analysis followed various steps Miles and Huberman (1994). NVivo software was used for data analysis to enhance the validity of the research and strengthen the rigour of the study [51], [52].

This study uses company documents, such as annual reports, mission statements, company culture values, press releases, newspaper clippings, and the company web site. Further, the researcher obtained a document about the innovation week event held by the organisation including details of the event's aims, workshops, activities, and exhibitors. Such documents are of great value to augment and strengthen the evidence collected from other sources and to enrich the researcher's knowledge about the constructs under study within the context of the organisation. These documents were collected to corroborate the findings from the interviews and enhance the study's dependability.

4 FINDINGS & DISCUSSION

This section addresses the most successful innovations in terms of customer experience introduced by the organisation under study that came out of open innovation practices. Successful innovations in this study are defined as innovations that achieved high net promoter scores, generated revenue streams, new to the market, and adopted by customers, thus ultimately leveraging the customer experience.

The interview results reported the organisation does not depend only on employees as a source of creative and innovative ideas, which is referred to as open innovation. Employees mentioned that the organisation uses external sources to increase the efficiency and effectiveness of the innovation process, to get new technologies and gain access to new and creative ideas from outside the organisation. Employees perceived open innovation practices positively and it was mentioned by the thirty-five employees as an important practice to enhance organisation innovativeness that would ultimately leverage the customer experience. The organisation launched a ventures incubator, which aims to develop small technology companies to expand the scope of their business, support youth entrepreneurship, and encourage innovation and creativity. Employees indicated that the incubator aims to stimulate and support innovation and develop new services and technologies that deliver value-added benefits to the customers: "...I am responsible for Ventures, which is outsourcing innovation rather than inventing in-house. I go to a company and acquire it or buy some of its shares and sponsor whatever they are innovating... we sponsor their innovations and help them to build their innovations up and make them grow." (Head, Joint Ventures)

Interviews also reported that the organisation uses external sources for ideas, such as university students, academics, partners, and customers to come up with product and service innovations. The results showed that the organisation established platforms for joint knowledge creation with partners including suppliers and vendors, university academics and researchers, university students' projects, the organisation's international markets and customers. An employee in the marketing unit mentioned that the organisation built an online portal to allow the developers of USSD and SMS services to develop new service innovations. It is a platform where each developer logs on and creates his own account, and creates a new service to the customers, such as an application, that can guide the customer about the location of the nearest retail store. The organisation provides the developers with access to its network infrastructure to create service innovations and handle its processes to ensure a smooth customer experience. Interviews revealed that open innovation practices have a positive effect on customer experience: "...the team works to produce innovative products and services, and when we don't get ideas from employees only, we go and search external sources such as universities... we get new ideas from internal and external sources and all this supports customer experience in an indirect way." (Head, Innovation and Strategy).

Employees confirmed that several service innovations that enhanced the customer experience came from open innovation practices, for example, creating an online platform for developers outside the organisation to innovate new services that would enhance the customers' experience: '...so, we build an online portal to let the developers of USSD and SMS services develop new service innovations. Each developer logs on and creates his own account, and creates a new service to the customers, such as an app that can guide the customer about the location of the nearest company store. We use our network infrastructure to create such services. Then the developer gets a percentage from the revenue generated by the service. It saved us time and resources and was very convenient for the customer. So, basically, we give developers access to our network infrastructure, limited access of course for security issues, and they create the services and handle its processes to ensure smooth customer experience' (Junior, Consumer Marketing).

One of the most successful innovations is the Balance Transfer services platform that was created to serve customers who run out of credit. This platform allows the customer to borrow credit from the organisation, pursue a call even when the credit runs out, send template messages to others to call back when the credit runs out, or transfer the balance to other customers. Employees posited that this platform is one of the organisation's top innovations that was successful in the market. Twenty-nine employees mentioned that this service innovation yielded a significant positive customer experience. The Retail Director mentioned that the balance transfer services innovation witnessed three million transactions per day. The underlying rationale behind this success is that this service innovation addressed an existing customer need when they run out of balance, thus adding value to customers. Fifteen employees mentioned that this innovation increased the net promoter score. This was evident in quotes such as: "it made huge customer satisfaction and positive customer experience, it is of a very relative need to the customer and leads to great customer experience. The whole portfolio is great and made huge revenues, which proves its success in terms of customer experience". Reviewing company documents and archival records, 89% of customers' comments were positive and reported great customer experiences with the Balance Transfer services portfolio innovation, while 11% of customers reported a negative experience. Nearly 70% of customers' comments indicated a positive experience in the variety of services offered in this portfolio and user-friendliness.

Interview results indicated that the Money Transfer application is another radical service innovation provided by the organisation that came out of open innovation practices. The application is basically an online wallet that allows the customer to pay at any store through their mobiles rather than using credit cards or cash, as well as transfer and receive money from anywhere in Egypt. Twenty-six employees stated that this is one of the organisation's top innovations that aims at enhancing the customer experience. Interview results revealed that the application offered customers convenience, accessibility and differentiation in several dimensions. First, Egyptian customers usually make their money transfers through banks who operate for only a few hours a day and are not available in all cities, especially rural areas. In contrast, the application provided by the organisation enables customers to transfer at any time of day through simply pressing a button. Also, there are 10 million bank accounts in Egypt versus 100 million mobile users, 41 million of which are customers of the organisation under study. Further, banks in Egypt require a minimum amount to have a bank account, while there is no minimum amount to be deposited to open an account to use the organisation's money transfer application. Therefore, the Money Transfer application has facilitated money transfers for Egyptian customers. The number of customers who adopted this service has exceeded one million in one year. This service innovation emerged from a gap in the banking industry in Egypt, thus enabling the organisation under study to differentiate its offerings in the market and enhance the customer experience.

The current findings support Steiber and Alänge (2013) study, which shows that Google is following an open innovation strategy through acquisitions, cooperating with leading researchers at universities and establishing its own venture business unit. Their study concludes that Google's innovation future will continue to rely on both internally and externally generated ideas. Other researchers emphasise the importance of using open innovation to access external knowledge from suppliers, partners, academics and researchers, and customers to compete effectively in the market and meet changing customer needs

[59], [60], [61], [18]. Within the telecommunications industry, Bigliardi, Ivo Dormio and Galati (2012) argue that open innovation provides significant advantages to the organisation, ranging from improved service quality, service innovation customisation, to cost reduction. Their study indicates that the three telecommunications organisations who adopted open innovation practices reported positive customer satisfaction. Thus, confirming the results of previous research, this study postulates that open innovation is a significant practice that enhances organisation innovativeness. Nonetheless, open innovation was not included in prior climate for innovation frameworks and its relationship with organisation innovativeness was examined separately. Hence, this study identifies open innovation as a main dimension of climate for innovation.

5 CONCLUSION

Telecommunications operators around the globe are faced with a number of threats affecting or threatening their revenues and growth. Telecommunications operators must discover new innovative products and services to enhance the customer experience and generate new revenue streams. Organisations can enhance their product and service quality, attract new customers and markets, and improve their market position through innovation. Drawing on previous research findings, the current study suggests that product and service innovations that meet customer needs are highly related to superior customer experience. To provide customers with a superior experience, an organisation should be constantly adapting to changing customer needs by being innovative. A service organisation can enhance the customer experience through open innovation practices. As mentioned earlier, there is a lack of studies investigating the relationship between open innovation between organisation innovativeness and customer experience. The study proposes a strong relationship between open innovation practices, organisation innovativeness and customer experience. The current study argues that external collaboration with partners and sources outside the organisation can generate innovations that enhance the customer experience. The innovations discussed in this study came from open innovation practices. They came out from collaboration with external stakeholders such as venture units, partners in global markets and customers. Therefore, it is crucial for an organisation to use external sources to innovate products and services that would enhance the customer experience.

REFERENCES

- [1] Chesbrough, H. W. (2003). Open innovation: The new imperative for creating and profiting from technology. Harvard Business Press.
- [2] da Silva Meireles, F. R., Azevedo, A. C., & Boaventura, J. M. G. (2022). Open innovation and collaboration: A systematic literature review. *Journal of Engineering and Technology Management*, 65, 101702.
- [3] Prahalad, C.K. and Ramaswamy, V., 2004. Co-creation experiences: The next practice in value creation. *Journal of Interactive Marketing*, 18 (3), pp.5-14.
- [4] Edvardsson, B., Tronvoll, B. and Gruber, T., 2011. Expanding understanding of service exchange and value co-creation: a social construction approach. *Journal of the Academy of Marketing Science*, 39 (2), pp.327-339.
- [5] Ferraris, A., et al. (2023). The Interplay of Digital Transformation, Open Innovation, and Customer Experience: A Strategic Framework. *Journal of Business Research*, 157, 113574.
- [6] Kang, K. H., & Kang, J. (2014). Do external knowledge sourcing modes matter for service innovation? Empirical Evidence from South Korean service Firms. *Journal of Product Innovation Management*, 31 (1), 176-191.
- [7] Kang, K. H., & Kang, J. (2010). Does partner type matter in R&D collaboration for product innovation?. *Technology Analysis & Strategic Management*, 22 (8), 945-959.
- [8] Randhawa, K., Wilden, R., & Hohberger, J. (2016). A bibliometric review of open innovation: Setting a research agenda. *Journal of product innovation management*, 33 (6), 750-772.
- [9] Chesbrough, H., & Crowther, A. K. (2006). Beyond high tech: early adopters of open innovation in other industries. *R&D Management*, 36 (3), 229-236.
- [10] Laursen, K., & Salter, A. (2006). Open for innovation: the role of openness in explaining innovation performance among UK manufacturing firms. *Strategic management journal*, 27 (2), 131-150.
- [11] Dahlander, L., & Gann, D. M. (2022). How Open is Innovation? *Research Policy*, 51 (9), 104741.
- [12] Piezunka, H., & Dahlander, L. (2019). Idea rejected, tie formed: Organizations' feedback on crowdsourced ideas. *Academy of Management Journal*, 62 (2), 503-530.
- [13] Gassmann, O., & Enkel, E. (2004). Towards a theory of open innovation: Three core process archetypes. R&D Management Conference.
- [14] Huang, H. C., Lai, M. C., Lin, L. H., & Chen, C. T. (2013). Overcoming organizational inertia to strengthen business model innovation: An open innovation perspective. *Journal of Organizational Change Management*, 26 (6), 977-1002.

- [15] Perkmann, M., & Walsh, K. (2007). University–industry relationships and open innovation: Towards a research agenda. *International journal of management reviews*, 9 (4), 259-280.
- [16] Chesbrough, H. W., & Appleyard, M. M. (2007). Open innovation and strategy. *California management review*, 50 (1), 57-76.
- [17] Chesbrough, H., Vanhaverbeke, W., Bakici, T., & Lopez-Vega, H. (2011). Open innovation and public policy in Europe.
- [18] West, J., & Bogers, M. (2020). Leveraging External Innovation Through Open Innovation: A Review of Research. *Research Policy*, 49 (1), 103932.
- [19] Dodgson, M., Gann, D., & Salter, A. (2006). The role of technology in the shift towards open innovation: the case of Procter & Gamble. *R&D Management*, 36 (3), 333-346.
- [20] West, J., & Bogers, M. (2014). Leveraging external sources of innovation: A review of research on open innovation. *Journal of product innovation management*, 31 (4), 814-831.
- [21] Tueanrat, Y., et al. (2021). Customer Journey Innovation Enabled by Emerging Technologies. *Journal of Service Research*, 24 (3), 330-344.
- [22] Nam, H., & Kannan, P. K. (2020). The Role of AI in Transforming Customer Experience. *Journal of Business Research*, 122, 25-37.
- [23] De Keyser, A., et al. (2021). Integrating AI Technology in Customer Experience: Interaction and Value Co-Creation. *Journal of Service Research*, 24 (3), 345-360.
- [24] Manthiou, A., & Klaus, P. (2022). Human-Robot Interaction and Customer Experience: The Future of Service Delivery. *Journal of Service Theory and Practice*, 32 (3), 405-422.
- [25] Frow, P., et al. (2020). Co-Creation and Innovation in Customer Experience Management. *Journal of Service Theory and Practice*, 30 (1), 92-118.
- [26] Chiu, Y. P., & Lin, C. H. (2022). The Role of Knowledge Management in Open Innovation Capability and Firm Performance. *Journal of Knowledge Management*, 26 (3), 719-738.
- [27] Trabucchi, D., Magistretti, S., Pellizzoni, E., & Frattini, F. (2021). Framework linking open innovation strategic goals with practices. In *Managing Collaborative R&D Projects: Leveraging Open Innovation Knowledge-Flows for Co-Creation* (pp. 121-138). Cham: Springer International Publishing.
- [28] Costa, R., & Matias, J. C. O. (2020). Open Innovation 3.0: A Collaborative and Digital Innovation Framework for Sustainable Innovation Ecosystems. *Technological Forecasting and Social Change*, 152, 119869.
- [29] Edvardsson, I. R., Óskarsson, G. K., & Durst, S. (2021). The outsourcing practice among small knowledge-intensive service firms. *VINE Journal of Information and Knowledge Management Systems*, 51 (1), 177-191.
- [30] von Hippel, E., Friedmann, J. C., Wu, N., Altman, E. J., & Szulanski, G. (2023). A journey into user innovation: an interview with Eric von Hippel. *Research-Technology Management*, 66 (3), 32-37.
- [31] Khairat, G. M., Elsherbiny, M. Z., Mandour, D. F., & Labib, S. G. (2025). The Impact of Open Innovation on Organizational Performance in Tourism Companies. *Journal of the Faculty of Tourism and Hotels-University of Sadat City*, 9 (1/1), 164-183.
- [32] Naruetharadhol, P., ConwayLenihan, A., & McGuirk, H. *Journal of Open Innovation: Technology, Market, and Complexity*.
- [33] Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of management*, 17 (1), 99-120.
- [34] Wernerfelt, B., 1984. A resource-based view of the firm. *Strategic Management Journal*, 5 (2), pp.171-180.
- [35] Grant, R.M., 1996. Prospering in dynamically-competitive environments: Organizational capability as knowledge integration. *Organization Science*, 7 (4), pp.375-387.
- [36] Conner, K.R. and Prahalad, C.K., 1996. A Resource-Based Theory of the Firm: Knowledge versus Opportunism. *Organization Science*, 7 (5), pp.477-501.
- [37] Workman, J.P., 1993. Marketing's limited role in new product development in one computer systems firm. *Journal of Marketing Research*, 30 (4), pp.405-421.
- [38] Wei, Y. and Morgan, N.A., 2004. Supportiveness of organizational climate, market orientation, and new product performance in chinese firms. *Journal of Product Innovation Management*, 21 (6), pp.375-388.
- [39] Damanpour, F., Walker, R.M. and Avellaneda, C.N., 2009. Combinative effects of innovation types and organizational performance: A longitudinal study of service organizations. *Journal of Management Studies*, 46 (4), pp.650-675.
- [40] Mol, M.J. and Birkinshaw, J., 2009. The sources of management innovation: When firms introduce new management practices. *Journal of Business Research*, 62 (12), pp.1269-1280.
- [41] Camisón, C. and Villar-López, A., 2014. Organizational innovation as an enabler of technological innovation capabilities and firm performance. *Journal of Business Research*, 67 (1), pp.2891-2902.
- [42] Coombs, J.E. and Bierly, P.E., 2006. Measuring technological capability and performance. *R&D Management*, 36 (4), pp.421-438.
- [43] Eisenhardt, K.M., 1989. Building theories from case study research. *The Academy of Management Review*, 14 (4), pp.532-550.

- [44] Eisenhardt, K.M. and Graebner, M.E., 2007. Theory building from cases: Opportunities and challenges. *Academy of Management Journal*, 50 (1), pp.25-32.
- [45] De Massis, A. and Kotlar, J., 2014. The case study method in family business research: Guidelines for qualitative scholarship. *Journal of Family Business Strategy*, 5 (1), pp.15-29.
- [46] Business Monitor International (BMI), 2016. *Egypt Telecommunications Report Q2*. London, United Kingdom: Business Monitor International Ltd.
- [47] Miles, M.B., Huberman, A.M. and Saldaña, J., 2014. *Qualitative data analysis*. 3rd ed. Thousand Oaks, CA: Sage Publications.
- [48] Daymon, C. and Holloway, I., 2011. *Qualitative research methods in public relations and marketing communications*. New York, NY: Routledge.
- [49] Ritchie, J., Lewis, J., McNaughton Nicholls, C. and Ormston, R., 2014. *Qualitative research practice: A guide for social science students and researchers*. Thousand Oaks, CA: Sage Publications.
- [50] Ritchie, J. and Lewis, J., 2003. *Qualitative research practice: A guide for social science students and researchers*. Thousand Oaks, CA: Sage Publications.
- [51] Richards, L., 1999. *Using NVIVO in qualitative research*. Thousand Oaks, CA: Sage Publications.
- [52] Siccama, C.J. and Penna, S., 2008. Enhancing validity of a qualitative dissertation research study by using NVIVO. *Qualitative Research Journal*, 8 (2), pp.91-103.
- [53] Yun, J. J., Zhao, X., Jung, K., & Yigitcanlar, T. (2020). The culture for open innovation dynamics. *Sustainability*, 12 (12), 5076.
- [54] Torchia, M., & Calabrò, A. (2019). Open innovation in SMEs: A systematic literature review. *Journal of Enterprising Culture*, 27 (02), 201-228.
- [55] Urbinati, A., Chiaroni, D., Chiesa, V., & Frattini, F. (2020). The role of digital technologies in open innovation processes: an exploratory multiple case study analysis. *R&d Management*, 50 (1), 136-160.
- [56] Bogers, M., Chesbrough, H., Heaton, S., & Teece, D. J. (2019). Strategic management of open innovation: A dynamic capabilities perspective. *California Management Review*, 62 (1), 77-94.
- [57] Kokins, G., Straujuma, A., & Lapiņa, I. (2021). The role of consumer and customer journeys in customer experience driven and open innovation. *Journal of Open Innovation: Technology, Market, and Complexity*, 7 (3), 185.
- [58] Steiber, A. and Alänge, S., 2013. A corporate system for continuous innovation: the case of Google Inc. *European Journal of Innovation Management*, 16 (2), pp.243-264.
- [59] Lawson, B. and Samson, D., 2001. Developing innovation capability in organisations: a dynamic capabilities approach. *International Journal of Innovation Management*, 05 (03), pp.377-400.
- [60] O'Connor, G.C., 2008. Major innovation as a dynamic capability: A systems approach. *Journal of Product Innovation Management*, 25 (4), pp.313-330.
- [61] Garud, R., Gehman, J. and Kumaraswamy, A., 2011. Complexity arrangements for sustained innovation: Lessons from 3M corporation. *Organization Studies*, 32 (6), pp.737-767.

Genotype × environment interaction on tuber yield of Tiger Nut (*Cyperus esculentus* L.) grown in West Africa

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ABSTRACT: The performance of most crop genotypes is strongly influenced by genotype-environment interactions. Thus, finding good-performing and adapted nutsedge genotypes is necessary for growers to improve their productivity. Consequently, the aim of this study is to understand the effect of genotype x environment interaction (GEI) on tuber yield and to select high-yielding genotypes specifically or broadly adapted to production. 36 genotypes were evaluated in three environments, following an alpha lattice design of 18 genotypes × 2 blocks in four replications. The combined AMMI analysis of variance indicated that the main effects due to environments, genotypes and genotype x environment interaction were significant. The contribution of environment (E), genotype (G) and genotype × environment interaction (G×E) to the total variation in tuber yield was 36.81%, 10.80% and 6.77% respectively. The genotypes × environments interaction was represented using the GGE-biplot method. The PCA1 and PCA2 axes accounted for 47.67% and 39.49% respectively of the total variability due to the G + G×E effect. Genotypes B32 (2.21Tonnes ha⁻¹), P123 (1.71Tonnes ha⁻¹) performed best specifically in environment 1, genotypes C65 (4.69Tonnes ha⁻¹), B43 (4.21Tonnes ha⁻¹) in environment 2 and genotypes K25 (3.17Tonnes ha⁻¹), M5 (3.10Tonnes ha⁻¹) in environment 3. Genotype C69 was the ideal genotype and genotypes P181, B44, C65 and B43 were the desirable genotypes for tuber yield in all three environments. The high-performance genotypes C65, B43 could be popularized for nutsedge production in the Soudano-Sahelian zone and the high-performance genotypes K25, C69 for the Soudanian zone in Burkina Faso.

KEYWORDS: *Cyperus esculentus* (L.), interaction, performance, stability, Burkina Faso.

1 INTRODUCTION

Tiger Nut or Yellow Nutsedge (*Cyperus esculentus* L. var. *Sativus* Boeckeler) also known as ground fine, sweet fine is the cultivated species [1] worldwide because of its many uses. In Africa, Tiger nut is mainly grown in the western part of the continent, in Côte d'Ivoire, Burkina Faso, Ghana, Mali, Niger, Nigeria, Senegal and Togo, where it is used as a side dish for many meals [2]. Yellow nutsedge tubers are very rich in starch, oil, sugars, proteins, dietary fiber, minerals and vitamins E and C [1]. Tiger nut milk is highly nutritious for infants and nursing mothers [3]. They are also used as livestock feed [4]; [5].

Although nutsedge has been widely cultivated and used in recent years, its adaptation on varied environments remains a challenge for research to reveal. Agro-morphological characterizations of a collection of genotypes from Burkina Faso, Togo and Mali were carried out in the Sudano-Sahelian zone in 2024. This study has established the morphological and phenological variation of nutsedge.

However, it is not sufficient to provide farmers with high-performance varieties capable of adapting to different environments. Variation in a genotypic trait can be highly dependent on the environment [6]. Phenotypic expression is the combined result of genotype, environment and genotype x environment interaction [7]. Thus, different agroclimatic zones require high-performance, stable varieties to guarantee production [8]. Multilocation trials are best suited to studying the performance, stability and adaptability of cultivars in different environments [9]. Thus, [10] demonstrated the usefulness of the GGE method in their study to find potential yielding genotypes

associated with stable performance under various environmental conditions. The GGE plot model provides breeders with a comprehensive visual assessment of the data, creating a biplot that simultaneously represents performance and stability, environment-specific genotypes and identifies mega-environments. This method is best suited to obtaining reliable results.

The aim of the present work is to (i) determine the effect of environment, genotype and genotype x environment interaction on tuber yield of yellow nutsedge, (ii) identify high-performance genotypes for each agroclimatic zone and (iii) identify ideal genotypes for all agroclimatic zones of Burkina Faso.

2 MATERIAL AND METHODS

2.1 MATERIAL

2.1.1 PLANT MATERIAL

The plant material consisted of 36 genotypes of cultivated strains. These genotypes came from four West African countries, including five genotypes from Togo, four genotypes from Mali and twenty-seven from Burkina Faso (Table 1).

Table 1. List of genotypes and their provenance

N°	Genotypes	Provenance	N°	Genotypes	Provenance
1	B132	Burkina Faso	19	K28	Burkina Faso
2	B135	Burkina Faso	20	K32	Burkina Faso
3	B13	Burkina Faso	21	K35	Burkina Faso
4	B32	Burkina Faso	22	K3	Burkina Faso
5	B43	Burkina Faso	23	K43	Burkina Faso
6	B44	Burkina Faso	24	K53	Burkina Faso
7	B45	Burkina Faso	25	K7	Burkina Faso
8	B90	Burkina Faso	26	P123	Burkina Faso
9	B911	Burkina Faso	27	P181	Burkina Faso
10	B95	Burkina Faso	28	M1	Mali
11	C60	Burkina Faso	29	M3	Mali
12	C64	Burkina Faso	30	M4	Mali
13	C65	Burkina Faso	31	M5	Mali
14	C69	Burkina Faso	32	T1	Togo
15	K10	Burkina Faso	33	T3	Togo
16	K243	Burkina Faso	34	T4	Togo
17	K24	Burkina Faso	35	T5	Togo
18	K25	Burkina Faso	36	T6	Togo

2.1.2 STUDY SITES

Environment 1 (E1) and Environment 2 (E2) were conducted over two successive years, 2021 and 2022, in the Soudan-Sahelian zone at the Institute of Environment and Agricultural Research of Kamboinse (INERA/K). The station is located about 12 km north of Ouagadougou, the capital of Burkina Faso. The station's geographic coordinates are 12°28' north latitude and 1°32' west longitude, at an altitude of 296 m. According to [11] (Guinko, 1985), the station belongs to the north Sudan type of climate, as it lies between isohyets 600 and 900 mm. Kamboinsé soils are classified as leached ferruginous soils, underlain by deeper sandy material, and low-humus hydromorphic soils.

In 2021, the station recorded 775.6 mm of water in 51 days during the 2021 crop year, with temperatures ranging from 26.1 to 33.6°C and an average temperature of 30.02°C. July and August were the wettest months, with rainfall of 198.3mm and 267.7mm respectively. Rainfall of 749.9mm was recorded during the nutsedge production cycle (July to November). In 2022, August and September were the wettest months, with 395.6mm and 268.2mm respectively. Rainfall of 756.8mm was recorded during the nutsedge production cycle (July to November).

Environment 3 (E3) was the trial planted in Bobo-Dioulasso, located in the Sudanian zone during the 2022 cropping season.

It was carried out at INERA's Farako-Bâ research station, located 10 km south-west of the town of Bobo-Dioulasso on the Bobo-Banfora axis (Route Nationale n°7). The geographical coordinates of the station are 40°20' West Longitude, 11°06 North Latitude and 405 m altitude. Farako-Bâ's soils are red, slightly ferrallitic (northern and western plots) and ferruginous in the south, with a 2% slope [11] (Guinko, 1985). They are highly permeable and sensitive to erosion. Their low clay and organic matter content weakens their cation exchange capacity. The station recorded 1262.4 mm of water during the 2022 rainy season, from January to September 2022 in 59 rainy days and minimum and maximum temperatures of 20.6°C and 33.6°C respectively. August and September were the wettest months, with rainfall of 316.6 mm and 299.1 mm respectively. Rainfall of 616.16 mm was recorded during the nutsedge production cycle.

2.2 METHODS

2.2.1 EXPERIMENTAL DESIGN AND TRIAL CONDUCT

The genotypes were sown in an alpha Lattice layout of 2 blocks × 18 genotypes in four replications. Each block measured 9.5 m by 3.8 m and was separated from each other by 1 m. The genotypes were each sown on a 1.4 m long ridge with a 0.5 m spacing between consecutive ridges, and a 20 cm spacing between bunches on the ridge. During ridge preparation, organic manure consisting of well-decomposed stable manure was applied at a rate of 4.5 t/ha. Maintenance mineral manure consisting of NPK (14-23-14) was applied at a rate of 200 kg/ha on the 15th day after sowing (DAS). Maintenance operations such as weeding were carried out as required.

2.2.2 DATA COLLECTION

Quantitative variables were collected from emergence to harvest. The variable of interest was tuber yield. Tiger nut tubers are the vegetative organs most commonly used for consumption or processing.

2.2.3 STATISTICAL ANALYSIS

Data were analyzed using R software version 4.5.0. Combined analysis of variance AMMI (Additive Main Effect and Multiplicative Interaction) and GGE biplot (Genotypes + Genotypes × Environments interaction) are the main methods used to analyze genotypes × environments interaction. The discrimination and representativeness capabilities of the GGE biplot make it more sophisticated than AMMI [12]. The advantage of the GEE model over the AMMI model is that the GEE model can be used to identify stable, high-yielding genotypes, genotypes with stable performance in several environments, genotypes that perform well in each environment, and to rank environments. But the two methods complement each other to better explain the effect of genotype × environment interactions, revealing the best genotypes and appropriate environments for plant breeding. In the GGE biplot method, yield and genotype stability were estimated using average environmental coordinate (AEC) methods [13].

3 RESULTS

3.1 COMBINED ANALYSIS OF VARIANCE OF GENOTYPES EVALUATED IN THE THREE ENVIRONMENTS

The combined analysis of variance (ANOVA) of the 36 genotypes evaluated in the three environments showed highly significant effects of genotype, environment and genotype × environment interaction on yellow nutsedge tuber yield (Table 2). Of the total variation, 6.77% was explained by genotype effect, 36.81% by environment effect and 10.80% by genotype × environment interaction. The AMMI biplots (Fig 1) showed the performance of the genotypes. The abscise axis (Fig 1) represents the main effect (mean genotype performance), while the y-axis represents the impact of the interaction (PCA scores). Thus, genotypes K3, B90, T4, B45, K32, B45 closer to the origin of the figure indicate that they recorded near-zero scores on the PCA1 axis. While genotypes C69, T6, T1 and B43 were far from the origin. Genotypes presented on the same line parallel to the ordered axis showed similar performance. In terms of genotype performance, the genotypes to the right of center in Fig 1 recorded the highest yields. On the other hand, genotypes to the left of center performed poorly. Genotypes B13, B44, C65, B43, P123, C69, P181, B32, B95, B132, K10, K25, M5 and B135 produced tuber yields above the overall average.

Table 2. Combined analysis of variance with the AMMI model

Source	Ddl	SS	MS	VE	G×E
Genotype (G)	35	52.233	1.492***	6.77	
Environment (E)	2	283.7	141.85***	36.81	
G×E	70	83.145	1.187***	10.8	
PC1	36	53.544	1.487***		64.4%
PC2	34	29.6	0.870***		35.6%
Residual	315	78.7	0.249		
Total	501	770.511	1.537		

Ddl: degree of freedom, SS: sum of squares, MS: mean square, VE: explained variance, G: genotype, E: environment, G×E: genotype-environment interaction, ***: very highly significant, %: percentage

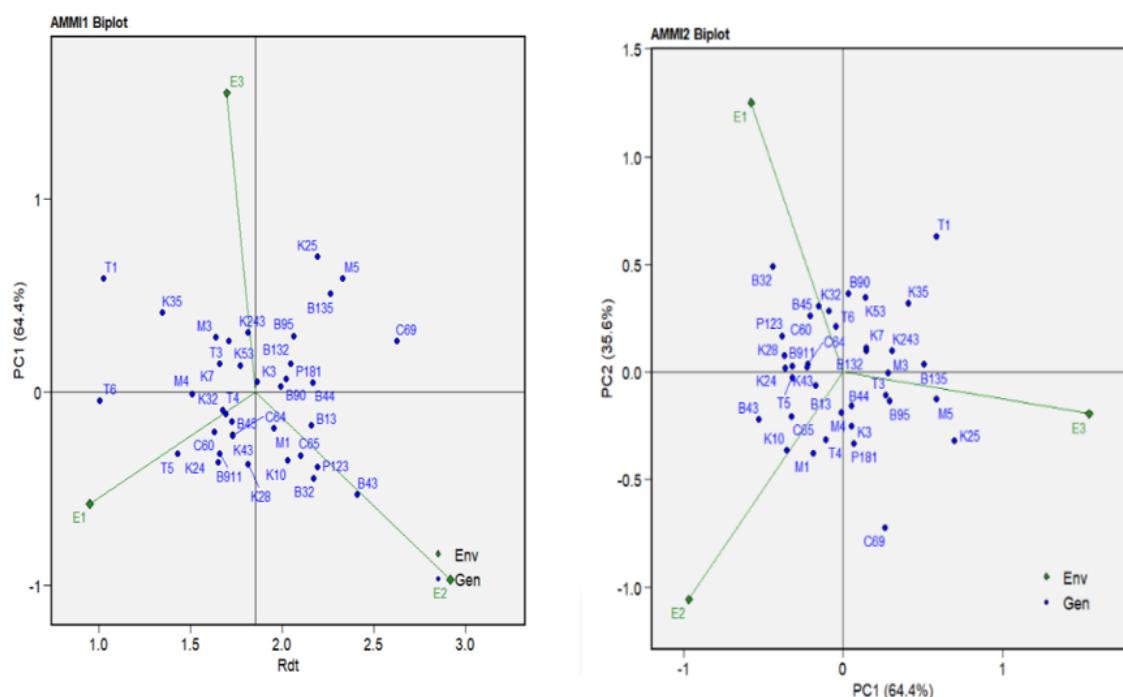


Fig. 1. AMMI 1 and AMMI2 biplot of genotype-environment interactions for tuber yield

3.2 AVERAGE PERFORMANCE AND STABILITY OF GENOTYPES IN TESTED ENVIRONMENTS

The “which-won-where” polygon (Fig 2) was used to show genotype performance as a function of environment, and to identify mega-environments. The biplot GGE is represented by two components (PC1 47.67% and PC2 39.49%) explaining a total of 87.16% of the variability (Fig 2). The polygon is divided into six sectors, and the environments are divided into two sectors. Genotypes B43 and B32 are positioned at the top of the polygon in the sector oriented towards environments E1 and E2, followed by genotypes K10, P123, C65 and K28 (Fig 2). Genotype K25 is positioned at the top of the polygon in the sector oriented towards environment E3 (Fig 2). It is followed by genotypes B135 and M5. Environments E1 and E2, positioned in the same sector, form a mega-environment, while environment E3 is a separate environment. The Fig 3 shows the GGE biplot, divided in two by the ordered axis to separate high-yielding and low-yielding genotypes. Genotypes positioned with short vectors are the most stable.

Genotypes C69, K25, B135, M5, B95, B132, B43, K10, C65, P123, B32, B13, M1, P181, B44 and K3 performed well in tuber yield. Genotypes P181, M4, B90, T4, B132, B44 and K3 showed short vectors in the biplot. These genotypes were the most stable in the environments tested (Fig 3).

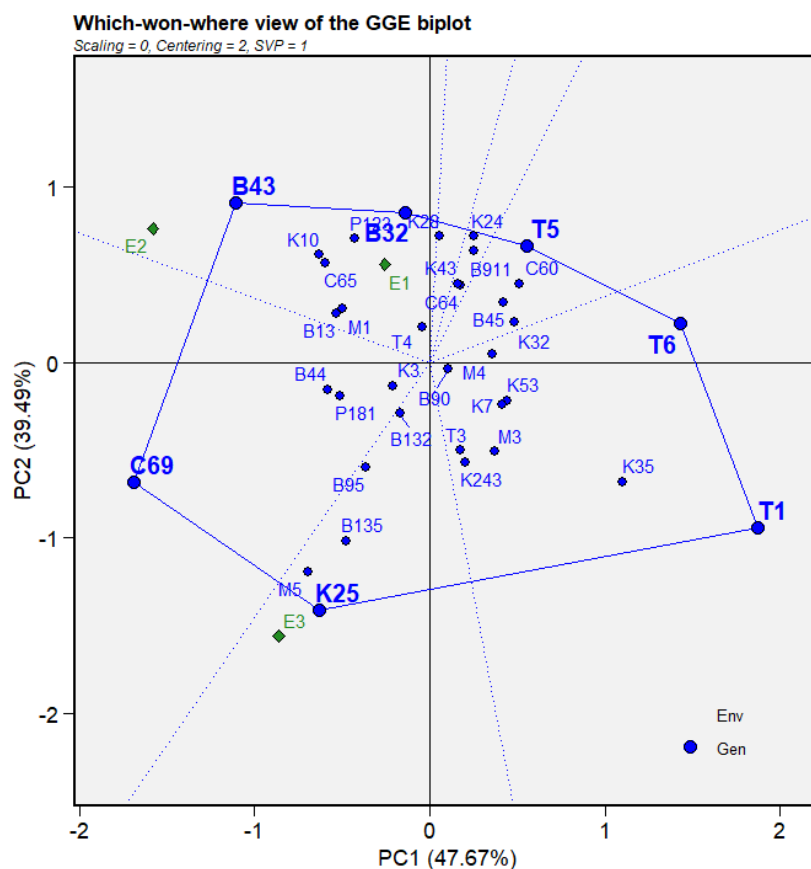


Fig. 2. Which-Won-Where, performances of genotypes in environments

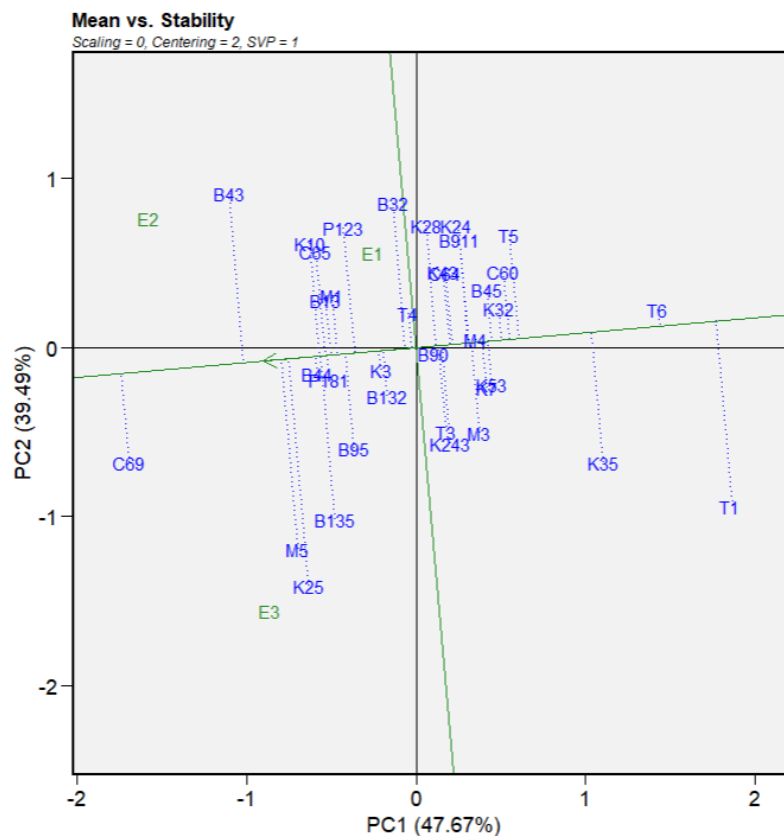


Fig. 3. Stability of genotypes in tested environments

3.3 IDENTIFICATION OF IDEAL GENOTYPES BY ENVIRONMENT

The ranking of genotypes is shown in figure 4. The biplot enabled us to identify the ideal genotype from among the genotypes tested. An ideal genotype has the highest average performance for a given variable, and is the most stable from one environment to the next. It is located at the center of the first concentric circle and oriented by the arrow on the x-axis. It is defined by a projection on the mean-environment axis equal to the longest vector of genotypes with above-average mean yield, and by a zero projection on the perpendicular line (zero variability between environments). Desirable genotypes are those located close to the ideal genotype. Thus, starting from the middle of the concentric circle pointed by an arrow, concentric circles have been drawn to visualize the distance between the ideal genotype and the desirable genotypes. Genotype C69 was very close to the center of the average environmental coordinates (AEC) of the concentric circles, followed by genotypes P181, B44, B43, B13, M1, K10, and C65 (Fig 4).

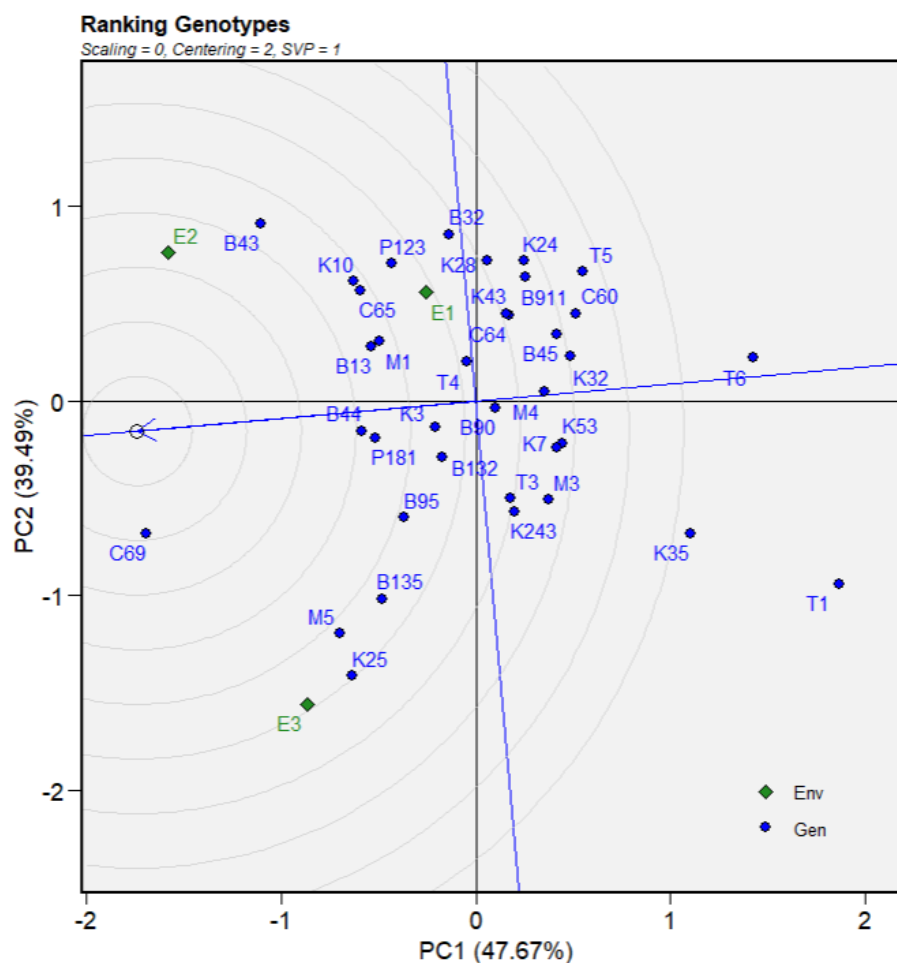


Fig. 4. Identification of ideal genotypes

4 DISCUSSION

To guarantee food security, we need to increase crop productivity through plant breeding and improvement programs. Multi-environment experiments, commonly referred to as genotype-environment interactions, are important stages in breeding programs. The combined AMMI analysis of variance showed very highly significant effects of environment, genotypes and genotype $\times$ environment interaction ($P \leq 0.001$) on tuber yield of yellow nutsedge.

The significant effect of genotypes showed that the tuber yield of genotypes depends on the genetic potential of the genotypes, while the significance of environment revealed that environments varied and positively influenced genotype yield. The 36.42% environmental effect shows that environmental conditions had a greater influence on genotype performance for tuber yield. Some authors [14]; [15]; [16] and [17] have also shown through studies on various crops that the high percentage of variance in the effect of environment is an indication that the major factor affecting genotype performance for yield is the growing environment.

The highly significant effect of the genotype x environment interaction (GEI) means that the environment must be taken into account in varietal selection programs. The AMMI model allows us to understand the interrelationship between genotypes and the environments involved. The AMMI1 model biplot is one of several AMMI versions for identifying high potential yield and stability [18]. The “which-won-where” polygon GGE biplot revealed which genotypes performed well in each environment. The GGE biplot showed that genotypes were well adapted to each environment and confirmed the presence of differentiation through interaction between genotypes and environments. Genotypes at the top of the polygon have been identified, indicating their performance and adaptability in their environments. Genotypes C65, B43 were the best performing with a yield of 4.21Tonnes ha⁻¹ for genotype B43, followed by 3.69T/ha for genotype C65 in environment 2, while genotypes B32 with a yield of 2.13Tonnes ha⁻¹ and P123 (1.71Tonnes ha⁻¹) were the best performing in environment 1. Tiger nut genotypes could be specifically adapted to the Sudano-Sahelian zone of Burkina Faso. On the other hand, genotypes K25 and C69, followed by M5 and B135 were the best performers, with the highest yields of 3.17Tonnes ha⁻¹ for genotype K25 and 3.01Tonnes ha⁻¹ for genotype C69 in environment 3. These genotypes would be best suited to the production of high-yielding tuberous nutsedge in the Sudanian zone of Burkina Faso. Similar results were found by [19]; [20] and [21] on sweet potato genotypes in Burkina Faso and Ethiopia. GGE biplot results showed that genotypes P181, M4, B90, T4, B132, B44 and K3 were identified as stable.

5 CONCLUSION

From these results, the main factors influencing tiger nut yields are the environment and genotype, but the environment is the most decisive factor in tiger nut yield potential. Genotypes C65 and B43 performed best and were specifically adapted to both environments E1 and E2 belonging to the Sudano-Sahelian zone. While genotypes K25 and C69 perform best in the Sudanian zone, genotypes P181 and B44 were the most stable genotypes in all three agroecological zones.

The ideal genotype C69 is the most stable, with average tuber yield performance in all three test environments. The high-performance genotypes specific to each zone could be used as the best tiger nut genotypes to be promoted for these two agroclimatic zones in Burkina Faso. The best genotypes identified for each agroclimatic zone and for both agroclimatic zones could be used to develop high-performance of Tiger nut varieties in Burkina Faso.

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REFERENCES

- [1] Yang X., Niu L., Zhang Y., Ren W., Yang C., Yang J., Xing G., Zhong X., Zhang J., Slaski, J., & Zhang, J. 2022. Morpho-Agronomic and Biochemical Characterization of Génotypes of Tiger Nut (*Cyperus esculentus* L.) Grown in the North Temperate Zone of China. *Plants*, 11 (7), 923. <https://doi.org/10.3390/plants11070923>.
- [2] Asare P. A., Kpankpari R., Adu M. O., Afutu E., and Adewumi A. S. 2020. Phenotypic Characterization of Tiger nut (*Cyperus esculentus* L.) from Major Growing Areas in Ghana. *Bank Kof*, 2020, 1-11. <https://doi.org/10.1155/2020/7232591>.
- [3] Ndiaye B. 2021. Contribution à la valorisation des tubercules de Tiger nut (*Cyperus esculentus*): Apport nutritionnel, itinéraires technologies, propriétés galactogènes. PhD, University Cheikh Anta Diop, Dakar. 183pp.
- [4] Coşkun Y., Ercan R., Karababa E., and Nazlıcan A. N. 2002. Physical and chemical properties of chufa (*Cyperus esculentus* L) tubers grown in the Çukurova region of Turkey. *Journal of the Science of Food and Agriculture*, 82 (6), 625-631. <https://doi.org/10.1002/jsfa.1091>.
- [5] Adejuyitan J. A., 2011. Tigernut Processing: Its Food uses and Health Benefits. *American Journal of Food Technology*, 6 (3), 197-201. <https://doi.org/10.3923/ajft.2011.197.201>
- [6] Hacini N., Djelloul R., and Desclaux D. 2022. Study of genotype X environment interactions and agro technological behavior of durum wheat varieties applied in different agro-climatic zones of Algeria. *PLANT ARCHIVES*, 22 (2), 193-200 <https://doi.org/10.51470/PLANTARCHIVES.2022.v22.no2.034>
- [7] Wasonga D. O., Ambuko J. L., Cheminingwa G. N., Odeny D. A., and Crampton B. G. 2015. Morphological Characterization and Selection of Spider Plant (*Cleome gynandra*) Génotypes from Kenya and South Africa. *Asian Journal of Agricultural Sciences*, 7 (4), 36-44. <https://doi.org/10.19026/ajas.7.2198>.
- [8] Akdeniz M., Kavukcu E., and İlhanlı N. 2019. DREEM in primary care: Students perspectives on educational environment of family medicine internship in primary care centres: experiences at Akdeniz University Faculty of Medicine in Turkey. *Postgraduate Medicine*, 131 (6), 397-404. <https://doi.org/10.1080/00325481.2019.1637759>.
- [9] Solonechnyi P. N. 2017. AMMI and GGE biplot analyses of genotype-environment interaction in spring barley lines. *Vavilov Journal of Genetics and Breeding*, 21 (6), 657-662. <https://doi.org/10.18699/VJ17.283>

- [10] Kaya Y., Akçura M., and Taner S. 2006. «GGE-Biplot Analysis of Multi-Environment Yield Trials in Bread Wheat,» *Turkish Journal of Agriculture and Forestry*: Vol. 30: No. 5, Article 3. Available at: <https://journals.tubitak.gov.tr/agriculture/vol30/iss5/3>.
- [11] Guinko S. 1985. Contribution à l'étude de la végétation et de la flore du Burkina Faso (ex Haute-Volta). Origine botanique de quelques outils et objets artisanaux en bois. *Journal d'agriculture traditionnelle et de botanique appliquée*, 32 (1), 235-239. <https://doi.org/10.3406/jatba.1985.3938>.
- [12] Wardofa G. A., Asnake D., and Mohammed H. 2019. GGE biplot analysis of genotype by environment interaction and grain yield stability of bread wheat genotypes in central ETHIOPIA. *Journal of Plant Breeding and Genetics*, 07 (02), 75-85. <https://doi.org/DOI:10.33687/pbg.007.02.2846>.
- [13] Yan W., and Tinker N. A. 2006. Biplot analysis of multi-environment trial data: Principles and applications. *Canadian Journal of Plant Science*, 86 (3), 623-645. <https://doi.org/10.4141/P05-169>.
- [14] Rea R., De Sousa-Vieira O., Díaz A., Ramón M., Briceño R., George J., and Demey J. 2015. Assessment of yield stability in sugarcane genotypes using non-parametric methods. *Agronomía Colombiana*, 33 (2), 131-138. <https://doi.org/10.15446/agron.colomb.v33n2.49324>.
- [15] Hannachi A. 2017. Combining ability, single and multi-trait selection and adaptability of durum wheat (*Triticum durum* Desf.) to semiarid conditions. PhD thesis, Université Ferhat Abbas Sétif 1. Faculté des Sciences de la Nature et de la Vie. 218p.
- [16] Sakande B., Sawadogo P., Tiendrebeogo J., Kiebre Z., and Bationo/Kando P. 2023. Assessment of the stability and genotype-environment interaction of a spider plant (*Cleome gynandra* L.) collection in Burkina Faso: Application of the AMMI and GGE models. *African Journal of Biotechnology*, 22 (11), 265-272. <https://doi.org/10.5897/AJB2023.17611>.
- [17] Haddad L., Bouzerzour H., Benmahammed A., Hannachi A., Bachir A., Salmi M., Fellahi Z E A., Nouar H., and Laala Z. 2016. Analysis of Genotype × Environment Interaction for Grain Yield in Early and Late Sowing Date on Durum Wheat (*Triticum durum* Desf.) Genotypes. *Jordan Journal of Biological Sciences*. 9 (3), 139 - 146.
- [18] Olivoto T., Lú c i o A. D. C., da Silva J. A. G., Marchioro V. S., de Souza V. Q., et Jost E. 2019. Performances moyenne et stabilité dans les essais multi-environnements I: combinaison des caractéristiques des techniques AMMI et BLUP. *Agronomy Journal* 111 (6), 2949-2960. Doi: 10.2134/agronj2019.03.0220.
- [19] Some K. 2012. *Genetic improvement of sweetpotato (ipomoea batatas [l.] lam) for beta-carotene and yield in Burkina Faso*. PhD, University of Ghana, West Africa Centre for crop improvement, School of agriculture, College of agriculture and consumer sciences, 209pp.
- [20] Gedif M., and Yigzaw D. Genotype by Environment Interaction Analysis for Tuber Yield of Potato (*Solanum tuberosum* L.) Using a GGE Biplot Method in Amhara Region, Ethiopia. *Agricultural Sciences* 2014. 05 (04), 239-249. <https://doi.org/10.4236/as.2014.54027>.
- [21] Gemechu G. E., Mulualem T., and Semman N. Genotype by environment interaction effect on some selected traits of orange fleshed sweet potato (*Ipomoea batatas* Lam.). *Heliyon*, 2022; 8 (12), e12395. <https://doi.org/10.1016/j.heliyon.2022.e12395>.

Precursory seismic signal of the May 19, 2023 eruption of Nyamulagira Volcano in the Virunga Volcanic Province, Democratic Republic of Congo

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ABSTRACT: The 2023 eruption of Nyamulagira volcano (DR Congo) began on May 19 with lava overflowing from the summit crater. We analyze seismic data from two nearby stations (RGB2 and RSY2) to investigate the precursory signals leading up to the eruption. Our results show a clear and gradual increase in RSAM (Real-time Seismic Amplitude Measurement) starting around 10 days before, followed by a seismic swarm from May 18 to early May 19. Correlation analyses reveal a weak relationship between RSAM and the number of daily volcanic events, suggesting distinct physical processes: RSAM is sensitive to continuous tremors linked to magma ascent, whereas event counts reflect brittle fracturing. Despite moderate correlation between RSAM values at both stations, local effects may influence amplitude differently. We conclude that RSAM trends, especially progressive increases followed by swarms, may serve as reliable early indicators of eruptive activity, even in the absence of detectable surface deformation.

KEYWORDS: volcano activity, seismic activity, seismic amplitude.

1 INTRODUCTION

1.1 THE NYAMULAGIRA VOLCANO

Nyamulagira is a volcano located in North Kivu, eastern Democratic Republic of Congo, about 15 km northwest of Nyiragongo volcano, in the East African Rift system. It is an active shield volcano located in the Virunga region, has an ancient existence and requires in-depth studies. It reaches an altitude of 3,058 meters and is located on the rim of a caldera 2,150 meters in diameter, formed 300 to 500 years ago. The lava emitted is mainly of leucitic basanite and other similar compositions. A N- NW/S-SE fault zone influences its morphology and eruptive behavior, playing a key role in the dynamics of its eruptions, including lava drainage during explosive events (Smets et al. 2015; Pouclet A., Bellon H., and Bram K. 2016).

The plumbing system of Nyamulagira volcano comprises three distinct reservoirs, essential for its magmatic activity. The first, located between 2 and 3 km deep, feeds historical eruptions and is linked to superficial dykes and reservoirs, particularly on the upper and middle flanks of the volcano. The second reservoir, at 6-8 km deep, is a shallow stratified magma chamber that supports successive eruptive phases. Finally, the third reservoir, located 10-14 km below the surface, corresponds to a deeper crustal magma chamber. (Pouclet and Bram 2021).

The volcano has experienced several eruptive phases, each with unique characteristics, including explosive phases that influenced its morphology. The first phase of eruptions at Nyamulagira volcano began in 1865 with a historic eruption on the Mushumangabo cone, followed by further eruptions between 1882 and 1884 (Pouclet 2021). These events marked the beginning of recorded eruptions, which occurred mainly on the flanks of the volcano, at a frequency of approximately one eruption every 1–3 years (Smets et al. 2015). Between 1901 and 1905, a second phase of volcanic activity occurred, characterized by Strombolian eruptions and summit activity, alternating with caldera filling and emptying. This period was marked by distinct lava flows and a change in the patterns of volcanic activity. (Pouclet and Bram 2021). A third phase began with the collapse of the caldera in the 1900s, leading to progressive filling and overflow of the caldera with various lava

compositions, including leucite-rich basanites. The remarkable eruptions of 1904 and 1912–1913 occurred without co-eruptive activity in the central caldera, suggesting the involvement of deeper magmatic reservoirs (Smets et al. 2015; Pouclet and Bram 2021). Between 1938–1940 an atypical eruption drained the upper magmatic system, triggering a caldera collapse. Five eruptions occurred in 1951, 1956, 1957, 1967, and 1971, with three major events in 1948, 1954, and 1958. The fourth phase of volcanic activity, extending from 1971 to 1982, was marked by an intensification of eruptions, particularly between 1971 and 1972, with notable effusive and explosive events. A prolonged eruption occurred from 1976 to 1977, creating three cinder cones, although the volume of lava was relatively small. In 1980, volcanic activity increased again, culminating in a large but brief eruption in 1981, followed by three more classic eruptions between 1984 and 1988. After a period of inactivity from 1982 to 2001, the Nyamulagira volcano experienced a fifth phase of activity between 2002 and 2014, marked by recurrent eruptions every two years. These eruptions, closer to the caldera, were concentrated along a network of NNW-SSE fissures (Smets et al. 2015; Pouclet and Bram 2021). A renewed effusive activity was observed in 2002, followed by further eruptions in 2004, 2006, 2008, 2010 and between 2011 and 2012 (Mavonga et al. 2006; Mavonga et al. 2010 a; Mavonga et al. 2010 b; Birimwiragi Namogo et al. 2016; RUSANGIZA et al. 2017).

Since June 2014, a new phase, called the sixth phase, has begun for the Nyamulagira volcano, marked by the formation of a lava lake in its central crater. This lava lake activity has remained permanent and active until now.

In June 2014, a lava lake formed in the central crater of Nyamulagira volcano, rising and expanding rapidly. According to Coppola et al. (2016), this shift in activity from the flanks to the center is not due to an increase in magma, but to a disruption of the magma plumbing system caused by a previous eruption in 2011–2012. To maintain an active lava lake, three conditions must be met: a stable magma supply, the ability of the plumbing system to handle the magma mass, and a favorable tectonic setting. The study by Coppola et al. also highlights that the plumbing system has been regularly fed by short-lived eruptions. Field observations show that during 2023-year, significant events, such as crater overflows and flank lava flows, occurred.

Since late 2022, Nyamulagira volcano has experienced a transition in activity from flank to central activity, marked by eruptions different from those observed between 2002 and 2012. Intracrater effusive activity has been noted, with lava fountaining on 10 March 2023 and an overflow of the central crater on 19–20 May 2023, resulting in a lava flow extending up to 3 km to the northwest (see OVG weekly bulletin of 26 May 2023). Although lava flows on the upper northwest flank began to solidify on 28 May 2023, effusive activity in the central crater continued until June 2024, with periods of intermittent activity.

Recording seismic events is essential for monitoring active volcanoes, and seismo-volcanology researchers are interested in analyzing them to understand the underlying mechanisms. Measuring seismic amplitudes via RSAM (Real Seismic Amplitude Measurement) has proven effective in predicting increased volcanic activity and eruptions at several volcanoes (Endo and Murray 1991; Endo, Murray, and Power 1996).

This study focuses on the events that took place at the Nyamulagira volcano between late 2022 and late 2023 based on analyses of seismic data, including RSAM measurements and daily counting of LP earthquakes as well as their location at the surface and at depth to better understand the dynamics of its lava lake but also improve the understanding and interpretation of the variations observed on the RSAM curve.

1.2 OVERVIEW ON THE PRE-ERUPTIVE SEISMICITY OF THE NYAMULAGIRA VOLCANO

The post-eruptive seismic activity of Nyamulagira volcano has been mainly characterized by volcanic Long Period (LP) earthquakes, according to different studies. Other events, such as hybrid earthquakes, have also been observed and analyzed as precursors of past eruptions. The long-period seismicity observed before eruptions often manifests itself in the form of swarms, with events documented from 2002 onwards. The study by Mavonga et al. (2006) analyzed the seismicity preceding the eruption of Nyamulagira on 8 May 2024. The authors observed swarm seismicity, mainly of long-period earthquakes, signaling the eruption 2–4 months before it, with a notable increase in seismic activity 10 months before. Seismic events included both shallow and deep earthquakes, with the former becoming more significant as the eruption approached.

Rusangiza et al. (2017) analyzed the frequency distribution and m-value variation before the Nyamulagira volcanic eruptions. The results showed several earthquake swarms, mainly LP events, with m-values generally between 0.9 and 1.6, but increasing to between 1.7 and 3.23 two to four months before the eruptions. This highlights the importance of long-term earthquake monitoring to improve eruption prediction at Nyamulagira. A study by Birimwiragi Namogo et al. (2016) between 2002 and 2011 revealed 73 swarms dominated by LP events and five eruptions of Nyamulagira, without an eruption of Nyiragongo. Analysis of the epicenters highlighted zones of weakness between the two volcanoes, essential for understanding magmatic intrusions.

Prior to the appearance of a new lava lake at Nyamulagira volcano in June 2014, significant seismic activity was observed, marked by a long-period earthquake swarm in April 2014. This swarm, which lasted four days, was located in the northeast of the crater (Birimwiragi Namogo et al. 2016). In June, seismic activity increased, leading to reactivation of the dyke intrusion and rapid magma ascent, accompanied by volcanic tremors and hybrid tremors leading to the formation of the lava lake. After the formation of the lava lake, seismic activity related to LP events decreased, but volcano-tectonic events remained constant, indicating underlying volcanic activity (Birimwiragi Namogo et al. 2016; Mateso Kasongo et al. 2017). Hybrid earthquakes, observed before the formation of the lava lake, occur at a depth of 0 to 5 km and in a frequency range of 3 to 10 Hz. They are related to rock rupture and intrusions in the superficial part of the crater (Mateso Kasongo et al. 2017).

2 DATA ANALYSIS

2.1 GVO SEISMIC NETWORK

All the data in this work were collected by the GVO Snet broadband seismic. The seismic stations are located around the two active volcanoes Nyiragongo and Nyamulagira and in the Lake Livu bassin. These stations are: Rumangabo (RGB2), Rusayo (RSY2), Munigi (MUN2), Goma (GOM2), Bulengo (BUL2), Kalehe (KAL2), Idjwi (IDJ2), Lwiro (LWI2) and Nyabibwe (NYA2) (Mavonga et al. 2023). The location of the earthquakes (epicentres and hypocentres), waveforms analyses and spectral content were examined using the SEISAN software. The maps were produced either by GMT or QGIS. On the other hand the RSAM analysis were done using scripts developed in python and has been used to analyse the seismic activity preceded the May 2021 Nyiragongo volcano eruption (Sadiki et al. 2023; Munguiko et al. 2024). The continuous RSAM seismic measurements from October 2022 to December 2023, we used data recorded at two seismic stations: RGB2 (or RGB) and RSY2 (or RSY), located near the volcano at 19.64 km and 18.89 km from the Nyamulagira volcano, respectively. Real-time Seismic Amplitude Measurement (RSAM) was calculated in the 0.3–5 Hz frequency band to track variations in seismic energy over time.

RSAM values were averaged daily to identify long-term trends. Tectonic earthquakes with magnitude ≥ 4.0 were included using regional seismic catalogs. All RSAM data were normalized to facilitate interstation comparison. Statistical correlations were computed between RSAM values, seismicity, and between stations.

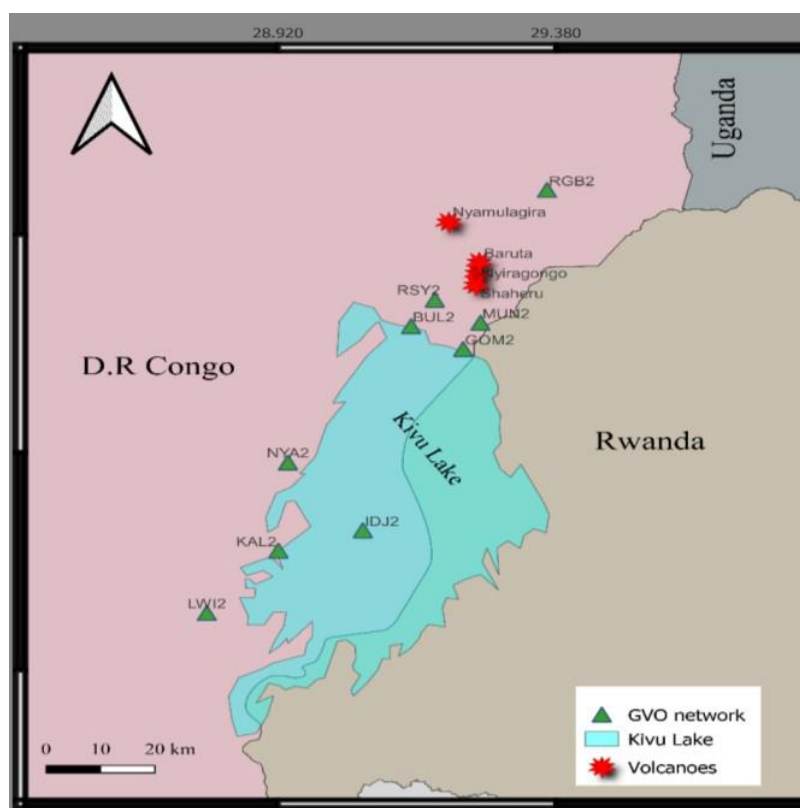


Fig. 1. GVO network: The seismographic network of the Goma Volcanological Observatory (source: QGIS)

2.2 LONG PERIOD LP SEISMICITY SIGNIFICANT

Long-period earthquakes are often associated with magmatic activity and may indicate an increase in this activity, potentially leading to volcanic eruptions. Examples include the eruptions of Nyamulagira volcanoes in 2004 and 2011 (Mavonga et al. 2006, 2010; Birimwiragi Namogo et al. 2016), Nyiragongo in May 2021 (Sadiki et al. 2023; Mavonga et al. 2023), Mt. Etna in 2004–2005 (Lokmer et al. 2008), and Tongariro in August 2012 (Hurst et al. 2014). Studies have shown that magmatic degassing is a key driver of volcanic events such as LPs, VLPs, and tremors. In particular, LPs and tremors are related to magma fragmentation, degassing, explosions, and oscillations in magma flow channels. They can also result from repeated injections of ash-laden gases or from variations in the voids of a magmatic conduit (B. Chouet, Dawson, et Arciniega-Ceballos 2005; Arciniega-Ceballos, Dawson, et Chouet 2012; Lokmer et al. 2008; B. A. Chouet et Matoza 2013; Lyons et al. 2016). Long-period earthquakes are often attributed to impulsive excitation and resonance of fluid-filled fissures resulting from magmatic–hydrothermal interactions, which can lead to volumetric oscillations in subhorizontal fissures (Matoza et al. 2015). At Popocatepetl volcano (Chouet et al. 2005), LPs are related to the opening of an escape route for volcanic gases and ash, resulting from a slow pressurization of the sill caused by magma crystallization. They are characterized by a cycle of compression, expansion and recompression, illustrating phases of pressurization, depressurization and repressurization. Depressurization occurs during gas evacuation, while pressurization is due to the diffusion of gases from the magma to the bubbles. The study by Bean et al. (2014) examines long-period seismicity in shallow volcanoes. The results show that long-period (LP) earthquakes are not only related to the resonance of fluid-filled conduits, but rather to the slow rupture of unconsolidated volcanic materials. Thus, LP events would be indicators of deformation of the upper edifice, without fluids directly intervening in the seismic process. Deep long-period (DLP) seismicity has been detected at various volcanoes and in different tectonic settings, at depths of 10 to 60 km. It is generally related to the transport of magma between the upper mantle and the lower crust, often preceding shallow seismic events, tremors and steam emissions a few hours later (Chouet and Matoza 2013).

Volcanic tremors are a series of seismic events and RSAM (Real-time Seismic Amplitude Measurement) is used to monitor these events by measuring the amplitude of seismic signals in real time. It allows to assess the magnitude of seismic activity, including various types of volcanic events (VT, LP, VLP and tremors). At Nyiragongo volcano, a study showed that RSAM increased significantly on the day of the May 2021 eruption and during the return of the lava lake (Munguiko et al. 2024). Although intense tectonic seismicity followed this eruption, RSAM rapidly decreased after the cessation of the eruption, indicating that it was directly related to magmatic activity and not influenced by the ongoing tectonic earthquake swarm that was indicative of tectonic activity.

3 RESULTS

3.1 EVOLUTION OF LONG PERIOD (LP) SEISMIC ACTIVITY

Following the eruption of Nyiragongo volcano on 22 May 2021, Nyamulagira volcano showed intense magmatic activity in its crater. Since August 2022, magma movement has been observed inside the central crater. In 2023, lava lake activity was marked by several events, with long-period seismicity dominated by earthquakes with a frequency in the 0.3 Hz to 5 Hz frequency range.

The distribution of long-period events in the Nyamulagira and Nyiragongo volcano fields are shown in the figure below:

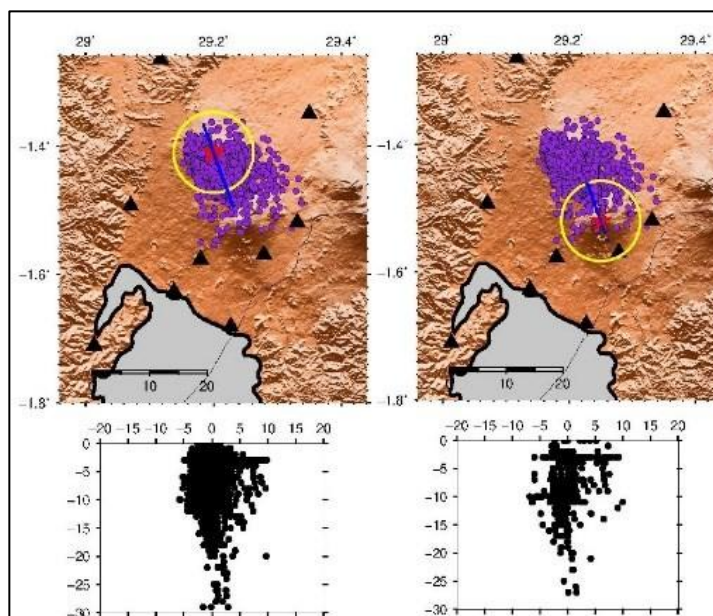


Fig. 2. The distribution of LP earthquake epicenters and hypocenters in the Virunga Volcanic Province between October 2022 and December 2023: on the left the Nyamulagira volcano and on the right the Nyiragongo volcano, with yellow circles delimiting their respective areas. An active seismic region, oriented along the fracture connecting the two volcanoes, is indicated by a blue line on the graph. The black triangles represent the seismic stations

This figure shows that both volcanoes were active, but the activity of Nyamulagira volcano involves a large number of LP earthquakes. LP seismic activity is most observed between the two volcanoes, along the fracture that connects them.

The time evolution of the hypocenters was analyzed separately and is shown in Figure (3) below:

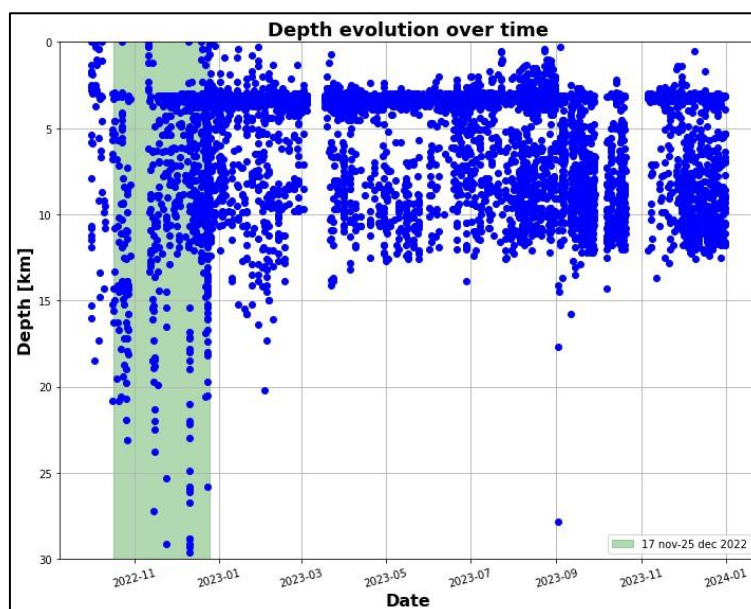


Fig. 3. Evolution of hypocenters over time

An evolution of seismic depths was observed, with deep earthquakes reaching 30 km between October and December 2022, indicating deep magmatic activity. In addition, long-period superficial earthquakes are observed, see figure (3). This long-period seismic activity at depth as in the superficial part may indicate a magmatic displacement from depth to the upper reservoirs. Subsequently, seismicity was concentrated at less than 15 km, especially between 2-4 km and 8-14 km, suggesting

a continuous and sustained supply of the first reservoir. According to (Pouclet and Bram 2021). Examining figure (3) we notice that from January 2023, long-period seismicity was more concentrated at less than 14 km depth until the event of May 19-20, 2023, marked by the overflow of lava in the crater of the Nyamulagira volcano.

3.2 RSAM EVOLUTION FROM OCTOBER 2022 TO DECEMBER 2023

Daily RSAM values at stations RGB2 (or RGB) and RSY2 (or RSY) exhibited temporal variations throughout the study period. A clear and sustained increase in RSAM was observed at both stations beginning on May 10, 2023. This trend continued over the following days and culminated on May 19, coinciding with the onset of the lava overflow eruption (Fig. 4a–b). Other transient RSAM peaks occurred in response to regional tectonic earthquakes, such as the March 27, 2023 events, but did not result in sustained RSAM elevation. The average RSAM (11.4 for RGB and 27.9 for RSY) level remained relatively stable outside these episodes.

Daily volcanic earthquake counts revealed episodic swarms. Notable increases in event numbers occurred from December 23–25, 2022, April 1, 2023, and October 17, 2023 (Fig. 2c). The 1st April swarm followed two tectonic events that occurred on 27 March that caused RSAM fluctuations. The average number of daily volcanic events remained below 20 for most of the year, with spikes exceeding 100 during swarm periods.

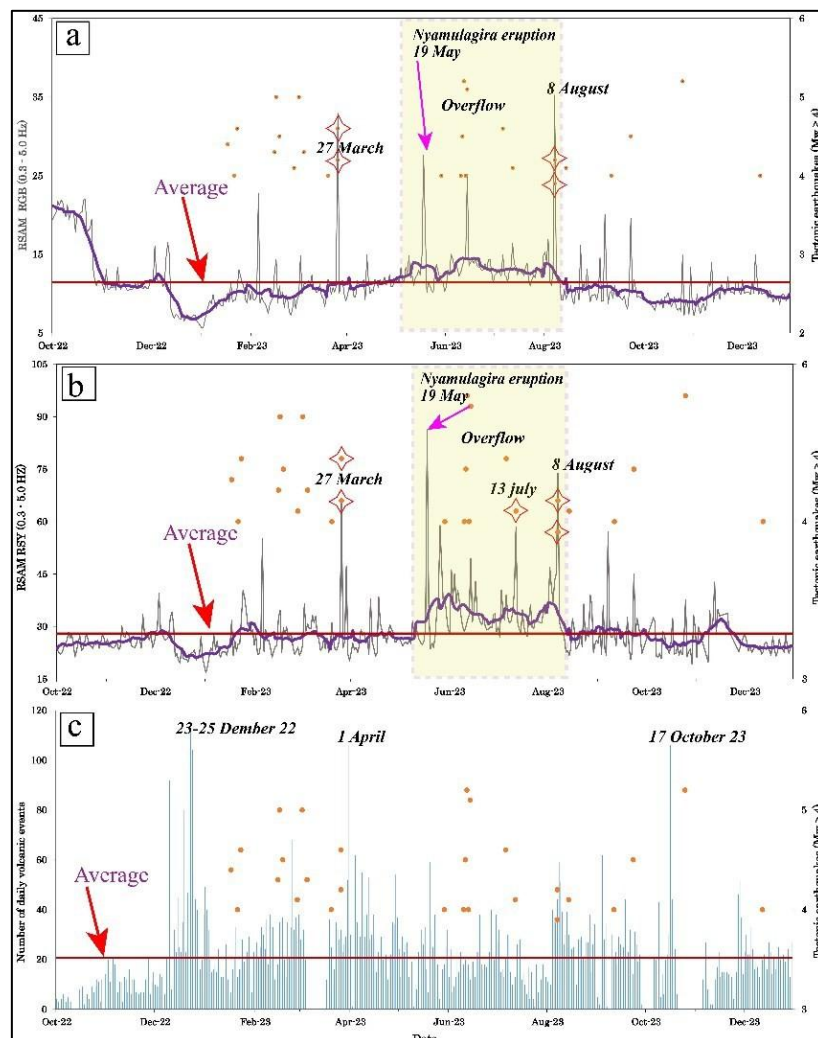


Fig. 4. Temporal evolution of seismic parameters recorded from October 2022 to December 2023: (a) Daily RSAM values at RGB and (b) Daily RSAM values at RSY (0.3-5Hz band) black curve, with a 15-days moving average (purple). (c) Daily count of volcanic earthquakes (light blue bars). Major regional tectonic earthquakes ($M \geq 4$) are marked with orange dots and highlighted with red star symbol when directly influencing RSAM. The horizontal red line indicates the average over the entire period. The onset of the eruption on 19 May 2023, associated with lava overflow, is indicated in the yellow shaded zone, along with additional overflow events on 8 August

3.3 CORRELATION BETWEEN RSAM AND SEISMICITY

Normalized RSAM curves from RGB2 and RSY2 showed a similar overall pattern (Fig. 5a). However, their correlation was moderate ($R^2 = 0.40$; Fig. 5b), reflecting both shared and local influences on seismic amplitude. Correlation between RSAM and the number of daily volcanic earthquakes was negligible ($R^2 < 0.04$; Fig. 5c–d), indicating that RSAM and earthquake count track different volcanic processes—one energy-based, the other event-based.

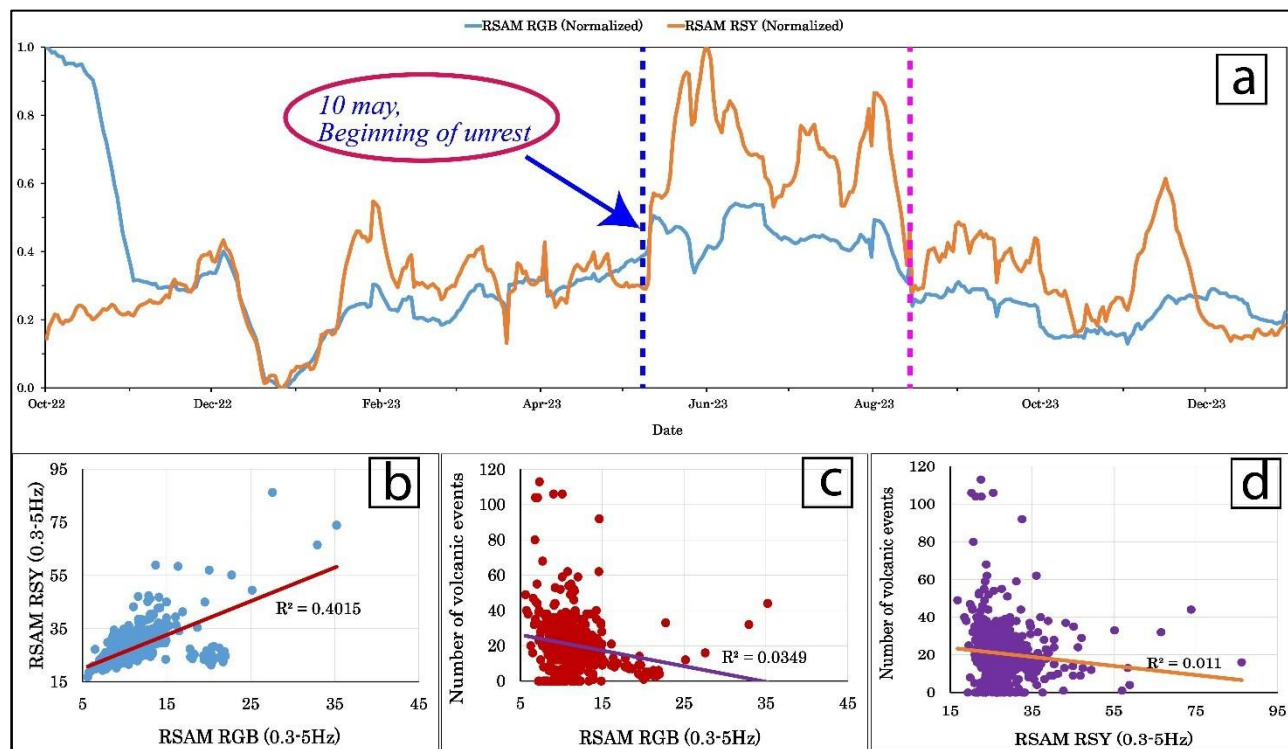


Fig. 5. (a) Normalized RSAM value from stations RGB (blue) and RSY (orange) between October 2022 and December 2023. A progressive increase starting around 10 May (first vertical dashed line) and the second vertical line (pink) marks the end of unrest period (overflow event) in August. (b) Scatter plot of RSAM values from RGB versus RSY, showing a moderate positive correlation, indicating partial coherence in seismic amplitude trends between these stations. (c) Scatter plot of RSAM RGB versus the number of daily volcanic events and (d) RSAM versus the number of daily volcanic events

3.4 PRE-ERUPTIVE SEISMIC SWARM AND EVENT ANALYSIS

An important seismic swarm was recorded between 22: 00 on May 18 and 02: 00 on May 19 (4 hours of duration) (Fig. 6). This swarm, observed across all three components at both stations, consisted primarily of volcano-tectonic (VT) events, with long-period (LP) signals. Spectral analysis of selected events confirmed dominant low-frequency peaks (~ 1 Hz) for LP events and higher frequencies (> 5 Hz) for VT events (Fig. 6). This swarm preceded the eruption onset by approximately 17 hours. These observations support the interpretation of magma migration and overpressure leading to the lava overflow observed later on 19 May at from 19: 00 (local time) where an intense glow was observed all night.

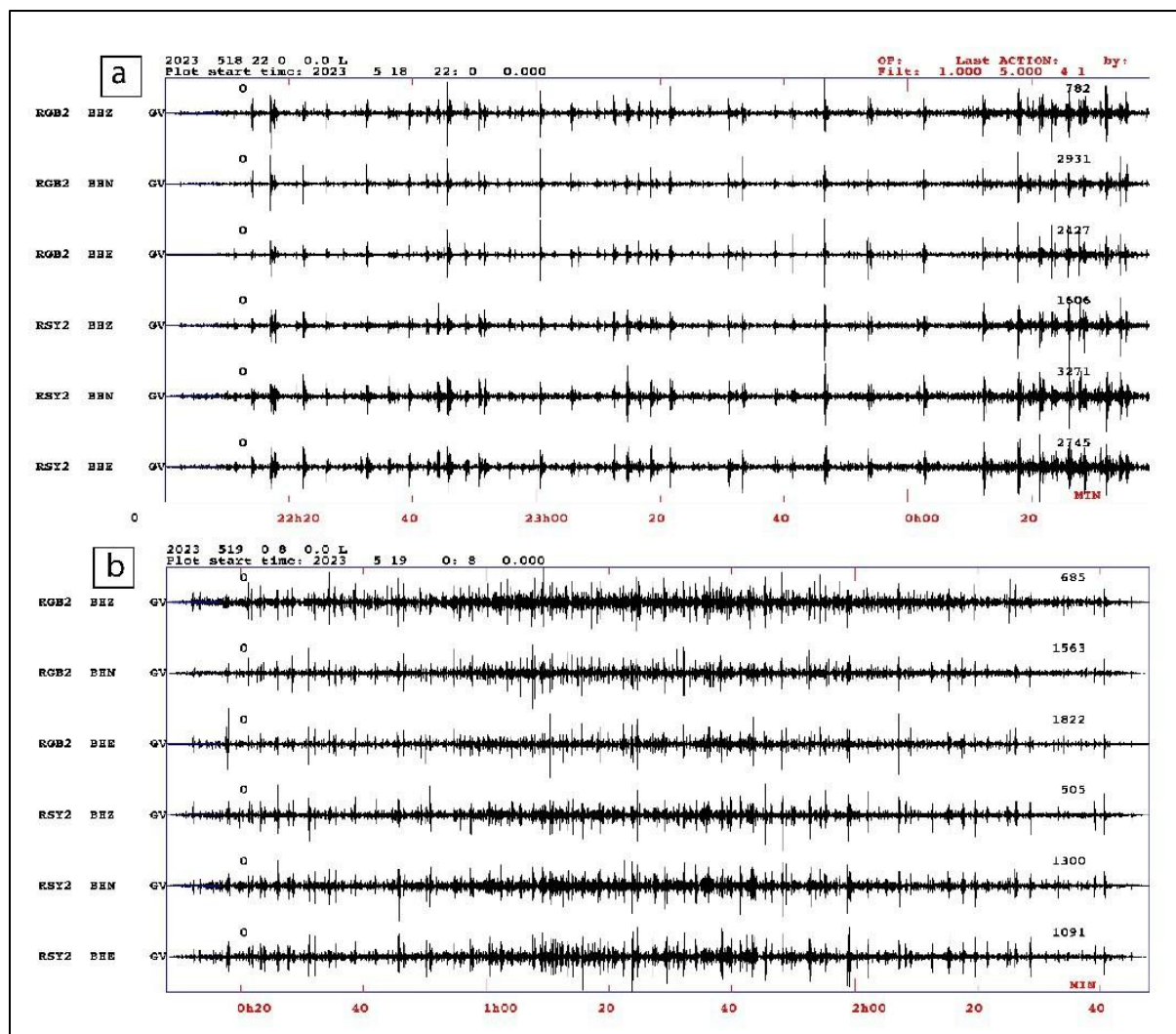


Fig. 6. Pre-eruptive seismic swarm recorded on 18-19 May 2023: (a) seismic waveforms recorded at RGB2 and RSY2 stations (three components each) between 22: 00 on 18 May to 00: 40 on 19 May and (b) Continuation of the swarm from 00: 20 to 02: 40 on 19 May

The LP events are characterized by emergent waveforms a dominant low frequency energy between 1-3Hz, as shown in their corresponding spectral plots (Fig. 7a-b). The VT events recorded on 19 May 2023, exhibiting impulsive and frequency content above 5Hz (Fig. 7c-d) while the tectonic earthquakes show a higher amplitude and broader spectral content typical of regional tectonic events (Fig. 7d).

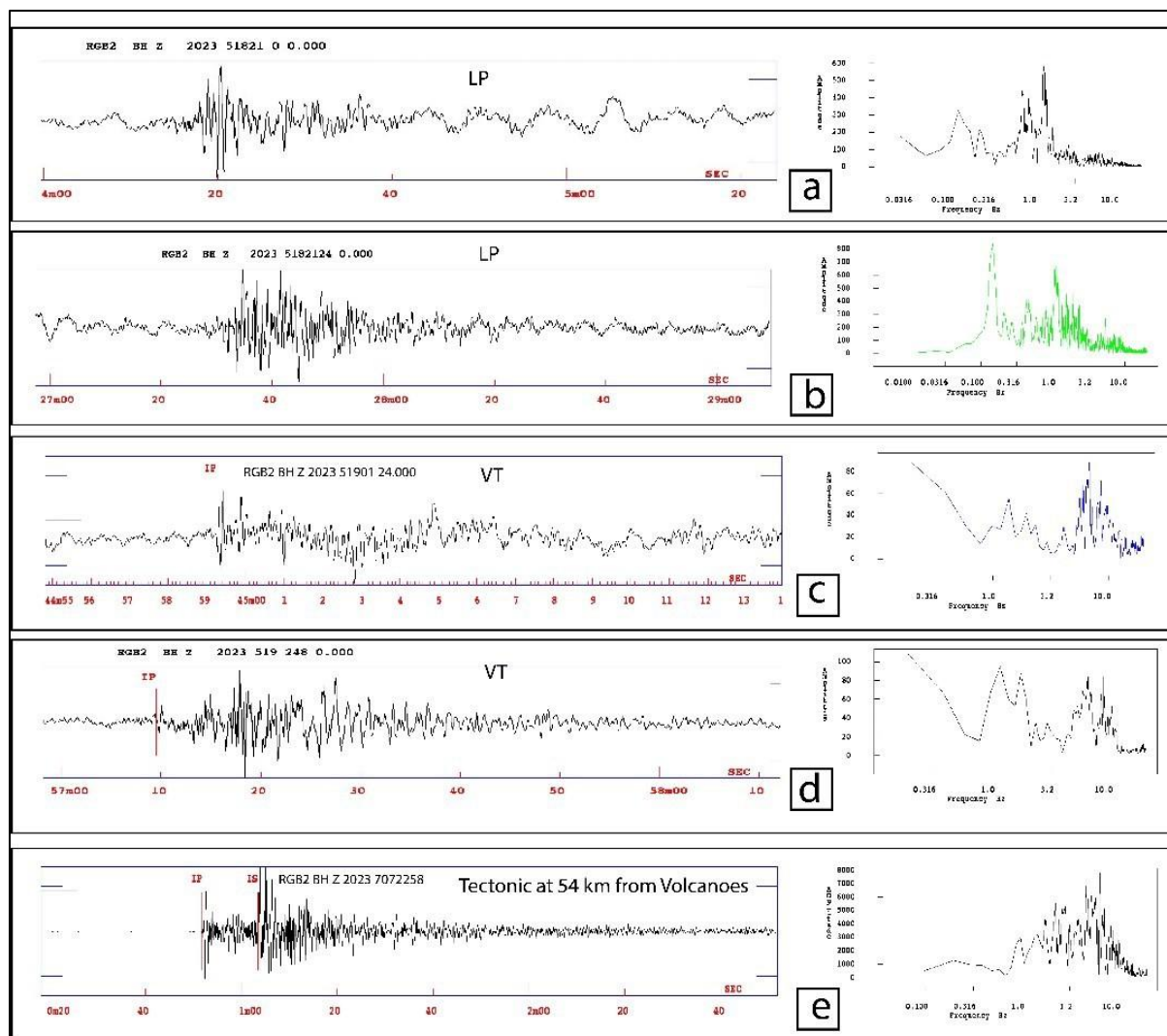


Fig. 7. Examples of seismic events recorded during the swarm and regional earthquake, Vertical component at RGB station: (a) and (b) LP events, (c) and (d) Volcano-tectonic (VT) events and (e) tectonic earthquake ($M_w \geq 4$) located at about 54 km from the volcanic area

4 DISCUSSION

On May 19-20, 2023, strong magmatic activity characterized the Nyamulagira volcano. A strong glow was observed at the summit of the crater; the lava having overflowed from the crater to flow on the northern flank of the volcano. Based on seismic data, GVO (Goma volcano Observatory) report indicate a shallow magma activity at Nyamulagira volcano since February (The Bulletin of the Goma Volcanological Observatory of February 19, 2023 n.d.). On March 14, 2023, lava fountains and a plume gas reach 1.5 km above the crater. A large thermal anomaly was observed on March 18, reports VAAC (Volcanic Ash Advisory Center of Toulouse) indicating the presence of the lava lake. (Global Volcanism Program, 2023. Report on Nyamulagira (DR Congo) (Venzke, E., ed.). Bulletin of the Global Volcanism Network, 48: 5. Smithsonian Institution. n.d.). All these observations were clear precursors to the May 19, 2023, event marking the beginning of the Lava Lake Activity series characterized by an overflow eruption followed by a short lava flow on the northwest flank of the volcano.

Analysis of seismic activity at Nyamulagira between October 2022 and December 2023 reveals a progressive evolution of the volcanic system, culminating in the effusive eruption of May 19, 2023. RSAM data, volcanic earthquake counting, and waveform analysis identified a consistent pre-eruptive sequence. A notable signal is the increase in RSAM, starting on May 10, 2023, approximately 9 days before the eruption, consistently observed at both RGB2 and RSY2 stations, although variable in magnitude due to site effects, indicates increasing unrest related to summit remobilization of magma. This phenomenon has been recognized as a precursor to effusive eruptions in other systems, such as at Pinatubo (Pilippines) in June 1991 and Mt St.

Helens (USA) en May 1985, where a slow rise of the RSAM precedes the final crisis, (Endo and Murray 1991; Endo et al. 1996 and Cornelius and Voight (1996) describe RSAM variations at Mt St. Helens. According to the authors, the first peak in RSAM occurred during doming in May 1985, followed by exponential increases that heralded imminent volcanic activity, correlated with rising magma in the dome.

Two major volcanic seismic swarms were observed before the eruption: on 23–25 December 2022 and 1 April 2023. These episodes indicate that the Nyamulagira magmatic system was under pressure for several months before the eruption, reflecting progressive instability. The recurrence of the seismic swarms suggests accumulation of magma at depth, with periodic energy releases. Several regional tectonic earthquakes, notably those of March 27, 2023, generated abrupt peaks in RSAM at both stations, without initiating a sustained increasing trend. Their effect on the RSAM curves manifests itself as brief pulses, suggesting a transient influence of seismic waves. However, these earthquakes were followed by a significant volcanic swarm on April 1, suggesting an interaction between magmatic and tectonic activity. In a continental rift setting such as this, the upwelling of magma from the crust causes regional stresses that can generate tectonic earthquakes (Wright et al. 2006; Ebinger et al. 2010). On the other hand, tectonic earthquakes can modify the stress state of the volcanic system, contributing to the reactivation of pre-existing structures and the release of magmatic fluids (Wong et al. 2019; Acocella 2021; Brauner et al. 2024).

Statistical analysis showed a moderate correlation between RSAMs from both stations ($R^2=0.40$), reflecting a partially common response to similar sources, but also local influences (orientation, substrate, distance). In contrast, the correlation between RSAM and the number of volcanic earthquakes is almost zero ($R^2<0.04$). This dissociation highlights that RSAM, and discrete seismicity reflect different processes: RSAM is sensitive to long signals (tremor, LP), sometimes non-localized, linked to fluid mobilization, while discrete volcanic earthquakes (VT) are more associated with brittle fracturing. Magmatic agitation phases can be expressed either by seismic swarms or by tremor-type signals, without these two manifestations being simultaneous. This reflects the complexity of the interactions between magmatic overpressure, fracturing, and system resonance. In periods when the RSAM is high, seismic noise can mask certain discrete volcanic earthquakes, artificially reducing their number in the catalogs.

Analysis of waveforms and spectra (Fig. 6–7) shows an intense volcanic swarm, dominated by VT events and some LPs, occurring between 22: 00 on May 18 and 02: 00 on May 19, less than 24 hours before the eruption. These signals reflect a rupture of the internal walls of the conduit, or a terminal pressurization, facilitating the final ascent of the magma. In an already open system, as is the case here with a lava lake active since 2022, this type of swarm is often the last precursor signal before an overflow, as observed in other volcanoes with permanent lava lakes (e.g., Chouet et Matoza 2013; Matoza et al. 2015; Thelen et al. 2022). However, the observed seismic signals (LP swarm + some VT) reveal a transition from a passive effusive regime to a dynamic instability regime, generally interpreted as fluid (gas or magma) mobilization (LP) and fracturing associated with increasing overpressure linked to a rapid magma rise or pressure change in the upper chamber. These signals reflect a progressive rupture of the conduit walls or a rapid remobilization of magma beneath an already active lava lake. The swarm thus represents an immediate precursor to the eruption, revealing a transition to a critical state in an already open magmatic system.

Our seismic analysis reveals a progressive RSAM increase starting on May 10, followed by a short seismic swarm on May 18-19, which preceded the lava overflow observed at 19: 00 (local time) on May 19. These precursory seismic signals contrast with the findings of (Polcari et al. 2025), who reported no significant ground deformation prior to the eruption using Sentinel-1 SAR coherence data. Their results support the interpretation of Nyamulagira as an open-system volcano, where magma ascent does not necessarily induce measurable surface deformation. This comparison highlights the value of combining seismic and satellite data, as seismic observations may provide earlier, immediate and very close precursors insight into pressurization or conduct dynamics that are not detectable via InSAR.

5 CONCLUSION

The May 19, 2023 eruption of Nyamulagira was preceded by a progressive increase in RSAM, 9 days before followed by a short but intense seismic swarm just hours before the lava overflow. Despite the absence of measurable ground deformation reported by InSAR studies, seismic indicators, particularly RSAM revealed clear signs of escalating volcanic unrest. We analysed the RSAM at two stations and noticed that their amplitudes are very different due to heterogeneous source processes, distance from the source or local site effects. In addition, analysis showed a lack of correlation between RSAM and the number of volcanic earthquakes suggests that seismic amplitude and event count reflect different processes: RSAM likely captures continuous magma movement, while discrete earthquake counts represent brittle failure in the surrounding rock. Therefore, we cannot directly compare the RSAM variations with the number of earthquakes, due to the overlap and the large number of seismic events that complicate the counting.

The analysis allowed several conclusions to be drawn, in particular:

1. RSAM was essential to analyze changes in activity at Nyamulagira volcano for the period October 2022 to December 2023. Fluctuations in the RSAM curve signal upcoming unusual events, with high peaks coinciding with lava movement in the upper part of the crater.
2. Variations in RSAM indicate the volume of magma supplied and pressure fluctuations at the supply source. An increase in RSAM signals a large volume of magma under pressure, while a decrease indicates a smaller volume. A constant curve at high levels suggests a continuous supply under stable pressure into the magma system.
3. RSAM is more reliable when seismic stations are close to the volcano, as this allows for the detection of seismic amplitude variations and the recording of a wide range of frequencies to better analyze those that influence RSAM.
4. Earthquake swarms were observed prior to the lava lake overflow on 19–20 May 2023. The evolution of hypocenters towards superficial areas in late 2022 suggests magmatic displacement towards the crater surface.

These results highlight the importance of combining multiple seismic indicators for effective eruption forecasting in open-conduit systems like Nyamulagira. Particular attention should be paid to progressive RSAM increases and seismic swarms, which may provide more reliable precursors than the absolute number of volcanic events.

DATA AVAILABILITY

The data used in this work cannot be shared with third parties for a period defined by the organization (Goma Volcano Observatory). However, they can be accessed through the corresponding author's contact for more credibility. The authors declare that there is no conflict of interest regarding these data.

COMPETING INTERESTS

We declare that there is no competing interests.

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REFERENCES

- [1] Acocella, Valerio. 2021. *Volcano-Tectonic Processes*. Cham: Springer International Publishing. doi: 10.1007/978-3-030-65968-4.
- [2] Aiuppa, A., A. Cannata, F. Cannavò, G. Di Grazia, F. Ferrari, G. Giudice, S. Gurrieri, et al. 2010. « Patterns in the Recent 2007–2008 Activity of Mount Etna Volcano Investigated by Integrated Geophysical and Geochemical Observations ». *Geochemistry, Geophysics, Geosystems* 11 (9):2010GC003168. doi: 10.1029/2010GC003168.
- [3] Arciniega-Ceballos, Alejandra, Phillip Dawson, et Bernard A. Chouet. 2012. « Long Period Seismic Source Characterization at Popocatepetl Volcano, Mexico ». *Geophysical Research Letters* 39 (20): 2012GL053494. doi: 10.1029/2012GL053494.
- [4] Bean, Christopher J., Louis De Barros, Ivan Lokmer, Jean-Philippe Métaxian, Gareth O'Brien, et Shane Murphy. 2014. « Long-period seismicity in the shallow volcanic edifice formed from slow-rupture earthquakes ». *Nature geoscience* 7 (1): 71-75.
- [5] Birimwiragi Namogo, Didier, Georges Mavonga, Josué Subira, Albert Kwambikwa, Osundundu Etoy, Delphin Assani, Rigobert Rusangiza, et al. 2016. « Weakness areas conducive to the intrusion of dykes by reference to the migration of the epicenters of swarms of long-periods around the volcanoes Nyiragongo and Nyamulagira for the period 2002-2011 ». *International Journal of innovation and scientific Research* Vol. 24 (1): 112-23.
- [6] Birimwiragi Namogo, Didier, Georges Mavonga, Josué Subira, Albert Kwambikwa, Modeste Etoy, Delphin Assani, Rigobert Rusangiza, et al. 2016. « Seismic activity related to the June 2014 New lava Lake apparition at Nyamulagira volcano in the Western Branch of the East African Rift ». *International Journal of Innovation and Scientific Research* 24 (1, Jun. 2016). <https://orbi.uliege.be/handle/2268/308426> (26 mai 2024).
- [7] Brauner, Jacob, Thomas R. Walter, Oscar A. N. Ela, et Loïc Vanderkluysen. 2024. « Volcano-Tectonic Controls on the Morphology and Volcanic Rift Zone Configuration on Bioko Island (Equatorial Guinea) Derived from TanDEM-X Data ». *Bulletin of Volcanology* 86 (8): 76. doi: 10.1007/s00445-024-01764-2.

- [8] Chouet, Bernard A., et Robin S. Matoza. 2013. « A multi-decadal view of seismic methods for detecting precursors of magma movement and eruption ». *Journal of Volcanology and Geothermal Research* 252: 108-75.
- [9] Chouet, Bernard, Phillip Dawson, et Alejandra Arciniega-Ceballos. 2005. « Source Mechanism of Vulcanian Degassing at Popocatepetl Volcano, Mexico, Determined from Waveform Inversions of Very Long Period Signals ». *Journal of Geophysical Research: Solid Earth* 110 (B7): 2004JB003524. doi: 10.1029/2004JB003524.
- [10] Coppola, D., R. Campion, M. Laiolo, E. Cuoco, C. Balagizi, M. Ripepe, C. Cigolini, et D. Tedesco. 2016. « Birth of a Lava Lake: Nyamulagira Volcano 2011–2015 ». *Bulletin of Volcanology* 78 (3): 20. doi: 10.1007/s00445-016-1014-7.
- [11] Ebinger, Cynthia, Atalay Ayele, Derek Keir, Julie Rowland, Gezahegn Yirgu, Tim Wright, Manahloh Belachew, et Ian Hamling. 2010. « Length and Timescales of Rift Faulting and Magma Intrusion: The Afar Rifting Cycle from 2005 to Present ». *Annual Review of Earth and Planetary Sciences* 38 (1):439-66. doi: 10.1146/annurev-earth-040809-152333.
- [12] Endo, Elliot T., Thomas L. Murray, et John A. Power. 1996. « A comparison of preeruption real-time seismic amplitude measurements for eruptions at Mount St. Helens, Redoubt Volcano, Mount Spurr, and Mount Pinatubo ». *Fire and Mud*: 233-47.
- [13] Endo, Elliot T, et Tom Murray. 1991. « Real-Time Seismic Amplitude Measurement (RSAM): A Volcano Monitoring and Prediction Tool ». *Bulletin of Volcanology* 53 (7): 533-45. doi: 10.1007/BF00298154.
- [14] Global Volcanism Program, 2023. Report on Nyamulagira (DR Congo) (Venzke, E., ed.). Bulletin of the Global Volcanism Network, 48: 5. Smithsonian Institution.
- [15] Hurst, Tony, Arthur D. Jolly, et Steven Sherburn. 2014. « Precursory characteristics of the seismicity before the 6 August 2012 eruption of Tongariro volcano, North Island, New Zealand ». *Journal of Volcanology and Geothermal Research* 286: 294-302.
- [16] Lokmer, Ivan, Gilberto Saccorotti, Bellina Di Lieto, et Christopher J. Bean. 2008. « Temporal evolution of long-period seismicity at Etna Volcano, Italy, and its relationships with the 2004–2005 eruption ». *Earth and Planetary Science Letters* 266 (1-2): 205-20.
- [17] Lyons, John J., Matthew M. Haney, Cynthia Werner, Peter Kelly, Matthew Patrick, Christoph Kern, et Frank Trusdell. 2016. « Long Period Seismicity and Very Long Period Infrasound Driven by Shallow Magmatic Degassing at Mount Pagan, Mariana Islands ». *Journal of Geophysical Research: Solid Earth* 121 (1): 188-209. doi: 10.1002/2015JB012490.
- [18] Mateso Kasongo, Desré, Didier Birimwiragi Namogo, Delphin Chiza Assani, Pascal Matamba, Vicky Kajeje, Joseph Lushoka, Laurent Bizimungu, et Yves Mwanjale. 2017. « Observation of Hybrid Earthquakes at Nyamulagira Volcano in the Democratic Republic of the Congo ». *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)*.
- [19] Matoza, Robin S., Bernard A. Chouet, Phillip B. Dawson, Peter M. Shearer, Matthew M. Haney, Gregory P. Waite, Seth C. Moran, et T. Dylan Mikesell. 2015. « Source Mechanism of Small Long- period Events at Mount St. Helens in July 2005 Using Template Matching, Phase-weighted Stacking, and Full-waveform Inversion ». *Journal of Geophysical Research: Solid Earth* 120 (9): 6351-64. doi: 10.1002/2015JB012279.
- [20] Mavonga, Tuluka, Georges, Thystere Matondo Bantidi, et Arsène Tumaini Sadiki. 2023. *Volcanic Seismicity for the East Democratic Republic of Congo: Volcanic Hazard for the Eastern DR Congo*. LAP LAMBERT Academic Publishing.
- [21] Mavonga, Tuluka, Sadaka K. Kavotha, Nyombo Lukaya, Osodundu Etoy, et Jacques Durieux. 2006. « Seismic activity prior to the May 8, 2004 eruption of volcano Nyamuragira, Western Rift Valley of Africa ». *Journal of Volcanology and Geothermal Research* 158 (3-4): 355-60.
- [22] Mavonga, Tuluka, Sadaka K. Kavotha, Nyombo Lukaya, Osodundu Etoy, Wafula Mifundu, Rusangiza K. Bizimungu, et Jacques Durieux. 2010. « Some aspect of seismicity prior to the 27 November 2006 eruption of Nyamuragira volcano and its implication for volcano monitoring and risk mitigation in the Virunga area, Western Rift Valley of Africa ». *Journal of African Earth Sciences* 58 (5): 829-32.
- [23] Mavonga, Tuluka, N Zana, et R.J Durrheim. 2010. « Studies of crustal structure, seismic precursors to volcanic eruptions and earthquake hazard in the eastern provinces of the Democratic Republic of Congo ». *Journal of African Earth Sciences* 58 (4): 623-33.
- [24] Munguiko, Olivier, Solange Maska, Faustin S. Habari, Abel S. Minani, Eliode Bakole, Tuluka Mavonga, Bonheur Ngangu, Arsène T. Sadiki, et Gentil Balezi. 2024. « Lava lake activity at Nyiragongo volcano between the years 2020 and 2021 documented by seismic activity and sulfur dioxide emissions, DRC ». *Volcanica* 7 (2): 607-19.
- [25] Polcari, Marco, Emanuele Ferrentino, Charles Balagizi, Diego Coppola, et Sébastien Valade. 2025. « 2023 Activity of Nyamulagira Volcano Monitored by sar Interferometric Coherence ». *Science of Remote Sensing*: 100261.
- [26] Pouclet, André, H. Bellon, et K. Bram. 2016. « The Cenozoic volcanism in the Kivu rift: Assessment of the tectonic setting, geochemistry, and geochronology of the volcanic activity in the South-Kivu and Virunga regions ». *Journal of African Earth Sciences* 121: 219-46.

- [27] Pouclet, André, et Kurt Bram. 2021. « Nyiragongo and Nyamuragira: A Review of Volcanic Activity in the Kivu Rift, Western Branch of the East African Rift System ». *Bulletin of Volcanology* 83 (2):10. doi: 10.1007/s00445-021-01435-6.
- [28] RUSANGIZA, Rigobert Bizimana, Georges Tuluka MAVONGA, et Josué Muhindo SUBIRA. 2017. « Numéro spécial ». *Geo-Eco-Trop* 41 (2): 219-32.
- [29] Sadiki, A. T., A. M. Kyambikwa, D. B. Namogo, L. N. Diomi, O. M. Munguiko, G. M. Balezi, L. L. Sifa, et al. 2023. « Analysis of the Seismicity Recorded before the May 22, 2021 Eruption of Nyiragongo Volcano, Democratic Republic of the Congo ». *Journal of Volcanology and Seismology* 17 (3): 246-57. doi: 10.1134/S0742046323700136.
- [30] Smets, Benoît, M. Kervyn, N. d'Oreye, et F. Kervyn. 2015. « Spatio-temporal dynamics of eruptions in a youthful extensional setting: Insights from Nyamulagira Volcano (DR Congo), in the western branch of the East African Rift ». *Earth-Science Reviews* 150: 305-28.
- [31] The Bulletin of the Goma Volcanological Observatory of February 19, 2023.
- [32] Thelen, Weston A., Robin S. Matoza, et Alicia J. Hotovec-Ellis. 2022. « Trends in Volcano Seismology: 2010 to 2020 and Beyond ». *Bulletin of Volcanology* 84 (3): 26. doi: 10.1007/s00445-022-01530-2.
- [33] Wong, Kevin, Emily Mason, Sascha Brune, Madison East, Marie Edmonds, et Sabin Zahirovic. 2019. « Deep carbon cycling over the past 200 million years: a review of fluxes in different tectonic settings ». *Frontiers in Earth Science* 7: 263.
- [34] Wright, Tim J., Cindy Ebinger, Juliet Biggs, Atalay Ayele, Gezahegn Yirgu, Derek Keir, et Anna Stork. 2006. « Magma-maintained rift segmentation at continental rupture in the 2005 Afar dyking episode ». *Nature* 442 (7100): 291-94.

Test de taux d'incorporation des gousses de *Piliostigma thonningii* (schum) dans la ration avec une utilisation du charbon de bambou chez les caprins en croissance

[Test of the incorporation rate of *Piliostigma thonningii* (schum) pods in the ration with the use of bamboo charcoal in growing goats]

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ABSTRACT: Sahelian livestock farming is faced with feeding problems, especially during the dry season. The aim of the study was to compare the effect of different rates of incorporation of *Piliostigma thonningii* pods, with or without the use of bamboo charcoal, on goat growth. This involved determining the chemical composition of the feed and assessing the impact of rations incorporating the pods on the weight gain of the goats. Chemical composition was determined using the FOSS DS2500F with the Global Feed Equation from the International Livestock Research Institute. Twenty-four goats of average age and live weight of 12.5 ± 5.5 months and 8.49 ± 1.33 kg, respectively, were fed a ration incorporating 20%, 40% and 60% of pods, respectively, in 6 batches. Batches 1, 2 and 3 received the ration without charcoal and batches 4, 5 and 6 with charcoal at a dose of 1g/kg PV. Bromatological analysis of the pods yielded contents of 91.5 and 8.69% DM for OM and MAT respectively, with a nitrogen digestibility of 45.51 g/kg DM. The trial yielded GMQs of 10.5 ± 3.32 , 18.59 ± 7.97 and 18.43 ± 6.93 g/d for batches 1, 2 and 3 respectively; lower than 17.54 ± 5.55 , 20.78 ± 9.2 and 21.71 ± 7.29 g/d for batches 4, 5 and 6, which had the highest DM intake (283.23 ± 52.81 , 240 ± 35.04 and 315 ± 50.9 g/d respectively). These results could be used in goat production improvement programmes.

KEYWORDS: feeding, GMQ, weight evolution, chemical composition, goat production.

RESUME: L'élevage sahélien est confronté à des problèmes alimentaires, surtout, en saison sèche. Le but de l'étude a été de comparer l'effet de différents taux d'incorporation des gousses de *Piliostigma thonningii*, avec ou sans utilisation du charbon de bambou, sur la croissance des caprins. Elle a consisté à déterminer la composition chimique des aliments et l'évaluation des rations incorporant les gousses sur l'évolution pondérale des caprins. La composition chimique a été déterminée en utilisant

le FOSS DS2500F à l'aide de l'équation Global Feed Equation de International Livestock Research Institute. L'essai a été réalisé avec vingt-quatre caprins d'âge et de poids vifs moyens respectifs de $12,5 \pm 5,5$ mois et $8,49 \pm 1,33$ kg, repartis en 6 lots ayant reçu une ration incorporant respectivement 20%, 40%, 60% de gousses. Les lots 1, 2 et 3 ont reçu la ration sans charbon et les lots 4, 5 et 6 avec le charbon à la dose de 1g/kg PV. L'analyse bromatologique des gousses a permis d'obtenir des teneurs de 91,5 et 8,69% MS; respectivement pour la MO et MAT avec une digestibilité de la matière azotée de 45,51g/kg MS. L'essai a permis d'enregistrer des GMQ de $10,5 \pm 3,32$; $18,59 \pm 7,97$ et $18,43 \pm 6,93$ g/j avec respectivement les lots 1, 2 et 3; inférieurs à $17,54 \pm 5,55$; $20,78 \pm 9,2$ et $21,71 \pm 7,29$ g/j pour les lots 4, 5 et 6 dont les quantités ingérées de la MS ont été les plus élevées ($283,23 \pm 52,81$; $240 \pm 35,04$ et $315 \pm 50,9$ g/j; respectivement). Ces résultats serviraient aux programmes d'amélioration de la production caprine.

MOTS-CLEFS: alimentation, GMQ, évolution pondérale, composition chimique, production caprine.

1 INTRODUCTION

Le Burkina Faso est un pays sahélien dont l'économie est essentiellement basée sur le secteur agricole dans lequel la contribution du sous-secteur de l'élevage est significative. Ce sous-secteur contribue au PIB à environ 18 % et près de 30 % aux recettes d'exportations [1]. De plus, il contribue fortement à la lutte contre la pauvreté, à la sécurité alimentaire et nutritionnelle et à la création d'emplois [1]. L'élevage reste ainsi la première source pour 38,8% des ruraux pour accéder aux services sociaux de base [2]. Le cheptel du Burkina Faso est l'un des plus importants d'Afrique de l'Ouest, avec environ 10 millions de bovins, 16 millions de caprins et 11 millions d'ovins. [3] Malgré cette importance numérique l'élevage extensif est de loin le plus pratiqué dans les différentes zones, dépendant directement du pâturage naturel en toute saison. Ces pâturages naturels sont dans la quasi-totalité dominés par des espèces annuelles, caractérisées par un cycle de développement court qui se déroule entièrement pendant la saison pluvieuse. A cette période, le pâturage arrive à assurer les besoins alimentaires des animaux. Pendant la saison sèche qui est la plus longue, il ne reste plus sur ces pâturages que de la paille qualitativement pauvre, quelque fois quantitativement insuffisante. Il se pose alors le problème de la couverture des besoins d'entretien des animaux. Ces derniers se tournent alors en ces moments vers les ligneux fourragers qui ont l'avantage de disposer de feuilles (souvent induites par les feux) et de fruits riches en protéines. Ils fournissent alors un fourrage dont la principale qualité est sa richesse en matière protéique et constituent un bon marché [4]. Malgré leur disponibilité beaucoup d'études ont montré que la plupart des fourrages ligneux renferment des substances anti-nutritionnelles telles que les tannins et divers autres composés secondaires, [5] [6]. Les tanins influencent négativement la digestibilité des fibres, la dégradation des protéines en inhibant les enzymes protéolytiques notamment celles des microorganismes [7]. La quantité idéale de tannins sera donc le minimum nécessaire pour protéger les protéines de l'hydrolyse dans le rumen et les rendre disponibles dans l'intestin grêle. Certains chercheurs recommandent une introduction des fourrages ligneux comme suppléments dans les rations des petits ruminants à des taux variant entre 15 et 45% [8]. Et d'autres recommandent des taux de 15; 15; 30; 50; 75% respectivement pour les feuilles de *Guiera senegalensis*, les fruits de *Faidherbia albida*, les feuilles d'*Andersonia digitata*, de *Pitcellobium dulce* et de *Colotropis procera*. [9] D'où la présente étude initiée pour tester différents taux d'incorporation des gousses de *Piliostigma thonningii* dans des rations de caprins en croissance avec ou sans l'utilisation du charbon de bambou.

2 MATÉRIEL ET MÉTHODES

2.1 SITE DE L'ÉTUDE

L'étude s'est déroulée dans la commune rurale de Bama (carte) [10] Elle couvre une superficie estimée à 1300 Km² et est située à une trentaine de kilomètre au Nord-ouest de Bobo-Dioulasso. Chef-lieu de la province du Houet et de la région des Hauts-Bassins, la commune de Bama est limitée au Nord-Ouest par la commune de Dandé, au Nord par la commune de Padéma, au Sud par la commune de Bobo-Dioulasso, à l'Est par la commune de Satiri et à l'Ouest par la commune de Karangasso-Sambla. La commune de Bama est traversée du Nord au Sud par le Kou, affluent du Mouhoun et possède une plaine rizicole et maraichère aménagée, ce qui garantit une disponibilité permanente des ressources en eau et en terre, principaux facteurs de production.

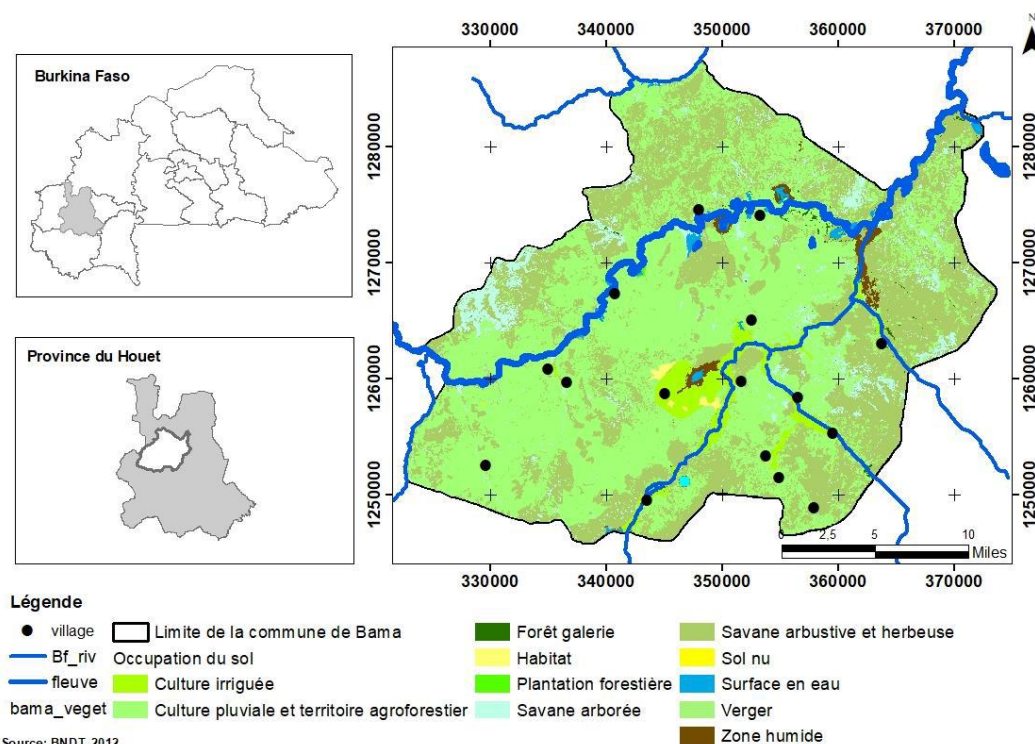


Fig. 1. Carte localisation de la zone d'étude

2.2 MATÉRIEL ANIMAL

L'expérience a nécessité l'utilisation de vingt-quatre (24) caprins de race Mossi dont 12 mâles non castrés et 12 femelles non gestantes d'un âge moyen de $12,5 \pm 5,5$ mois et d'un poids moyen initial de $8,49 \pm 0,71$ kg. Le Tableau I présente l'effectif et les poids moyens initiaux des animaux expérimentaux

Tableau 1. Effectif et poids moyen initial (kg) des animaux expérimentaux

Lots d'animaux	Effectif	Poids vif moyen initial (kg)
1	4	$10,75 \pm 1,71$
2	4	$7,13 \pm 0,42$
3	4	$7,93 \pm 0,49$
4	4	$9,30 \pm 0,75$
5	4	$8,37 \pm 0,40$
6	4	$7,50 \pm 0,5$



Fig. 2. Photo 1: Chèvre Mossi

2.3 TRAITEMENT DES INGREDIENTS ET FORMULATION DES RATIONS DISTRIBUEES

2.3.1 TRAITEMENT APPLIQUÉS AUX INGRÉDIENTS

Les gousses de *Piliostigma thonningii* broyées et incorporées à d à des taux variables dans les rations. La paille de riz (récolté dans la plaine rizicole de Bama) a été séchée, hachée et traitée à la mélasse puis séchée au soleil pendant 24 heures avant d'être distribuée aux animaux. Le traitement a consisté à étaler la paille, ensuite à asperger la mélasse diluée à l'aide d'un pulvérisateur. La dilution a été de 250 ml d'eau pour 600 g de paille de riz hachée selon [11]. Le charbon de bambou a été obtenu par carbonisation complète du bois sec de bambou. Car selon [12] le charbon de bambou (*Oxythenanthera abyssinica*) absorberait certains éléments végétaux secondaires et améliorerait la valeur nutritive du fourrage. Il a été broyé et tamisé pour obtenir une poudre qui a été mélangée à la ration des animaux Tous les ingrédients étaient broyés et mélangés pour faciliter l'ingestion

2.3.2 FORMULATION DES RATIONS

Les rations expérimentales utilisées étaient constituées de la paille de riz traitée à la mélasse comme d'aliments de base auquel ont été ajouté le son de maïs, la pierre à lécher et les gousses de *Piliostigma thonningii* utilisées à différents taux d'incorporation dans ces rations. L'adjonction du charbon de bambou a été utilisation à cause de son effet d'amélioration de l'ingestibilité et de la digestibilité des gousses [13]. L'eau et la pierre à lécher ont été administrées *ad libitum* (à volonté). La mélasse est dilué à 5% avant son utilisation et [11] recommandent 250 ml pour 600 g de paille à traiter. Le tableau II ci-dessous présente la composition journalière de rations administrées. La composition chimique et les valeurs nutritives des différents aliments ont été déterminée en utilisant le FOSS DS2500F à l'aide de l'équation Global Feed Equation de l'ILRI (International Livestock Research Institute)

Tableau 2. Composition centésimale des rations des rations distribués aux caprins

Ingrédients	R1	R2	R3	R4	R5	R6
Paille de riz mélassée	45	25	5	45	25	5
Son de maïs	35	35	35	35	35	35
Gousses de <i>P. thonningii</i>	20	40	60	20	40	60
Charbon de bambou (g/kg PV)				1	1	1
Pierre à lécher et l'eau				<i>ad libitum</i>		
Total	100	100	100	100	100	100

2.4 DISPOSITIF EXPÉRIMENTAL

Les animaux ont été répartis en six lots de 04 animaux chacun. Les lots 1, 2 et 3 ont reçu une ration incorporant les gousses comme compléments à différents taux d'incorporations sans addiction de charbon de bambou. Les lots 4, 5 et 6 ont reçu les mêmes rations, mais avec l'adjonction du charbon de bambou. Le charbon de bambou a été incorporé à une dose de 1g/kg PV de l'animal. Les animaux ont été en stabulation complète et logés individuellement.

Par ailleurs, avant le début de l'expérience, les animaux ont reçu un déparasitage interne externe à l'aide de lévamisole 0,3g et de l'ivermectine 1g. Les animaux ont été également ont été traité contre la pasteurellose avec le Pastovin-50 doses et contre la peste des petits ruminants avec l'Oxytetracycline.

COLLECTE DES DONNÉES

Le protocole expérimental a comporté deux phases: une phase d'adaptation qui a duré 2 semaines et une phase de collecte de données de 8 semaines. Les animaux ont été pesés au début et à la fin de la phase d'adaptation et chaque semaine au cours de la phase de collecte des données en vue d'apprécier l'évolution pondérale. La pesée des animaux a été faite à l'aide d'un peson électronique de portée 50 kg $\pm$ 10 g et celle des aliments a été faite avec un peson de 10 kg $\pm$ 5 g... La distribution des aliments a été faite individuellement et en deux repas par jour (8h et 16h) aux taux de 5% du poids vif de l'animal. Les quantités non consommées étaient retirées des mangeoires tous les matins et pesées puis cumulées par animal pour calculer l'ingestion volontaire. Les paramètres mesurés ont été: l'ingestion volontaire, l'indice de consommation, le GMQ, l'évolution pondérale et le gain de poids (GP).

✓ L'ingestion volontaire (IV)

La quantité d'aliment ingérée (QI) en gMS/animal/jour, a été déterminée selon l'équation 1 ci-dessous:

$$QI = \text{Quantité distribuée}(Qd) - \text{Quantité refusée}(Qr)$$

✓ L'indice de consommation alimentaire (IC)

L'IC est le rapport de la quantité d'aliment ingérée (Qi) sur le gain de poids (GP). Il traduit l'efficacité de la transformation de l'aliment. Il reflète la quantité d'aliment complémentaire (en kilogramme) utilisée pour l'élaboration d'un kilogramme de croît (équation 2).

$$IC = \frac{\text{quantité de Matière Sèche ingérée (kg)}}{\text{Poids Vif final (kg)} - \text{Poids Vif initial (kg)}}$$

✓ Gain Moyen Quotidien (en g/j)

Cette variable qui traduit la vitesse de croissance pondérale a été calculée à partir des mesures hebdomadaires de poids vif exprimé en gramme. Les GMQ ont été déterminés avec la formule proposée par [9] donnée à l'équation 3 ci-dessous.

$$GMQ \left(\frac{g}{j} \right) = \frac{\sum(wf - wi)}{\Delta T} * 1000$$

Où: Wf = poids final; Wi = poids initial; ΔT = durée entre deux pesées en jours

✓ Evolution pondérale

Le poids vif (PV) a été mesuré par des pesées hebdomadaires. Les pesées ont été faites à jeun le matin avant la distribution de la ration du jour et ont permis de calculer les gains de poids (GP) en kg.

3 RÉSULTATS ET DISCUSSION

3.1 COMPOSITION CHIMIQUE ET VALEURS NUTRITIVES DES ALIMENTS DISTRIBUES

Tableau 3. Composition chimique et valeur nutritive des aliments distribués

Paramètres	Ingredients	Paille de riz	Paille de riz mélassée	Son de maïs	<i>Piliostigma Thonningii</i>
MS (%)		92,44	90,42	94,95	94,49,
MM(%MS)		14,86	17,15	6,72	5,41
MAT(%MS)		5,9	5,09	12,6	8,69
NDF(%MS)		56,5	60,84	33,62	72,24
ADF(%MS)		38,18	44,86	9,88	41,6
Lignine(%MS)		2,63	3,01	3,36	7,81
IVOMD (%)		54,52	49,63	66,3	56,6
MAD(%MS)		19,57	12,12	81,83	45,51
EM(MJ/kgMS)		8,02	7,14	9,73	8,76

Légende: MS = Matière Sèche; MAT = Matière Azotée Totale; EM = Energie Métabolisable; IVOMD = Digestibilité in vitro de la Matière Organique; NDF = Neutral Detergent Fiber; ADF = Acid Detergent Fiber

Le tableau III présente les résultats de l'analyse bromatologique, montrent que les gousses de *Piliostigma thonningii* utilisées ont une teneur élevée en matières sèches et matières organique et une teneur moyenne en matière azotée digestibles.

D'après ces résultats obtenus, les teneurs en matières azotées totales (MAT) des différents ingrédients utilisés ont été similaires à celles obtenues par [10]. Cependant, nos valeurs ont été inférieures à celles trouvées par [6] et [7] qui ont trouvé des teneurs de 10,53 % MS et 9,51 % MS respectivement pour les gousses de *Piliostigma thonningii* et de *Piliostigma reticulatum*. De même, ces valeurs ont été supérieures aux valeurs rapportées par [11] pour les gousses de *Faidherbia albida* (6,10 %MS) et par [12] pour celles de *Piliostigma reticulatum* (5.06% MS). Cette différence de teneur en MAT pourrait être liée à l'espèce. En effet, [13] avaient stipulé qu'il existe une différence entre les espèces en termes de composition chimique chez ces ligneux fourragers au Nord-Est du Nigeria. Cette différence pourrait dépendre également du type de climat, des types de sol, l'état de maturité et la durée de conservation.

La teneur en MAT enregistré au niveau de l'analyse du son de maïs (12,60%MS) a été comparable à celle obtenue par [8]. Par contre, elle a été inférieure à celles trouvées par [14] et [15] qui ont obtenu des teneurs en MAT de 13,28 et 17,49%MS, respectivement. Cette teneur a été également supérieure à 6,63%MS obtenues par [9]. Cette différence pourrait être liée à la variété de maïs, aux techniques de la meunerie. Selon certains nutritionnistes tels que [16], il faut un minimum de teneurs en MAT (8 % de MS) pour assurer un fonctionnement adéquat aux microorganismes du rumen. Nos résultats montrent que la teneur en MAT des gousses (8.69 %MS) a été au-dessus de la teneur d'azote en dessous de laquelle la microflore du rumen ne fonctionne pas de manière efficiente. Les gousses de *Piliostigma thonningii* contiennent des teneurs de matière azotée acceptables et peuvent être utilisées comme concentré

Les valeurs de la digestibilité de la matière organique de nos aliments ont été de 49,63; 56,60; 66,30 % respectivement pour la paille de riz mélassée, les gousses de *Piliostigma thonningii*, et le son de maïs. Ces valeurs confirment ceux des travaux de [14] et [15] qui note que la plupart des fourrages consommés par le bétail dans les pays en développement ont une faible digestibilité qui ne dépasse que rarement 55 % et se situe la plupart du temps dans la fourchette 40–45 %. Quant à l'énergie métabolisable les valeurs que nous avons obtenues ont varié de 7,14; 8, 16; et 9,73 MJ/kgMS respectivement pour la paille de riz mélassée, les gousses de *Piliostigma thonningii* et le son de maïs. Ces valeurs se situent juste au-delà de la norme car selon [14] l'énergie métabolisable calculée dans la matière sèche (EM/MS) varie donc de 7,5 à 4,8 MJ. Or selon les normes, les fourrages qui ont une teneur en énergie métabolisable de 7,5 MJ permettent aux animaux d'accuser un taux de croissance d'environ 2 g/MJ de EM absorbée. Ce qui permet d'expliquer les prises de poids observées au niveau de nos différentes rations administrées.

3.2 INGESTION VOLONTAIRE

Les résultats de l'ingestion volontaire obtenue avec les différents lots de notre essai (tableau IV) montrent que les niveaux d'ingestion volontaire ont été significativement différents. L'ingestion la plus élevée de l'essai a été enregistrée avec le lot 6 et la plus faible a été enregistrée avec le lot 1. Sans l'utilisation du charbon, le lot 2 a présenté l'ingestion la plus élevée. Avec l'incorporation du charbon, l'ingestion volontaire obtenue avec le lot 6 a demeuré la plus élevée. Les différences significatives notées entre les lots pourraient être attribuées à la différence des taux d'incorporation des gousses et aussi à l'adjonction du charbon de bambou.

D'une manière générale, plusieurs paramètres pourraient expliquer nos résultats. Il y a d'une part le taux d'incorporation des gousses de *Piliostigma thonningii* dans la ration et d'autre part les traitements apportés à la paille de riz. En effet plusieurs auteurs ont souligné que les ligneux contiennent des facteurs antinutritionnels qui entraînent souvent une diminution de l'ingestibilité et de la digestibilité [16], [17]. Dans notre étude la faible ingestion du lot 1 pourrait être expliquée par la présence de ces facteurs antinutritionnels [18] et d'autres paramètres aussi liés à l'âge et à l'espèce. La plus forte ingestion du lot 6 pourrait s'expliquer par les différents traitements tels l'adjonction du charbon de bambou car [13] et [19] ont noté que l'adjonction du charbon de bambou améliorerait la digestibilité des gousses de *Piliostigma reticulatum* ce qui pourrait favoriser un bon transit dans le tube digestif donc une bonne ingestion de la ration. La valeur élevée de l'ingestion volontaire du lot 6 pourrait aussi s'expliquer par la préférence alimentaire des animaux, leur capacité individuelle de consommation, la teneur élevée en MAT de la ration, favorable à une bonne digestibilité et aussi à l'adjonction du charbon de bambou comme la souligné [13]. En effet, [20] ont montré qu'une augmentation du niveau d'azote à travers un complément dans une ration stimulerait les fonctions du rumen et par conséquent entraînerait une augmentation du niveau d'ingestion chez les moutons. En plus, l'inclusion de la mélasse fournit l'énergie et le squelette carboné nécessaires aux micro-organismes du complexe rumen-réseau pour assurer la dégradation des fourrages [21]; avec pour conséquence, une amélioration de la digestibilité des nutriments. Le niveau d'ingestion volontaire élevé obtenu avec le lot 2 à 40 % de taux d'incorporation des gousses sans le charbon montre clairement qu'au-delà de ce taux, les gousses pourraient apporter des facteurs qui limiteraient la consommation de la ration par les animaux. Cela justifierait le meilleur niveau d'ingestion volontaire obtenu jusqu'à 60 % de taux d'incorporation de gousses avec l'adjonction du charbon [22].

Des résultats similaires furent aussi mentionnés par [23] qui, dans son étude avait obtenu des valeurs comprises entre $304,08 \pm 72,93$ g et $371,75 \pm 92,63$ g/animal/j pour des rations incorporant les mêmes gousses broyées à 40%. D'autres auteurs comme [24] ont aussi obtenu des résultats similaires en substituant le tourteau de graines de coton par des gousses de *Piliostigma reticulatum* et avaient enregistré des valeurs d'ingestion respectives de 390,83; 386,35; 384,25 et 362,48 g/j avec des rations incorporant des gousses broyées à 20%, 50%, 30% et 0%. La consommation volontaire par jour que nous avons obtenu a été largement inférieure aux valeurs de 449,5 g/j et 549,2 g/j obtenue par [15] qui avaient travaillé sur des animaux soumis à des rations incorporant les gousses à 20% de *Piliostigma reticulatum*. Ces différences pourraient être attribuées au taux d'incorporation de gousses dans les rations, aux espèces ligneuses, aux ingrédients utilisés, à l'âge des animaux et à l'espèce animale.

3.3 ÉVOLUTION PONDÉRALE

Les figures 1 et 2 donnent l'évolution pondérale des animaux au cours de notre étude. L'allure des courbes est croissante ce qui explique une prise de poids dans tous les lots. Durant l'essai les gains de poids ont varié de 0,9237 kg à 2,59675 kg par animal durant la période de l'essai. Les lots 2 et 6 se distinguent par leur allure qui indique une prise de poids beaucoup plus que chez les autres lots. Cette prise de poids avec les rations incorporant de gousses de *Piliostigma thonningii* confirme les travaux de [25] et [11]. En outre de nombreux auteurs ont trouvé des résultats intéressants sur la valorisation des ligneux fourragers (gousses) dans l'alimentation animale ([13], [25]).

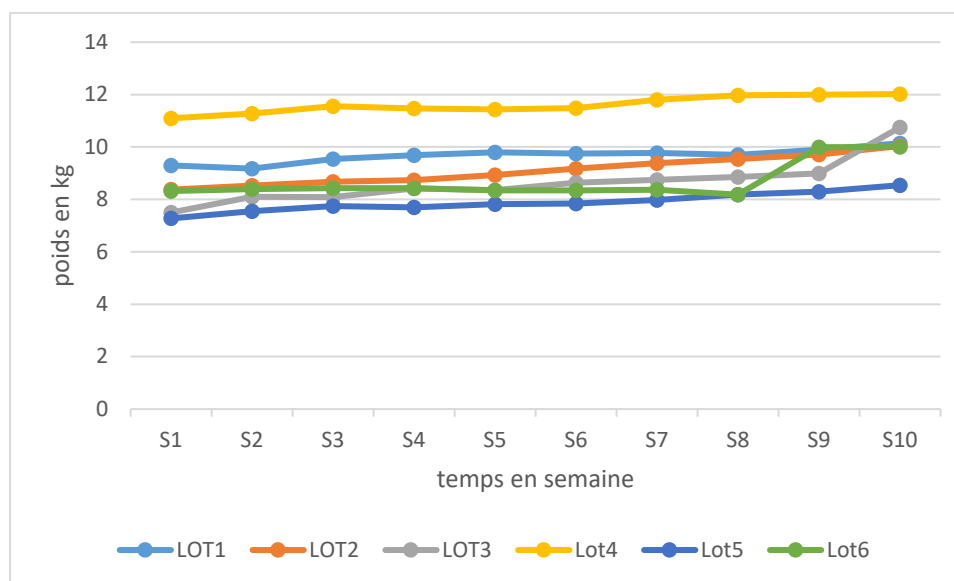


Fig. 3. Evolution pondérale des caprins en fonction du temps avec ou sans adjonction du charbon de bambou

3.4 GAINS MOYENS QUOTIDIENS

Tableau 4. Ingestion volontaire (IV); Indice de Consommation (IC); Gain Moyen Quotidien (GMQ) et Gain de Poids (GP)

Traitements	IV	IC	GMQ (g/)	GP(Kg)
Lot 1	243±44,65a	20,78±13,61a	10,5±3,32a	0,9675±0,306a
Lot 2	300,80±43,75 c	18,5±3,71b	18,59±7,97b	1,6625±1,52b
Lot 3	280 ±44,44b	20,31±10,90a	18,43±6,93b	1,625±1,146b
Lot 4	283,23±52,81b	24,83±16,27a	17,54±5,55b	0,92375±0,292a
Lot 5	240,8±35,04a	22,7±12,19a	20,78±9,20c	1,26725±1,159b
Lot 6	315±5 c	17,7±3,09b	21,71±7,29c	2,59675±1,831c

$P \leq 0,05$; Par colonne les lettres différentes donnent une différence significative

Le tableau IV montre les résultats des gains moyens quotidiens (GMQ) enregistrés dans notre étude. Le GMQ est un paramètre qui permet d'évaluer la croissance des animaux. Le GMQ le plus élevé (21,71±7,29 g/animal/jour) a été obtenu avec le Lot 6 et le plus faible a été observé avec le lot 1 (10,5±3,32 g/animal/jour). La plus forte valeur de GMQ du lot 6 pourrait s'expliquer par une bonne disponibilité des éléments nutritifs dans l'organisme des animaux. En effet selon [11], l'action du charbon pourrait être expliquée par une dénaturation des complexes azotés rendant ainsi l'azote utilisable par les microorganismes. La prise de poids observée avec les différentes rations pourrait s'expliquer par l'adjonction du charbon de bambou car selon [12] l'adjonction du charbon sur les gousses de *Piliostigma reticulatum* à la dose de 0,5g/kg PV améliorerait la digestibilité des gousses permettraient une augmentation des flux de protéines assimilables au niveau du rumen. Nos valeurs de GMQ sont similaires à celles obtenues par qui ont noté des GMQ compris entre 19,94 dès les quatre première semaines de son étude et 11; 42 les quatre dernières semaines durant les neuf semaines chez la même race d'animaux complémentés avec des gousses de *Piliostigma reticulatum*. En plus nos résultats sont comparables à ceux de [24] qui ont obtenu des GMQ compris entre 13,20 et 22,06 g/j avec la substitution partielle des gousses broyées de *Piliostigma reticulatum* sur les boucs de Maradi. De même ces GMQ sont semblables à ceux de [23] qui ont enregistré un GMQ compris entre 16,39 et 31,39g/j sur des caprins nourris avec de la paille de riz complémentées avec des gousses de *Piliostigma thonningii* et du tourteau de coton. Cependant la valeur de 28,6 g observé par [26] à l'issu de la complémentation avec les gousses de *Prosopis africana* sur les moutons métisse Mossi-Djallonké sont inférieurs à nos résultats.

3.5 INDICE DE CONSOMMATION (IC)

L'indice de consommation traduit l'efficacité de transformation des aliments: il est plus faible lorsque l'aliment est bien valorisé. Les meilleurs indices de consommation ont été obtenus avec le lot 6 ($17,7 \pm 3,09$) suivi du lot 2 ($18,5 \pm 3,71$) le plus faible a été obtenu avec le lot 4 ($24,83 \pm 16,27$). Ces valeurs montrent que c'est le lot 6 qui a le plus valorisé la ration, suivi du lot 2. La plus faible valeur du lot 4 montre que ce lot a moins valorisé la ration comparativement aux autres lots.

Selon [13] l'adjonction du charbon de bambou améliore la digestibilité des gosses et c'est cette amélioration de la digestibilité qui pourrait expliquer les résultats du lot 6. Les auteurs comme [27] ont obtenus les mêmes effets d'amélioration de la digestibilité avec le charbon avec les feuilles d'*Acacia magium*. Nos valeurs sont au-dessus des valeurs notées par [24] qui, avec les boucs de Maradi a enregistré des valeurs de $7,65 \pm 6,23$; $8,42 \pm 3,89$; $4,17 \pm 4,91$ et $12,76 \pm 3,72$ en utilisant des incorporant 0; 20; 30 et 50% de gosses de *Piliostigma reticulatum*. En plus, elles ont été aussi supérieures à celles obtenues par [23] qui, avec des caprins de race Mossi dont les résultats donne des valeurs comprises entre $18,06 \pm 9,32$ et $10,3 \pm 4$ avec rations incorporant les gosses de *Piliostigma thonningii* et tourteau de coton à 40% dans les rations. La différence entre nos résultats et ceux de ces auteurs pourrait être liée au type de ration, aux traitements appliqués aux ingrédients dans la ration, à l'espèce, à la race et aussi à l'âge des animaux.

4 CONCLUSION

Au terme de cette étude les meilleurs taux d'ingestion, de GMQ et d'indice de consommation ont été enregistré avec le lot 2 qui contenant 40% de gosses de *Piliostigma thonningii* sans adjonction du charbon de bambou. Tant dis que les meilleurs taux sur les différents paramètres mesurés avec l'adjonction du charbon de bambou ont été obtenus avec le lot 6 contenant un taux de 60% des gosses de *Piliostigma thonningii* dans la ration. D'une manière général tous les lots ont connu une prise de poids mais la prise du poids est plus accentuée le lot 6 ce qui montre l'effet bénéfique de l'adjonction du charbon de bambou. Donc les gosses de *Piliostigma thonningii* permettent une prise de poids et peuvent être utilisées jusqu'à un certain taux comme complément en production intensive Ces résultats sont intéressants d'autant plus que le coût des gosses est relativement faible comparativement aux autres aliments de production intensive tel que les sous-produits agro-industriels et les tourteaux qui sont utilisés dans l'intensification de la production animale. L'incorporation des gosses de *Piliostigma thonningii* au taux de 60% dans les rations aurait un impact positif sur les coûts de production.

REFERENCES

- [1] MRA, Plan d'Actions et Programme d'Investissements du Sous-secteur de l'Élevage (PAPISE). 61 p 2010-2015, 2010.
- [2] A ZERBO, D SIRI, Contribution de l'élevage à l'économie et à la lutte contre la pauvreté, les déterminants de son développement. Ouagadougou/Burkina Faso, 67 p, 2012.
- [3] ANNUAIRE NATIONAL STATISTIQUE, Institut national des statistiques et de la démographie (INSD) 362 pages, 2020.
- [4] B TOUTAIN, Le rôle des ligneux pour l'élevage dans les régions soudanaises de l'Afrique de l'Ouest. In LE HOUEROU H. N. éd. Les fourrages ligneux en Afrique. Etat actuel des connaissances. Addis Abeba, Ethiopie. 8-12 avril. CIPEA. pp. 105-110; 1980.
- [5] J C TANNER, J D REED, F OWEN, The nutritive value of fruits (pods with seeds) from four *Acacia* spp. compared with extracted noug (*Guizotia abyssinica*) meal as supplements to maize stover for Ethiopian Highland sheep. Anim. Prod., 51 (1): 127-133, 1990.
- [6] A A DEGEN, K BECKER, H P S MAKAR AND N BOROWY, Acacia saligna as a fodder tree for desert livestock and the interaction of its tannins with fibre fractions Journal of the Science of Food and Agriculture 68 (1), pp. 65-71, 1995.
- [7] C Y KABORE-ZOUNGRANA, Composition chimique et valeur nutritive des herbacées et ligneux des pâturages naturels soudanais et des sous-produits du Burkina Faso. Thèse d'Etat Doctorat ès Sciences Naturelles, Université de Ouagadougou, Burkina Faso. 224p + annexes. 1995.
- [8] M SANGARE, Intérêt et limites de l'utilisation des fourrages ligneux dans l'alimentation des petits ruminants nourris à l'auge. Revue Africaine de Santé et de production animale 3 (3-4): 190-199, 2005.
- [9] S FALL-TOURÉ, S A N'DIAYE, F TRAORÉ, Exploitation des arbres à usages multiples dans les systèmes d'élevage des zones soudanienne et sahélienne. In Gintzburger G., Bounejmate M., Agola C. and Mossi K. (Eds.); Production and utilization of multipurpose fodder shrubs and trees in West Asia, North Africa and the Sahel. ICARD, Aleppo, Syria, IRLI, Nairobi, Kenya. Viii + 60pp 2000.
- [10] INSD, Fichier des localités des Hauts-Bassins - principaux résultats par provinces et communes 2007.

- [11] N MOUAJHED, C KAYOULI. ET A RAACH-MOUJAHED, la complémentation des fourrages pauvres par des blocs nutritionnels chez les ruminants Livestock Research for Rural Development (15) 3 2003.
- [12] M CHENOST ET C KAYOULI, Utilisation des fourrages grossiers en régions chaudes. FAO 1997. 226p, 1997.
- [13] S SANOU. L SAWADOGO., C-Y KABORE-ZOUNGRANA, Amélioration de la valeur nutritionnelle des gousses de *Piliostigma reticulatum* (D. C.) Hochst dans l'alimentation du bétail en période de soudure Int. J. Biol. Chem. Sci. 4 (5): 1519-1528, 2010.
- [14] S OUEDRAOGO, Potentialités fourragères et essai d'amélioration de la valeur nutritive de trois ligneux fourragers: *Piliostigma thonningii* Schumacher, *Piliostigma reticulatum* (D.C) Hoscht et *Khaya senegalensis* (Desr.) A. Juss. Mémoire de fin d'étude IDR/ UPB. 2006.
- [15] «Working Party» of l'Agricultural Research Council (Great Britain) ARC, The Nutrient Requirements of Ruminant Livestock. Technical Review by an Agricultural Research Council Working Party Commonwealth Agricultural Bureaux (CAB International), Farnham Royal, Royaume-Uni. 1980.
- [16] A. J. F. WEBSTER, Bioenergetics, bioengineering and growth Animal Production, volume 48, numéro 2, pages 249–269, 1989.
- [17] G GETACHEW, H P S MAKAR and K BECKER, effect of polyethylene glycol in vitro degradability of nitrogen and microbial protein synthesis from tannin-rich browse and herbaceous legumes. British Journal of Nutrition, 84: 73-83, 1999.
- [18] A A AGANGA; K J W MOSASF, Tannin content nutritive value and dry matter digestibility of *Lonchocarpus capasa*, *Zizyphus mucronata*, *Sclerocarya birrea*, *Kirkia obovatifolia* and *Rhus lancea* seeds Animal Feed Science and Technology, 91 (2001) 107-113, 2001.
- [19] J Lemoufouet, F Tendonkeng, E Miégoué, S N Soumo, B Mbainissiem, B Fogang Zogang, A V Mboko, F N E Matumuini, B Boukila, E T Pamo, Ingestion et digestibilité chez le mouton des chaumes de maïs traitées à urée associées à la mélasse. Livestock Research for Rural Development. 26 (3), 2014a.
- [20] S SANOU, *Piliostigma reticulatum* (D.C.) Hoscht.: Potentialités fourragères et essai d'amélioration de la Valeur nutritive des gousses. Mémoire de fin d'études, Université Polytechnique de Bobo-Dioulasso/IDR, Burkina Faso, 57p, 2005.
- [21] M M ABDU, S ISSA, A D GOMMA, G J SAWADOGO. Analyse technico-économique des Aliments densifiés sur les performances de croissance des boucs roux de Maradi au Niger. Int. J. Biol. Chem. Sci. 2017.11 (1): 280-292, 2017.
- [22] M DECANDIA, G MOLLE, M SITZIA, A CABIDDU, F PAMPIRO, P A RUIU, Effect of polyethylene glycol on feeding behaviour of dairy goats browsing on bushland with different herbage cover. Options Méditerranéennes: Série A; 59, 29-33.6, 2004.
- [23] T A HANLEY, C T ROBBINS, A E HAGERMAN, C McARTHUR, Predicting digestible protein and digestible dry matter in tannin-containing forages consumed by ruminants. Ecology 73 (2): 537–541, 1992.
- [24] I Iyibma, Effet des rations incorporant les gousses de *Piliostigma thonningii* (SCHUM.) sur l'évolution pondérale et les parasites gastro-intestinaux chez les caprins dans la zone subhumide du Burkina Faso. Mémoire: Elevage: Bobo Dioulasso (IDR/UNB). 48p 2019.
- [25] M F NOUHO, Effets d'une substitution du tourteau de graines de coton par les gousses de *Piliostigma reticulatum* (De.Candolle) Hochstetter dans l'alimentation, sur les performances de croissance de la chèvre rousse de Maradi. Mémoire de diplôme de master. Ecole Inter-Etats des Sciences et Médecine Vétérinaires de Dakar (EISMV). 40p 2014.
- [26] S A KIMA, Valorisation des gousses de *Piliostigma thonningii* (schum) en production animale et étude de l'infestation par des insectes. Mémoire: Elevage: Bobo Dioulasso (IDR/UPB). pp. 84-96 2008.
- [27] T T V DO; T M NGUYEN; L INGER, Effect of method of processing foliage of *Acacia mangium* and inclusion of bamboo charcoal in the diet on performance of growing goats Animal Feed Science and Technology, vol. 130, pp. 242–256, 2006.

Effets des technologies de l'aménagement en courbes de niveau et des bandes enherbées sur la conservation de l'humidité et les rendements du sorgho dans les villages de Zanzoni et Finkoloni au Mali

[Effects of contour ridge tillage and grass strip technologies on moisture conservation and sorghum yields in the Southern Mali: Case Zanzon and Finkoloni]

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ABSTRACT: The decline in soil fertility through water erosion greatly affects rainfed crops productivity in the North-East of southern zone of Mali. The objective of this study is to contribute to improving sorghum productivity in rainfed crops. A split plot design was used in 7 replications, with 3 factors. The first factor was the water and soil conservation technique with 2 levels including contour bunding with ado (big ridge) (ACN) and grass strip, the second factor was the tillage at 2 levels of which ridging and scraping, factor 3 was fertilization with 3 levels including zero input, micro dose (40kg.ha⁻¹) and extended dose (100kg.ha⁻¹). The measurements focused on sorghum grain and straw weight and soil moisture in the plots. The results showed that ACN with ridging and popularized fertilization was the most efficient treatment in terms of both moisture conservation and sorghum yields increasing, with 159% increase in grain yield and 195% increase in straw yield compared with the control and 40%, 61% increase in moisture respectively at Zanzoni and Finkoloni. All treatments outperformed the control. These results showed the performance of the technologies used in water conservation and improving sorghum yields and will allow farmers to make a choice of technique according to the level of intensification.

KEYWORDS: erosion, soil, yield, sorghum, Mali.

RESUME: La baisse de fertilité des sols à travers l'érosion hydrique affecte beaucoup la productivité des cultures pluviales au Nord Est de la zone soudanienne du Mali, malgré la disponibilité des technologies antiérosives. L'objectif de cette étude est de contribuer à l'amélioration de la productivité du sorgho en culture pluviale. Pour ce faire, un dispositif en split split plot a été utilisé en 7 répétitions, avec 3 facteurs que sont la technique de conservation de l'eau et du sol à deux niveaux dont l'aménagement en courbes de niveau avec ado (ACN) et la bande enherbée; le travail du sol avec deux niveaux que sont le billonnage et le grattage; la fertilisation à trois niveaux notamment le zéro apport, la microdose (40kg.ha⁻¹) et la dose vulgarisée (100kg.ha⁻¹). Les mesures ont concerné les poids grain et paille du sorgho et le taux d'humidité du sol. Les résultats ont montré que l'ACN avec billonnage et fertilisation vulgarisée était le meilleur traitement avec une augmentation de 159,3% de rendement grain, 195,8% de rendement par rapport au témoin puis, une amélioration de 40% et 61,8% de l'humidité respectivement à Zanzoni et Finkoloni. Tous les traitements ont été meilleurs que le témoin dans la conservation de l'humidité que dans l'augmentation des rendements. Ces résultats ont montré une performance des technologies utilisées dans la

conservation des eaux et dans l'amélioration des rendements de sorgho et permettront au producteur de faire un choix de technique selon le niveau d'intensification.

MOTS-CLEFS: érosion, sol, rendement, sorgho, Mali.

1 INTRODUCTION

La baisse de fertilité des sols à travers l'érosion hydrique et la disponibilité faible de l'eau pour les plantes sont des contraintes majeures dans la production des cultures au sud du Sahara menaçant l'autosuffisance alimentaire de la région. Au Mali, la croissance démographique dans les zones de production agricole, en particulier le vieux bassin cotonnier au Mali Sud, a conduit à l'occupation de l'espace tendant à disparaître la jachère au profit de la culture continue, exposant ainsi les terres au ruissellement. Cette situation a favorisé l'érosion hydrique qui est le principal facteur de la dégradation des sols cultivés dans la zone soudanienne du pays [1]. Ce fait est accentué par les mauvaises pratiques culturales des producteurs. Elle est certes un phénomène naturel mais, aggravée par les activités humaines [2]. Selon la référence [3], dans une même zone climatique, ce sont surtout les pratiques agricoles qui vont déterminer le niveau de fertilité d'un sol donné. Pour lutter contre le phénomène, des premières techniques anti-érosives ont été testées et vulgarisées dans le but de conserver le sol et les eaux de pluies pour les plantes. Ainsi, depuis les années 1984-1987 des technologies comme les haies vives, les bandes enherbées, des cordons pierreux ont été vulgarisées par la Compagnie Malienne de Développement des textiles (CMDT) [4]. D'autres technologies ont suivi, comme, le billonnage cloisonné, les aménagements en courbe de niveau avec ados (ACN), mises au point par la recherche, et testées efficaces dans la conservation des eaux et des sols et l'amélioration des rendements des céréales [5, 6]. Cependant, les études de gestion de la fertilité des sols, à travers ces technologies, ont peu utilisé des combinaisons de facteurs socio-économiques pour une meilleure adaptabilité, permettant aux différents types d'exploitation de faire un choix convenable à ses conditions économiques et pratiques culturales. Donc, l'utilisation convenable de ces technologies disponibles reste toujours limitée, alors que la production des céréales de grande productivité en culture pluviale, que sont le maïs et le sorgho, est de plus en plus confrontée à ces problèmes de fertilité des sols et de disponibilité de l'eau dans la zone. La production du sorgho est ainsi en baisse dans certains terroirs, laissant progressivement la place à la culture de mil qui est plus rustique [7].

Il est donc important de travailler dans le sens d'une amélioration et diversification des technologies pour une meilleure adaptabilité aux pratiques paysannes. La présente étude s'inscrit dans ce cadre et a pour objectif de contribuer à l'amélioration de la productivité du sorgho à partir d'une utilisation plus adaptée des technologies.

2 MATERIEL ET METHODES

2.1 MATÉRIEL

2.1.1 ZONE D'ÉTUDE

Les travaux ont été réalisés dans le cercle de Koutiala qui se caractérise par une forte densité de population (70habts/km²) [7]. Le climat est soudanien avec une pluviométrie moyenne comprise entre 600 et 1000 mm/an et une saison pluvieuse de 5 mois allant de Mai-Juin à Octobre-Septembre. Les moyennes d'évapotranspiration dans la station météorologique de Koutiala ont été de 170,25 mm/mois en 2018 et 182,9 mm/mois en 2019 (données Station météo de Koutiala, 2020). Les systèmes de culture qui intègrent coton et céréales occupent plus de 80% de l'assolement avec un recours important aux intrants [8]. Les principales cultures restent le coton, le sorgho et le mil. Quant au travail du sol, le labour à plat, le billonnage et le grattage sont pratiqués. Les sols sont majoritairement sablo limoneux et profonds. Cette étude a été réalisée dans deux villages du cercle. Il s'agit de Zanzoni qui est situé par -5,56965 longitude Ouest, 12,609019 latitude Nord dans la commune rurale de Fakolo et Finkoloni défini par -5,497410 longitude Ouest, 12,263009 latitude Nord dans la commune rurale de N'Goutjina (figure1). Le choix des villages se justifie par le niveau d'intervention limité des services d'encadrement en relation avec la gestion conservatoire des sols et de l'eau et leur accessibilité et la volonté de collaborer avec la recherche

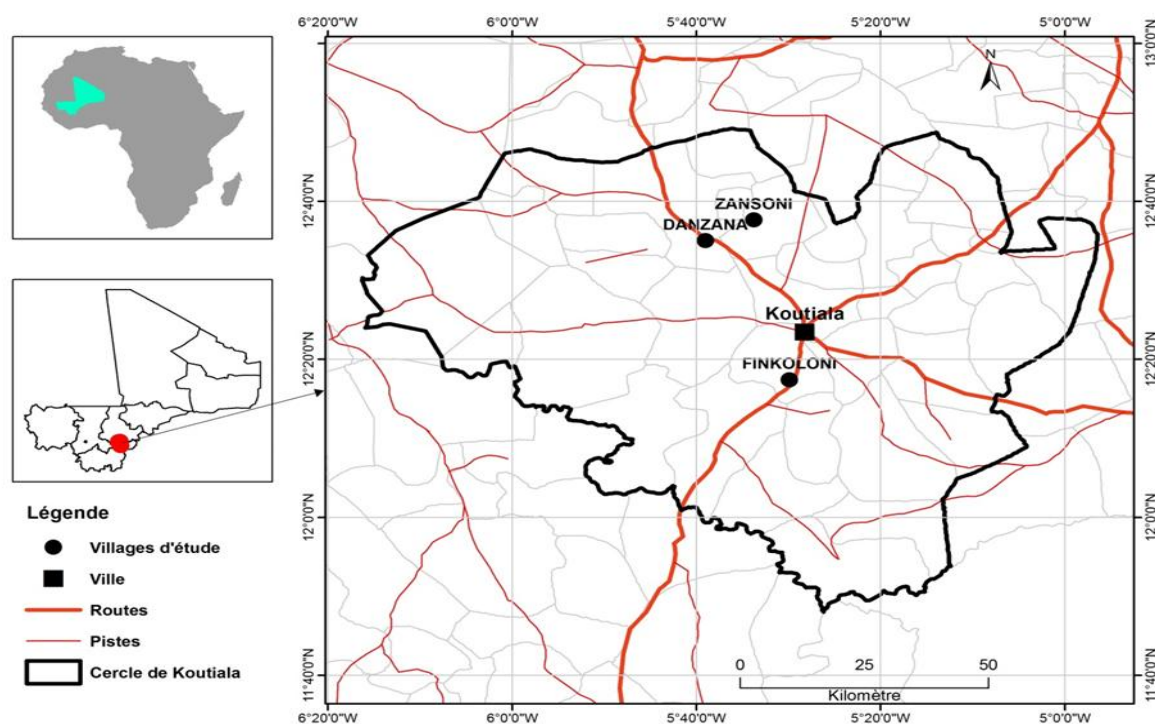


Fig. 1. Carte administrative du cercle de Koutiala

2.1.2 MATÉRIEL BIOLOGIQUE ET FERTILISANT

Les travaux ont été réalisés sur des sols ferrugineux tropicaux peu lessivés. Au niveau de la toposéquence, les glacis ont été plus considérés où se trouve concentrés l'essentiel de la production végétale. Le type de sol dominant est le type sablo limoneux. La variété de sorgho Bobodjè a été utilisée dans les essais pour apprécier les effets des techniques utilisées sur le rendement des cultures. Elle est une variété améliorée de la recherche à bon rendement et adaptée à la zone d'étude. *L'Andropogon gayanus* a été utilisé comme bandes enherbées à cause de ses multiples usages à savoir: bon fixateur du sol, matériel de confection de toit de grenier et de hangar, bon fourrage etc. La fertilisation à base de complexe céréale 17-17-17 a été apportée en microdose à raison de 1,4 g par poquet et en dose vulgarisée de 100 kg $\cdot$ ha $^{-1}$. Cet engrais est le plus utilisé sur les céréales dans la zone.

2.2 MÉTHODES

L'expérimentation a été réalisée sur des parcelles sans apport de fumure organique pour que les technologies expriment leur potentiel intrinsèque. Elle a consisté à mettre en place des technologies de conservation des eaux et des sols dans un dispositif de split-split plot en bloc dispersés chez 7 producteurs dans les 2 villages où chaque producteur constituait un bloc ou une répétition.

Il s'agit d'un essai factoriel à 3 facteurs. Le facteur principal était la technique de conservation de l'eau et du sol à 2 niveaux (ACN et bande enherbée), le deuxième facteur était constitué par le labour à 2 niveaux dont le billonnage et le grattage, et la fertilisation de trois niveaux dont le sans apport, la microdose à 1,4g par poquet (40kg $\cdot$ ha $^{-1}$) et la dose vulgarisée à 100kg $\cdot$ ha $^{-1}$. Le complexe céréale 17-17-17 a été utilisé 15 jours après la levée et en apport unique.

L'ACN est un aménagement en courbes de niveau avec des ados qui constituent le matériel de gestion du ruissellement. C'est une technologie de conservation des eaux et des sols, faite à l'échelle du champ. Sa mise en place consiste à réaliser des courbes de niveau perpendiculaires au sens de la pente puis, la construction d'un grand billon le long de chaque courbe de niveau appelé ado. La distance entre deux ados est fonction du niveau de la pente mais, la distance de 50m est conseillée pour les pentes inférieures à 1,6%. Un billonnage, qui matérialise aussi les lignes de semis, est ensuite réalisé suivant les courbes de niveau. Par définition, une courbe de niveau est une ligne joignant tous les points situés à la même altitude. Ce dispositif permet non seulement de contrôler le ruissellement, mais aussi de maintenir l'eau dans le champ pour les cultures [8]. Les courbes de

niveau permettent de réduire le ruissellement d'environ 10% de la pluviométrie annuelle, ce qui permet d'améliorer la nutrition hydrique des cultures [9].

La bande enherbée est la production d'une bande herbacée le long de la courbe de niveau. Sa réalisation consiste à semer ou repiquer une espèce d'herbacée (*Andropogon gayanus* dans notre cas) formant une bande de 1m dans notre cas contre 3 m généralement utilisée au Mali [4]. La largeur de la bande a été réduite dans notre cas après discussion avec les producteurs collaborateurs. La distance entre deux bandes enherbées était de 50 m.

La combinaison de ces trois facteurs a donné 12 niveaux dont l'ACN x Billonnage x zéro fertilisation (BBiF0), ACN x Billonnage x microdose (BBiF1), ACN x Billonnage x dose vulgarisée (BBiF3), ACN x grattage x zéro fertilisation (BGrF0), ACN x grattage x microdose (BGrF1), ACN x grattage x dose vulgarisée (BGrF3), Bande enherbée x Billonnage x zéro fertilisation (BBiF0), Bande enherbée x Billonnage x microdose (BBiF1), Bande enherbée x Billonnage x dose vulgarisée (BBiF3), Bande enherbée x grattage x zéro fertilisation (BGrF0), Bande enherbée x grattage x microdose (BGrF1), Bande enherbée x grattage x dose vulgarisée (BGrF3).

Un témoin absolu a été constitué au niveau de chaque bloc où le billonnage a été choisi comme travail du sol selon la pratique paysanne.

La superficie a été de 4000 m² (0,4 ha) par bloc. La culture utilisée a été le sorgho avec la variété Bobodjè. Les écartements se semis ont été de 0,5m entre les poquets et 0,7 m entre les lignes

Le démarrage a été fait à 3 plants par poquet.

Le complexe céréale 17-17-17 a été apporté à la dose vulgarisée de 100 kg.ha⁻¹ et à 40 kg.ha⁻¹ en micro dose 15 jours après levée suivi par un hersage. L'expérimentation a été conduite pendant deux ans de campagne agricole.

Les Paramètres observés ont concerné l'humidité volumique du sol et les rendements grain et paille du sorgho.

Humidité du sol

Les mesures étaient réalisées tous les 30 jours, du semis à la récolte en calculant le l'humidité pondérale. L'humidité pondérale (Hp) correspond au rapport entre la masse d'eau (Mw) contenue dans le sol et la masse du sol sec (Ms) où Mw = poids frais-poids sec [10]

$$HP (\%) = \frac{\text{poids frais} - \text{poids sec}}{\text{poids sec}} \quad \text{ou} \quad Hp (\%) = \frac{Mw}{Ms} * 100 \quad (1)$$

L'humidité volumique est ensuite obtenue en multipliant l'humidité pondérale par la densité apparente [11].

$$Hv (\%) = Hp \times Da \quad (2)$$

Pour ce faire, des prélèvements de sol ont été faits à la tarière dans chacun des traitements, deux échantillons ont été prélevés par traitement avec 5m d'écart entre les points de prélèvement dans le sens de la pente autour du milieu de la parcelle pour une bonne couverture de la parcelle. Ces prélèvements ont été faits dans les profondeurs de 10, 20, 40 et 60cm et cela tous les 30 jours. Les échantillons sont directement pesés après prélèvement pour avoir le poids frais puis, passés à l'étuve à 105°C pour séchage. Le choix de cette profondeur s'explique par la faible profondeur des sols de certaines parcelles de prélèvement et le profil 0 – 20 cm étant la zone la plus occupée par le système racinaire du sorgho [12].

RENDEMENTS DU SORGHO

Le rendement grain du sorgho exprimé en kg ha⁻¹ a été déterminé à la récolte. Un carré de rendement d'une surface de 6 m² a été utilisé. Pour ce faire, 2 carrés de rendement ont été placés dans chaque parcelle élémentaire. Un carré était à 5 m du milieu en haut de pente et un deuxième à 5m du milieu en bas de pente. Après récolte et battage, les grains ont été directement pesés avec une balance de précision.

Le rendement paille du sorgho (matière sèche) exprimé en kg ha⁻¹ a été déterminé dans les mêmes carrés de rendement. La paille a été séchée à l'air libre pendant 20 jours et pesée avec un peson. Le poids après séchage est le poids de la matière sèche.

L'aspect économique de la micro dose n'a pas été prise compte car, il a été traité par beaucoup d'auteurs et confirmé rentable [13].

2.3 ANALYSE DES DONNÉES

Une base de données a été constituée sous Excel 2007. Les analyses statistiques des données ont porté sur la comparaison des moyennes avec le logiciel Genstat (General statistic) en utilisant le test de Student-Newman-Keuls au seuil de 5%

3 RESULTATS

3.1 CARACTÉRISTIQUES PHYSICOCHIMIQUES DES PARCELLES

Les propriétés physicochimiques des parcelles ont été déterminées à partir des échantillons prélevés dans le profil 0 – 20 cm avant l'installation des essais. Les résultats d'analyse ont montré que sont de types soit sablo limoneux ou limono sableux avec une densité apparente comprise entre 1,57 et 1,74 (Tableau2). Le pH est compris entre 4,41et 5,88 donc, des sols acides à légèrement acides. Les sols à Zanzoni, sont plus acides que ceux de Finkoloni. Ces sols sont pauvres en matière organique avec un taux compris entre 0,02 et 0,28, Ils sont déficitaires en Azote, Potassium et Phosphore avec une CEC comprise entre 1,65 et 2,36. (tableau1).

Tableau 1. Analyse initiale des sols

Paramètres	Paysan F1	Paysan F2	Paysan F3	Paysan F4	Paysan Z1	Paysan Z2	Paysan Z3	Moy
pH (eau)	5,88	5,40	5,49	4,41	5,32	5,22	5,20	5,27
MO (C%)	0.28	0.23	0.24	0.11	0.23	0.02	0,02	0,16
N total (%N)	0,01	0,01	0,01	0,01	0,02	0,05	0,02	0,02
P assim ppm	1,07	3,70	1,69	1,43	2,56	1,58	3,15	2,17
CEC meq/100g	2,30	2,36	2,00	1,81	2,02	1,77	1,65	1,99
Ca échangeable	0,46	0,65	0,32	0,25	0,41	0,19	0,08	0,34
Mg+	0,14	0,12	0,18	0,12	0,18	0,12	0,05	0,13
K+	0,08	0,08	0,09	0,06	0,10	0,08	0,03	0,07
Na+	0,02	0,01	0,01	0,00	0,00	0,00	0,00	0,01
K assim ppm	1,28	2,23	2,14	3,21	1,25	1,36	2,45	1,99
Sable % >0,05mm	80	72	10	59	29	79	78	
Limon fin % 0,05 - 0,002mm	18	26	89	37	69	19	20	
Argile % < 0,002mm	2	2	1	4	2	2	2	
Type de sol	SL	SL	L	LS	LS	SL	SL	
Da	1,61	1,57	1,59	1,61	1,68	1,74	1,61	

3.2 EFFETS DES TECHNOLOGIES SUR LA CONSERVATION DE L'HUMIDITE DU SOL

Les aménagements ont permis une meilleure conservation de l'humidité par rapport à la parcelle non aménagée qui constituait le témoin et représentait la pratique du paysan. Les résultats ont montré que le taux d'humidité augmentait avec la profondeur et variait selon les traitements. Les figures 2, 3 et 4 présentées en fonction de la fertilisation, ont montré que plus la quantité d'engrais augmentait, plus la conservation de l'humidité était améliorée par rapport au témoin. Ainsi, avec la dose vulgarisée au niveau de l'ACN avec billonnage, des augmentations de 40% et 61,8% ont été observées, contre 31,9% et 49,7% pour la microdose et 20% et 35,2% ont été observées avec le sans apport respectivement à Zanzoni et Finkoloni. Ces résultats concernent le profil 0-20 cm (figure 2, 3 et 4). Pour chaque niveau de fertilisation, les aménagements faits avec billonnage ont été les plus performants. Ainsi, l'ACN associé au billonnage plus la dose vulgarisée a été le plus performant dans la conservation de l'humidité où on avait observé une augmentation de 40%, 42,3%, et 41,6 % de l'humidité du sol par rapport au témoin respectivement dans les profondeurs 0-20 cm, 20-40 cm et 40-60 cm, suivi de la Bande enherbée associée au billonnage plus dose vulgarisée avec une augmentation de 33,4% et 35% respectivement dans les profondeurs 0-20 cm, 20-40 cm et 40-60 cm sur le site de Zanzoni. Les mêmes tendances ont été observées sur le site de Finkoloni.

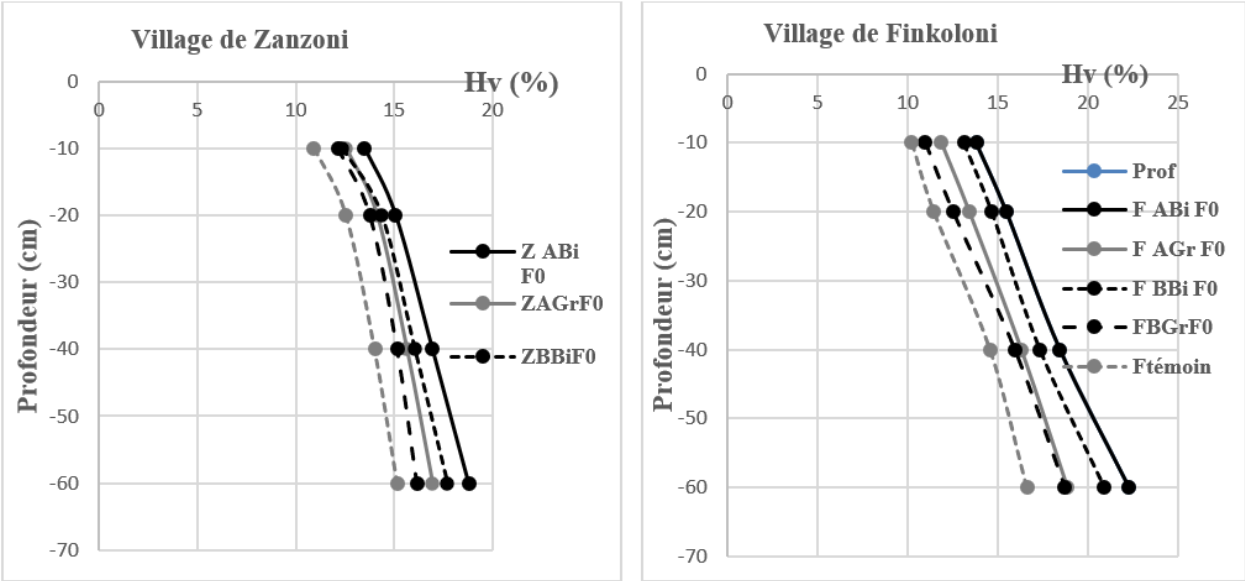


Fig. 2. Effets comparatifs des différentes techniques sur l'humidité du sol sans apport

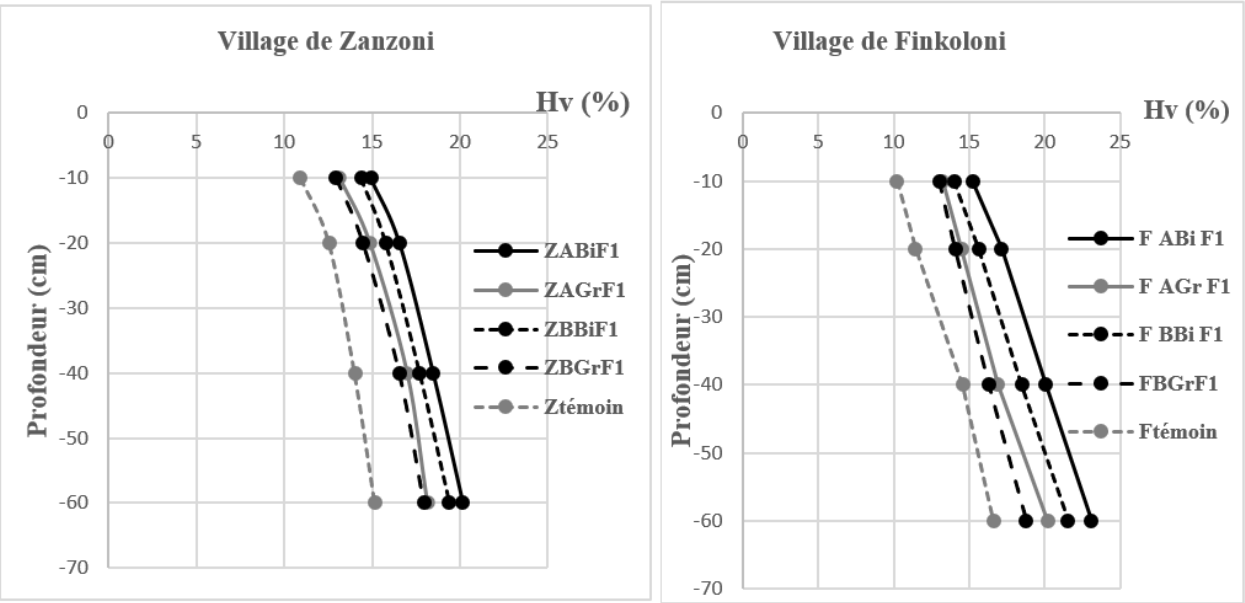


Fig. 3. Effets comparatifs des différentes techniques sur l'humidité du sol avec microdose

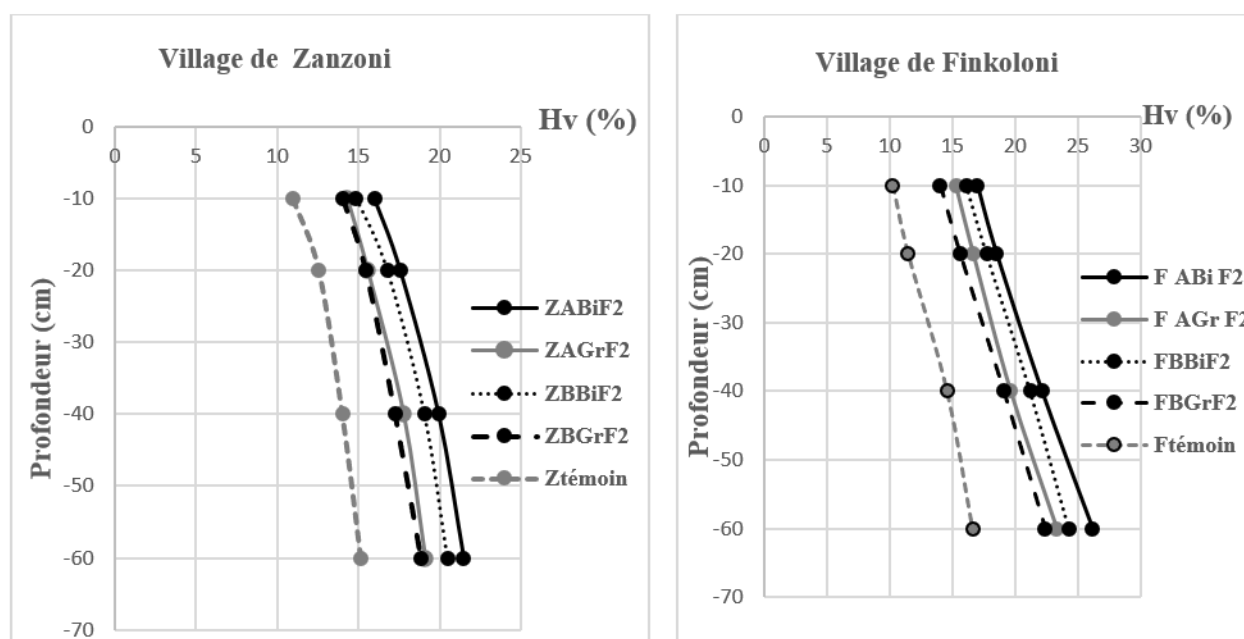


Fig. 4. Effets comparatifs des différentes techniques sur l'humidité du sol avec dose vulgarisée

Légende: ACN = Aménagement en courbe de niveau avec ado, B= Bande Enherbée, Z= Zanzoni (nom de site), F (placé en début) = Finkoloni (nom de site). ABiF signifie ACN avec Billon et Fertilisation, AGrF= ACN avec Grattage et Fertilisation, BBiF signifie Bande enherbée avec Billons et Fertilisation, BGrF = Bande enherbée avec Grattage et Fertilisation. Les chiffres 0,1,2 signifient respectivement sans apport d'engrais, Microdose et dose vulgarisée de 100 kg.ha⁻¹

3.3 EFFETS DES TECHNOLOGIES SUR LES RENDEMENTS DU SORGHO

Les résultats ont montré que les rendements du sorgho ont été augmentés dans les aménagements par rapport au témoin, avec une différence hautement significative au seuil de 5% ($p < 0,001$). Cependant, cette augmentation varie selon les facteurs. Ainsi, l'ACN avec billonnage et dose vulgarisée d'engrais a donné le meilleur rendement avec une augmentation de rendement grain de 159,3% et 195,8% pour la paille, suivi de la bande enherbée avec billonnage et dose vulgarisée 121,4% et 176,5% respectivement pour les rendements grain et paille. L'ACN avec billonnage et microdose et la Bande enherbée avec grattage et dose vulgarisée se trouvent dans un même groupe avec une augmentation de 107,5% et 101,3% pour le grain et 165,9% et 157,9% pour la paille respectivement. Puis, suivent successivement les traitements Bande enherbée avec billonnage et micro dose 90,5% et 145,6%, Bande enherbée avec grattage et dose vulgarisée 84,9% et 135,3%, ACN avec grattage et micro dose 73,6%) et 116,2%, Bande enherbée avec grattage et microdose 62% pour le grain. Ces premiers traitements qui ont eu un effet important sur les rendements du sorgho n'ont concerné que la fertilisation avec dose vulgarisée et micro dose. Cependant, tous les traitements sans fertilisation ont aussi observé une augmentation de rendement par rapport au témoin. Ainsi, le traitement ACN avec billonnage et sans fertilisation a induit une augmentation de rendement grain de 99,2% puis, viennent respectivement les traitements Bande enherbée avec billonnage sans fertilisation 49,3% et 71,2%, l'ACN avec grattage sans fertilisation au niveau du grain 37,5% et 45,7 et la Bande enherbée avec grattage sans fertilisation 25,1% et 31,2% par rapport au témoin absolu (tableau 2,3). Pour classer les traitements suivant leur efficacité dans l'augmentation des rendements du sorgho, des groupes homogènes ont été constitués suivant la méthode de Student-Newman-Keuls (tableaux 2, 3).

Tableau 2. Effets des technologies sur le rendement grain du sorgho

Traitements	Rdmt_grain (kg.ha-1)	Aug (%)
ACN x Billonnage x Dose vulgarisée	1289,5 a	159,3
BE x Billonnage x Dose vulgarisée	1100,9 b	121,4
ACN x Billonnage x Micro dose	1031,9 c	107,5
ACN x Grattage x Dose Vulgarisée	1001,2 c	101,3
BE x Billonnage x Micro dose	947,6 d	90,5
BE x Grattage x Dose vulgarisée	919,3 d	84,9
ACN x Grattage x Micro dose	863,1 e	73,6
BE x Grattage x Micro dose	805,6 f	62,0
ACN x Billonnage x sans fertilisation	786,9 f	58,2
BE x Billonnage x Sans fertilisation	742,6 f	49,3
ACN x Grattage x Sans fertilisation	683,9 g	37,5
BE x Grattage x Sans fertilisation	622,1 h	25,1
Témoin	497,3 i	-
Moyenne	797,5	
Probabilité	0,001	
Signification	THS	
CV%	8,9	

Tableau 3. Effets des technologies sur le rendement paille du sorgho

Traitement	Rdmt_Paille (Kg.ha ⁻¹)	Aug (%)
ACN x Billonnage x Dose vulgarisée	8329 a	195,8
BE x Billonnage x Dose vulgarisée	7786 b	176,5
ACN x Billonnage x Micro dose	7487 bc	165,9
ACN x Grattage x Dose Vulgarisée	7263 c	157,9
BE x Billonnage x Micro dose	6915 d	145,6
BE x Grattage x Dose vulgarisée	6626 d	135,3
ACN x Grattage x Micro dose	6088 e	116,2
ACN x Billonnage x Sans fertilisation	5609 f	99,2
BE x Grattage x Micro dose	5443 f	93,3
BE x Billonnage x Sans fertilisation	4822 g	71,2
ACN x Grattage x Sans fertilisation	4102 h	45,7
BE x Grattage x Sans fertilisation	3694 i	31,2
Témoin	2816 j	-
Moyenne	5338	
Probabilité	0,001	
Signification	HS	
CV%	7,6	

Légende: Rdmt = rendement, ACN = Aménagement en courbes de niveau avec ado, Aug = Augmentation, BE = Bande Enherbée, HS= hautement significatif, CV%= Coefficient de Variation. Les lettres (a, b, c, d,...k) désignent les classes.

4 DISCUSSION

4.1 CARACTÉRISTIQUES PHYSICOCHIMIQUES DES PARCELLES

Les résultats ont montré que le niveau de fertilité des sols de ces terroirs est faible avec une carence en phosphore assimilable, potassium assimilable, un taux faible en Azote. Le taux d'argile est faible mais également de type kaolinique, un taux en matière organique faible et un pH légèrement bas. Ces résultats sont conformes à ceux des références [14] à Zanzoni

et [15] en zone sahélienne. Les résultats d'analyse du sol ont permis de classer les sols d'étude dans les sols sablo limoneux et limono sableux. Cette faible fertilité des sols est tout d'abord liée aux types de sol qui, dans cette zone, sont des sols ferrugineux tropicaux lessivés, de classes texturales sableuse, sablo limoneuse ou limono sableuse [16], mais aussi à son type d'argile qui est kaolinique et les pratiques paysannes. La production insuffisante de la fumure organique en est une cause. Des études sur ces types de sol dans l'horizon 0-20cm à Kolokani et Diema au Nord-ouest du Mali et au Burkina Faso ont montré des niveaux faibles de matière organique, de phosphore, d'Azote et de CEC [17].

4.2 EFFETS DES TECHNOLOGIES SUR LA CONSERVATION DE L'EAU

La majorité des champs dans la zone d'étude sont au niveau des glacis où le ruissellement est généralement en nappe créant par endroit des griffes. Les dispositifs d'aménagement pour la conservation des eaux et des sols ont permis de conserver l'eau pour les plantes par rapport au témoin. Ces résultats corroborent ceux de la référence [6], qui ont montré une meilleure conservation de l'eau par les aménagements en courbe de niveau à Konobougou. Cependant ce niveau de conservation de l'humidité diffère en fonction des facteurs appliqués. Dans ces aménagements, l'utilisation des ados avec billonnage a permis la meilleure conservation de l'humidité dans la parcelle. Les résultats sont en accord avec ceux de la référence [18] qui avaient obtenu une augmentation de 10% d'infiltration des eaux de pluies dus aux ados et billons (ACN) au Sud du Mali. Ce fait s'expliquerait par la grande capacité des ados à retenir les eaux de pluie dans la parcelle par rapport aux bandes enherbées qui laissent une certaine marge d'écoulement des eaux. Des travaux de [19] avaient abouti à des résultats similaires à Kani et Nounpinesso. Les bandes enherbées permettent aussi une réduction importante du ruissellement [20]. Quant au billonnage comme travail du sol, son efficacité dans la conservation de l'humidité s'expliquerait par le fait que l'eau de pluie est maintenue dans les sillons de façon uniforme à travers la parcelle, les billons étant réalisés suivant la courbe de niveau. Ainsi, l'eau s'infiltre progressivement, ce qui permet une bonne recharge de la nappe réduisant les effets des poches de sécheresse. Des augmentations de 31% d'humidité dans la parcelle billonnée par rapport au témoin avaient été trouvées à l'est du Kenya [21]. Quant au grattage, il permet certes de remuer la parcelle, mais conserve moins les eaux de pluie que les billons. Dans ce cas, ce sont les ados et les bandes enherbées qui vont jouer le grand rôle de rétention d'eau jusqu'au buttage des cultures, qui a lieu 45 à 60 jours après semis. Cependant, le grattage dans les aménagements en ados ou en bandes enherbées, ont permis une meilleure conservation de l'humidité par rapport au témoin. Au niveau de la fertilisation, l'effet combiné des aménagements avec la dose vulgarisée a été plus efficace dans l'amélioration de la conservation de l'humidité. Les engrais minéraux permettent de renforcer le réservoir du sol en éléments nutritifs et leurs éléments sont plus disponibles pour les plantes. Ces engrais minéraux sont plus fournis en quantité à travers l'apport vulgarisé, ce qui a permis un meilleur développement des cultures, qui vont rapidement couvrir le sol pour limiter l'évaporation et l'agression des pluies. Ainsi, l'humidité est plus conservée [22]. Quant à la microdose, elle a permis une meilleure conservation de l'humidité par rapport au sans apport et au témoin à cause de la production de biomasse.

4.3 EFFETS DES TECHNOLOGIES SUR LES RENDEMENTS DU SORGHO

Les technologies évaluées ont permis d'augmenter les rendements grain et paille du sorgho quel que soit le travail du sol ou le niveau de fertilisation. Ces résultats corroborent ceux de [23] sur l'effet des aménagements en bandes enherbées sur le rendement du sorgho au Burkina et de [6] qui avaient trouvé des augmentations de rendements grain de sorgho de 85% en 2013 et 58% en 2014 dues aux ACNs dans la commune de Zinzana. Des augmentations respectivement de 19% et 21% de rendements grain et paille du sorgho due aux aménagements en courbe de niveau avaient été obtenues à Kani [24]. Les résultats obtenus sont conformes avec ceux de [1] qui ont montré que les aménagements en courbe de niveau ont augmenté le rendement grain du maïs de 87% par rapport au témoin à Koutiala et Bougouni.

Dans les aménagements, les eaux de pluie sont maintenues dans la parcelle pour s'infiltrer sur place. Ce processus favorise non seulement la bonne alimentation des plantes en eau et en éléments nutritifs, mais aussi une bonne charge des nappes qui par remontée capillaire, permet d'amoindrir les effets des périodes de sécheresse [25]. Quant au travail du sol, le grand effet du billonnage sur les rendements s'expliquerait par le fait que lors de la formation des billons, toutes les matières organiques et d'autres matériaux (résidus végétation) sont concentrés dans et sous le billon, permettant une libération graduelle des éléments minéraux pour les plantes [26]. Ces aménagements associés à la fertilisation minérale ont permis d'améliorer d'avantage les rendements grain et paille de la culture et selon le niveau de fertilisation [27]. Ces résultats corroborent ceux de [28] qui ont montré une augmentation de rendements grain et paille du maïs, sorgho et mil dans des aménagements en courbe de niveau avec ado, combinés avec la fertilisation. La référence [9] avait obtenu des résultats similaires sur le coton avec une augmentation de

584 kg.ha⁻¹ de coton graine avec effet combiné de la fertilisation. C'est ainsi que les traitements avec billonnage et dose vulgarisée, ont donnés les meilleurs rendements. Ceux avec micro dose ont permis d'augmenter significativement les

rendements par rapport aux traitements sans apports et le témoin. Ces résultats corroborent ceux de [17] à Kolokani et Diema, [29] à Sotuba, Kopro-pen et Madina Kagora au Mali et de [30] au Burkina Faso sur le sorgho. Cependant, la microdose avec 1,4g/poquet a donné des rendements inférieurs à ceux de la dose vulgarisée (100kg.ha⁻¹). Ces résultats sont confirmés par ceux de [31] qui avaient utilisé 1,5 g/poquet. Tous les traitements ont permis une augmentation de rendements grain et paille par rapport au témoin.

5 CONCLUSION

Dans un contexte difficile pour une meilleure production de céréales dans la zone soudanienne du Mali, il est impératif de conjuguer les efforts en vue de développer des technologies diversifiées et mieux adaptées aux conditions socioéconomiques des producteurs. La présente étude est faite dans ce cadre en vue de contribuer à l'amélioration de la productivité du sorgho. Il ressort de l'étude que les aménagements avec ado et les bandes enherbées sont efficaces dans la conservation de l'humidité et l'amélioration des rendements de sorgho quel que soit le type de travail du sol. Ainsi, à travers les différents traitements, une gamme de techniques appliquées en courbes de niveau s'est avérée performante dans la conservation des eaux de pluies et l'augmentation des rendements de sorgho dont les plus efficaces ont été l'aménagement avec ado couplé au billonnage avec la dose vulgarisée (ABiF2) et la bande enherbée associée au billonnage avec dose vulgarisée (BBiF2). Ces résultats permettront aux producteurs une bonne gestion de la fertilité de leurs sols en vue d'une meilleure production végétale. Ainsi, le producteur, en fonction de ses moyens ou de son objectif d'intensification, pourra en faire un choix. Cette étude mérite d'être conduite dans d'autres zones et sur d'autres spéculations comme le maïs en variant la quantité d'engrais en microdose.

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CONFLIT D'INTERET

Tous les auteurs déclarent aucun conflit d'intérêt

CONTRIBUTION DES AUTEURS

Dr. Kalifa TRAORE a contribué à l'élaboration du protocole expérimental, la lecture et amendement de l'article, Pr. Boubakar BENGALY a participé au suivi de l'activité, à la correction de l'article

REFERENCES

- [1] Traoré K., Birhanu Z. B. Soil erosion control and conservation of moisture using contour ridge tillage in Bougouni and Koutiala, southern Mali, *Journal of environmental protection (TSI)*, 10 (10), 1333-1360, 2019.
- [2] Brabant P. Activités humaines et dégradation des terres, indicateurs et indices, IRD, Planète terre, 369p, 2008.
- [3] BACYE B., KAMBIRE H. S., SOME A. S. Effets des pratiques paysannes de fertilisation sur les caractéristiques chimiques d'un sol ferrugineux tropical lessivé en zone cotonnière à l'Ouest du Burkina Faso, *International Journal of Biological and Chemical Sciences* 13 (6), 2930-2941, 12P, 2019.
- [4] Ba L., Campen V., Hijkoop J., Poel P. V., Kaya D. Le Sahel en lutte contre la désertification; Leçons d'expériences, GIZ, P.369 – 387, 1988.
- [5] Gigou J. et Coulibaly L. F. Aménagement des champs pour la culture en courbe de niveau au sud du Mali, 14P, 1997.
- [6] Traoré K., Sidibé D. K., Coulibaly H., Bayala J. Optimizing yield of improved varieties of millet and sorghum under highly variable rainfall conditions using contour ridges in Cinzana, Mali, *Agriculture & Food security*, 11 (6), 13p, 2017.
- [7] Soumaré M., Bazile D., Kouressy M., Vaksman M., Diallo K., Diakité C. H. Diversité agroécosystémique et devenir des céréales traditionnelles au sud du Mali, *Caractérisation de l'agrobiodiversité de l'agrosystème aux gènes*, Cahiers Agricultures, 17 (2), 79 – 85, 2008.

- [8] Traoré K., Gigou J. Yamada M., Samaké O., Coulibaly H., Doumbia M. Aménagement en courbes de niveau pour la conservation des sols en champs paysans, Guide pour la gestion et la conservation des ressources naturelles, Fiche technique, 16P, 2012.
- [9] Gigou J., Traoré K., Giraudy F., Coulibaly H., Sogoba B., Doumbia M. Aménagement paysan des terres et réduction du ruissellement dans les savanes africaines, Cahier Agricultures, N°1 - Vol15, 7P, 2006.
- [10] Braund A. et Coquet Y. Les sols et le cycle de l'eau, chapitre 15, CNRS-ISTO et INRA, 23P, 2005.
- [11] Burgaud J. C., Silvera N., Faye A. Mesure de l'humidité des sols, Evaluation de la consommation en eau sous couvert des cocotiers à Port Bouët, ORSTOM, 1986.
- [12] Weill A., Roy-Fortin V. Evaluation du système racinaire de quatre mélanges d'engrais vert pour réduire la compaction, Rapport final, Projet 11-INNO1-07, CETAB+, 36p, 2014.
- [13] Kelly V., Diakité L., Teme B. Sorghum productivity in Mali: Pas, Present and Futur, MSU International Development Working Paper 138, MICHIGAN STATE UNIVERSITY, 84p, 2015.
- [14] Guindo M., Traoré B., Birhanu B. Z., Coulibaly A., Tabo A. R. Microdosing of Compost for Sustainable Production of Improved Sorghum in Southern Mali, *Agronomy*, 12, 1480. <https://doi.org/10.3390/agronomy12061480>, 15p, 2022.
- [15] Kouyaté A. B., Sermé I. Evaluation de l'efficacité du Phosphate Naturel de Tilemsi (PNT) sous différentes pratiques de travail du sol en zone Sahélienne du Mali, *International journal of Innovation and Applied Studies*, 34 (4), 845-857, 2021.
- [16] Ngoudjeb Y., Nje P., Havard M. Déterminants de l'adoption des techniques de lutte contre l'érosion hydrique en zone cotonnière du Cameroun, *Recherche Innovation-Agriculture Elevage*, 12P, 2011.
- [17] Zéromé M., Traoré K., Famanta M., Maïga B. S., Samaké O., Togo M. A. Effets de l'aménagement en courbe de niveau avec différentes doses de fertilisation sur les rendements du sorgho dans les localités de Kolokani et de Diéma au Mali, *In. J. Biol. Chem. Sci.* 13 (3), 1547-1557, 2019.
- [18] Birhanu B. Z., Traoré K., Sanogo K., Tabo R., Fischer G., Whitbread A. M. Contour bunding technology – evident and experience in the semiarid region of southern Mali, *Renewable Agriculture and Food Systems*, 9P, 2020.
- [19] Dembélé C. O., Traoré K., Karembé M., Zemadim B., Samaké O. Contour ridge tillage for improved crops and fodder trees production in the villages of Kani and Noupinesso, southern - Mali, *Journal of agricultural studies*, 9 (2), 550-572P, 2021.
- [20] Zougmore R., Ouattara A., Mando A., Ouattara B. Rôle des nutriments dans le succès des techniques de conservation des eaux et des sols (cordons pierreux, bandes enherbées, Zaï, et demi-lunes) au Burkina Faso, *SECHERESSE*, 15 (1), P. 41-48, 2004.
- [21] Musyimi D., Ouma E. O., Too E. J., Ngode L., Kamau C. K., Gudu S. Effet of ridging and intercropping on sorghum productivity in arid and semi- arid lands of Eastern Kenya, *African Crop Science Journal* 30 (1), 87 – 100, 2022.
- [22] Sissoko F., Traoré A., Ouattara B., Ouédraogo S. Analyse des flux d'eau dans les systèmes de culture à base de sorgho dans un contexte de changement climatique (N'Tarla, Mali), Chapitre 21, *Risques climatiques et agriculture en Afrique de l'ouest*, 277 – 287, 2020.
- [23] Da C. E.D. Impact des techniques de conservation des eaux et des sols sur le rendement du sorgho au centre-nord du Burkina Faso, *Cahier d'Outre-Mer, Revue de géographie de Bordeaux*, 61 (241-242), 99-110, 2008.
- [24] Dembélé C. O., Traoré K., Karembé M., Zemadim B., Samaké O. Intercropping sorghum and soybean efficiency using contour ridge technology in southern Mali, *Journal agricultural science*, 14 (4), 126-135, 2022.
- [25] Traoré, K. B, Gigou, J. S, Coulibaly, H., Doumbia, M.D. Le travail du sol sur billons profilés augmente les rendements céréaliers et la séquestration du carbone, 13e Conférence internationale de l'organisation de conservation des sols – Brisbane, 6p, 2004.
- [26] Sawadogo H., Kini J. Revue de littérature sur les techniques de conservation des eaux et des sols au Burkina Faso, *Revue des technologies au Burkina Faso, Institut de l'Environnement et de Recherches Agricoles (IN. R. A)*, 19P, 2011.
- [27] Ouedraogo J., Sermé I., Pouya M. B., Sanou S. B., Ouattara K., Lompo F. Amélioration de la production du sorgho par l'introduction d'options technologiques de gestion intégrée de la fertilité des sols en zone Nord soudanienne du Burkina Faso, *In. J. Biol. Chem. Sci.* 14 (9), 3262-3274, 2020.
- [28] Traoré K. B, McCarthy G., Gigou J. S., Doumbia M. D., Bagayoko A. et al. Aménagement en courbes de niveau et conservation du carbone, 10P, 2004.
- [29] Coulibaly A., Woumou K., Aune J. B. Sustainable Intensification of Sorghum and Pearl Millet Production by Seed Priming, Seed Treatment and Fertilizer Microdosing under Different Rainfall regimes in Mali, *Agronomy*, MDPI, 14P, 2019.
- [30] Saba F., Taonda J. B., Sermé I., Bandaogo A. A., Sourwema A. P., Kabré A. Effets de la microdose sur la production du niébé, du mil et du sorgho en fonction e la topséquence, *International Journal of Biological and Chemical*, 11 (5), Sciences, 2082-2092, 2017.
- [31] Somda B. B., Badiori O., Idriss S., Mathias B. P., François L., Taonda S. J. B., Sedogo P. M. Détermination des doses optimales de fumure organo-minérale en microdose dans la zone soudano sahélienne du Burkina Faso, *Int. J. Biol. Chem. Sci.* 11 (2), 670-683, 2017.

- [32] Pautrot C. Erosion et dégradation des sols, La seille en Crue à Metz, Mémoires de l'Académie Nationale de Metz, 20P, 2012.
- [33] Taonda S. J. B, Bertrand R., Dickey J., Morel J. L., Sanon K. Dégradation des sols en agriculture minière au Burkina Faso, Cahiers agricultures 4-363-9, 7p, 1995.

