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ARTICLE

Establishment of Fungal Decomposition Model Based on OLS and Logistic Model

Mingkai Zhou Bingjie Sun Wentao Wu*

North University of China, Taiyuan, Shanxi, 030051, China

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ABSTRACT

By using the OLS model, an equation for the rate of decomposing wood by a variety of fungi was established. We analyzed the effects of various fungi in the experimental data under different temperature and humidity. Based on the growth performance of different fungi at different temperatures and humidity, we use the method of systematic cluster to divide the fungi into 5 categories, and introduce competition levels as the viability of different species of fungi. We have established a logistic model that introduces competition levels to obtain a fungal habitat model. The fungal habitat model includes predictions about the relative advantages and disadvantages for each species and combinations of species likely to persist, and do so for different environments including arid, semi-arid, temperate, arboreal, and tropical rain forests.

1. Introduction

1.1 Problem Background

Fungi account for 81-95% of soil microbial biomass^[1], which play a key role in the plant-soil-atmosphere carbon cycle, but unfortunately have not received much attention. Undoubtedly, the study of the role of fungi in the carbon cycle of terrestrial ecosystems is of great significance to our understanding of the mechanisms by which organisms regulate the global carbon cycle. A key component of the carbon cycle is the decomposition of plants and wood fibers, so it is necessary to study the role of fungi in the decomposition of wood fibers and the fungal traits that determine the rate of decomposition during the process.

A recent article about fungi decompose lumber^[2], in the laboratory, analysis of 34 kinds of rot fungi, from North America and in combination with a 5 years of field research, the research which properties can affect the fungal decomposition rate, come to a conclusion: the effect of fungal growth rate for wood decomposition rate effect is strongest, and to individuals, decomposition rate, and negatively correlated with wet resistance. Below are pictures of the fungus we used in our paper:

1.2 Restatement of the Problem

Considering the background information and restricted conditions identified in the problem statement, we need to solve the following problems:

*Corresponding Author:

Wentao Wu,

North University of China, Taiyuan, Shanxi, 030051, China;

Email: 2396352599@qq.com

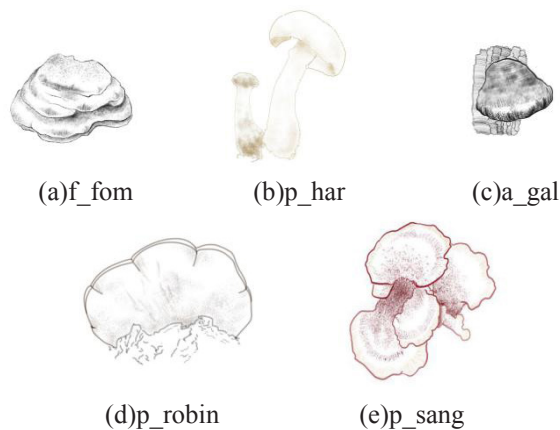


Figure 1. Pictures of fungi

(To avoid copyright infringement, we draw and generate Figure 1 on our own)

- In general, a mathematical model is set up, to describe fungal activity effects on litter and wood fiber.
- Further thinking about how to represent in the model and growth rate and how to make different fungi during the merger process.
- We need to build model is: under the same initial conditions, what will happen between different types of fungal evolution of types of community. The short - term and long - term trends of the interaction are obtained. And to study whether small changes in initial conditions will affect the different trends of subsequent community evolution. For example, a fungus goes from being an advantage to a disadvantage. It is further considered to add initial environmental factors into the model to further assist the influence of local weather pattern changes on the model.
- Using model for each species or could continue for a period of time the combination of comparative advantage, disadvantage, and in different circumstances.
- The model is used to analyze the influence of the number of fungi species on the overall efficiency of the ground waste classification system, and to analyze and predict the influence of biodiversity when the environment changes to different degrees.

2. Assumptions and Justifications

- We assume that environmental resources are limited, and there is only competition between different species, and there is no other relationship.
- Fungal growth is affected by a variety of variables ^[4], but we only take into account temperature and humidity and the moisture tolerance, growth rate and decomposition rate of the fungus itself. The influence of other factors on the growth of fungi, such as pH, oxygen concentration, carbon dioxide concentration, REDOX potential, and the utilization

tion of required substances, were not considered.

- When we think about environmental change, we only think about temperature and humidity. As we know from the literature given by the title: temperature has a strong correlation with the decomposition rate, and the fungus growth rate has the strongest effect on the decomposition rate of wood, and the moisture resistance also has a strong negative correlation with the decomposition rate ^[5].

3. Method

3.1 Notations

The key mathematical notations used in this paper are listed in Table 1.

Table 1. Notations used in this paper

Variable	Description	Unit
σ_i	The competitive factor of the i th fungus	-
$x_i(t)$	The initial number of fungus at time t	-
$x_i(0)$	The number of the i th fungus at $t = 0$	-
N_i	The maximum number of species i in the initial environment	-
r_i	The growth rate of species i	-
r_{i0}	The growth rate of the i th species at the initial moment	-
AI	de Martonne Dry index	-
P	Mean precipitation	mm
T	The average temperature	°C
α	Competitive factors after introducing environmental variables	-
Y	Mass loss over 122 days (% dry weight), geometric mean across 10, 16, and 22 °C	-
x_1	Linear extension rate	(mm day ⁻¹)
Hyphal density	Dry mass ($\mu\text{g cm}^{-2}$) at 1 cm from the edge of the growing front	-

3.2 Wood Decomposition Rate Model

Given the decomposition of wood ^[7] is a key factor in a variety of fungal activity, it can be judged that there is a mathematical relationship between the growth of fungi and the rate of wood decomposition. In this model, we limit the focus to the discussion: in the presence of a variety of fungi, to study the factors affecting the rate of wood decomposition.

3.2.1 Establishment of Wood Decomposition Rate Model

According to Nicky Lustenhouwer's research ^[2], the main factors affecting the decomposition rate of fungi

are the growth rate and moisture resistance. And different kinds of fungi also have different decomposition rates. Based on these three factors of fungal decomposition. We use multiple linear regression (OLS) to build a model without considering environmental factors. We use this equation to describe the quantitative relationship between fungal decomposition rate and other variables. We first standardize the data to remove the impact of different dimensions. Building the following OLS model [8]:

$$\begin{cases} y_1 = \beta_0 + \beta_1 x_{11} + \beta_2 x_{12} + \cdots + \beta_p x_{1p} \\ y_2 = \beta_0 + \beta_1 x_{21} + \beta_2 x_{22} + \cdots + \beta_p x_{2p} \\ \vdots \\ y_n = \beta_0 + \beta_1 x_{n1} + \beta_2 x_{n2} + \cdots + \beta_p x_{np} \end{cases}$$

In this model, y_n represents the decomposition rate [16] of the fungus, The independent variable X_{nn} is the factor that affects the rate of fungal decomposition. X_{n1} represents growth rate. X_{n2} represents Moisture resistance. X_{n3} to X_{nn} represents fungus species (Fungus species as a qualitative variable, using dummy variables to describe). And β is the coefficient of multiple linear regression.

3.2.2 Solution of Wood Decomposition Rate Model

Regression using 20 sets ($x_{11}, x_{21}, x_{31}, \dots, x_{201}$) of observations. The table is part of the data obtained by regression:

Table 2. OLS results

	β_1	β_2	β_3	β_4
result	0.77	-0.34	0.05	0

The equation obtained through OLS regression can describe the relationship between each independent variable and the dependent variable. In the same environment and without considering interaction, analyzing the regression results, we can get that the decomposition rate of most bacteria is not much different. The coefficient value before the dummy variable is relatively small, indicating that the type of bacteria has a limited influence on the decomposition rate. The growth rate of the bacteria has a greater impact on the decomposition rate of the bacteria, and the coefficient before the variable is 0.77. Indicates that the faster the bacteria grow, the faster the decomposition rate. The humidity has a negative correlation with the decomposition rate.

3.2.3 Checking of Model Wood Decomposition Rate Model

Since the data are cross-sectional data, heteroscedasticity may occur. Compared with BP test, the White test can test various forms of heteroscedasticity. Therefore, we perform

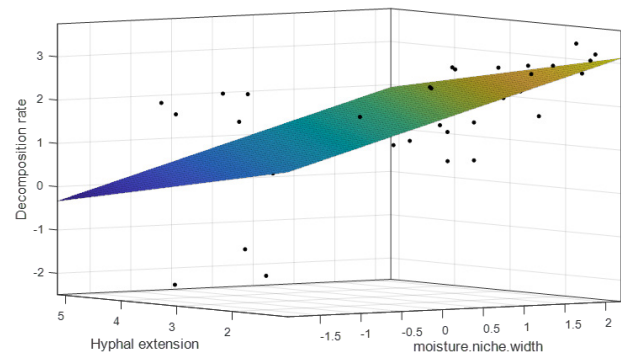


Figure 2. Simplified multivariate equation image

Table 3. White test

	Chi2(151)	Probin>chi2
result	28	0.4658

White's test on the multivariate linear equation to check whether the equation has heteroscedasticity. White test results are as follows:

The P value is greater than 0.05, and the null hypothesis is rejected at the 95% confidence level. We believe that the disturbance term has no heteroscedasticity. Then check the multicollinearity of the equation, see the appendix for the results. Its mean VIF is 8.91, which is less than 10. Therefore, we believe that there is no multicollinearity in the equation.

3.3 Clustering and Growth Competition Model

3.3.1 Fungi Cluster Model

Establishment of Fungi Cluster Model

We used systematic cluster analysis to classify the fungi in the data. We take the optimum temperature and humidity for the fungus to survive as indicators [13]. And standardized it before the algorithm to eliminate unreasonable clustering results caused by large dimensional differences.

$$d(\vec{x}_i, \vec{x}_j) = \sqrt{\sum_{k=1}^p (x_{ik} - x_{jk})^2}$$

Combine the two data points that are closest to each other, and iterate over and over again. We do this until we put all the data points together. Finally, the cluster spectra are generated and the results are obtained.

Solution of The Establishment of Fungi Cluster Model

We can use Elbow Method when we choose the final category total, Here's how it works: assume a value, That is, assume the largest possible number of class clusters, and then increase the number of class clusters from 1 to i. After calculating, we get i value of SSE, Based on the underlying pattern of the data, When the set number of

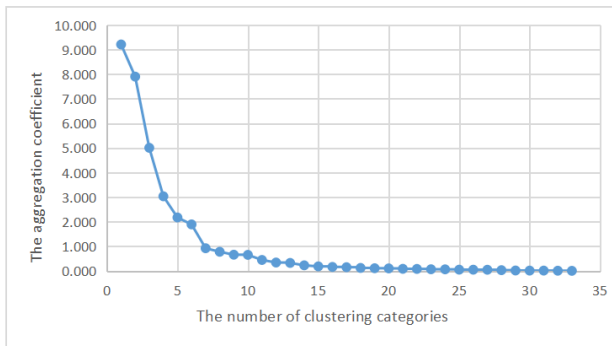


Figure 3. pedigree diagram

class clusters keeps approaching the real number of class clusters, When the set number of class clusters keeps approaching the real number of class clusters SSE, It shows a trend of rapid decline. When the set number of class clusters exceeds the real number of class clusters, SSE will go down. But there is no rapid decline, So by looking for an inflection point in the SSE minus K curve, you can effectively find the value of K.

According to the Polymerization coefficient line chart, We can draw the conclusion: When K changes from 0 to 5, the distortion degree changes the most. When K exceeds 5,

the variation of distortion degree decreases significantly, and the downward trend of broken lines gradually slows down. We can set the number of categories as 5.

Figure 4 shows the clustering results, and there are 5 types of copolymerization. The list is as follows:

Table 4. Compete for league tables

Fungal species	Group 1 fungi	Group 2 fungi	Group 3 fungi	Group 4 fungi	Group 5 fungi
Optimal temperature	normal	high	high	low	high
Optimum humidity	dry	semi-arid	wet	semi-arid	semi-arid

3.3.2 Logistic-Based Fungal Growth Competition Model

Establishment of Logistic-Based Fungal Growth Competition Model

We define σ_i as the competitive factor for the i th fungus, $x_i(t)$ is the initial number of the i th fungus at time t , $x_i(0)$ is the number of the i th species at time $t=0$, N_i is the maximum number of the i th species in the initial environment, r_i is the growth rate of species I , r_{i0} is the growth rate

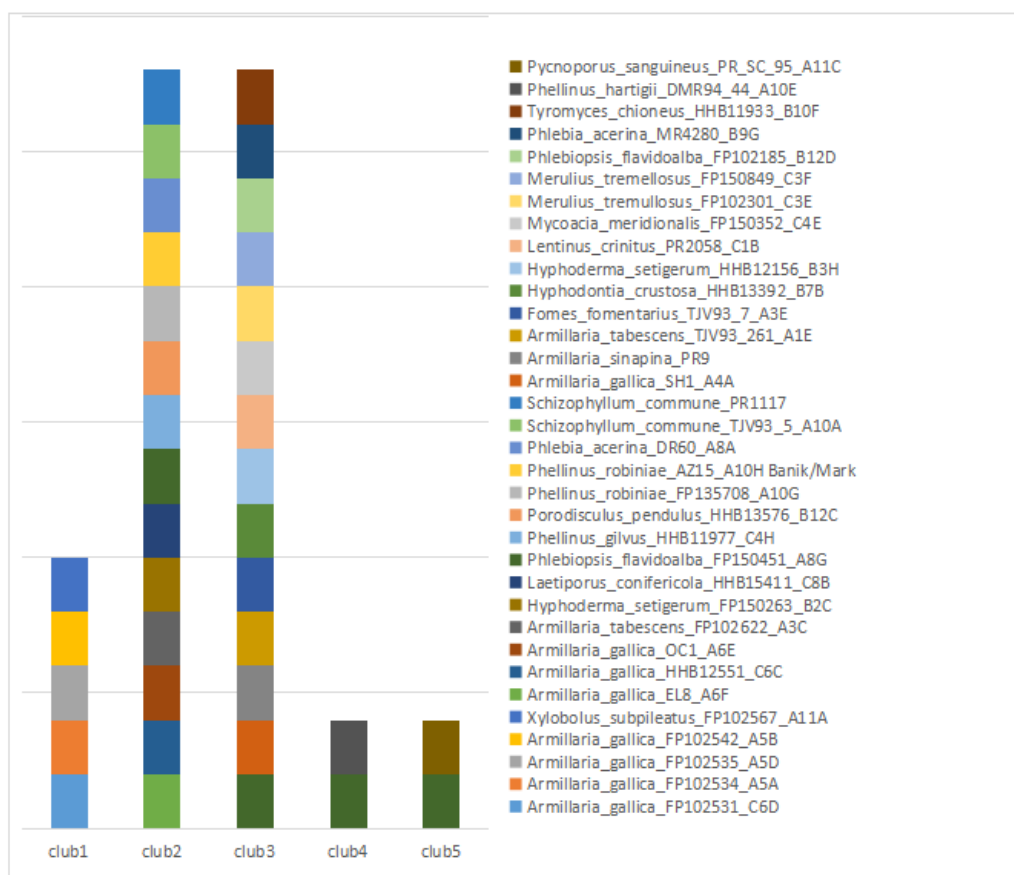


Figure 4. Cluster analysis result diagram

of the i th species at the initial moment.

We further assume that environmental resources are finite, The relationship between I species of fungi is competitive relationship, The initial numbers of different fungi were equal and the maximum number of different fungi in the initial environment was the same, Assume that the growth rate of the i th fungus is 0 under the initial environment.

Consider two species competing with each other as they survive with limited natural resources (let's consider the first and second fungi first). If the effect of the second fungus is not considered, the population change of the first fungus obeys that:

$$\frac{dx_1(t)}{dt} = r_1 x_1 \left(1 - \frac{x_1}{N_1} \right)$$

Where, the factor that $1 - x_1/N_1$ reflects the retarding effect of the first fungus on its own growth due to the consumption of limited resources. If we add to that the competing effects of a second fungus, It means that the second fungus's consumption of food affects the growth of the first fungus, So we change the factor to this:

$$1 - \frac{x_1}{N_1} - \sigma_1 \frac{x_2}{N_2}$$

So this is the conclusion of the first fungus:

$$\frac{dx_1(t)}{dt} = r_1 x_1 \left(1 - \frac{x_1}{N_1} - \sigma_1 \frac{x_2}{N_2} \right)$$

Similarly, this is the conclusion of the second fungus:

$$\frac{dx_2(t)}{dt} = r_2 x_2 \left(1 - \frac{x_2}{N_2} - \sigma_2 \frac{x_1}{N_1} \right)$$

When n species of fungi survive under the condition

of limited natural environmental resources, they compete with each other, For $1 \sim N$ species of fungi, there are the following formulas:

$$\begin{cases} \frac{dx_1(t)}{dt} = r_1 x_1 \left(1 - \frac{x_1}{N_1} - \frac{\sigma_1}{N} \sum_{i=2}^n x_i \right) \\ \vdots \\ \frac{dx_n(t)}{dt} = r_n x_n \left(1 - \frac{x_n}{N_n} - \frac{\sigma_n}{N} \sum_{i=2}^n x_i \right) \end{cases}$$

Solution of Logistic-Based Fungal Growth Competition Model

In the previous paper we divided 34 fungi into five groups, namely $n=1,2,3,4,5$, but we will consider only the first group of five fungi here. So we get the results of the growth of five fungi in the same environment:

Through Figure 5, there is little difference in their optimal temperature, but there are differences when they grow in the same environment. This also supports our hypothesis that there is competition between the fungi.

The reason there are only three curves in the figure is: The three types of fungi, a.gal1.s, a.gal2.s, a.gal3.s, compete in the same ranking, so the competitiveness is almost the same. It causes the curves to overlap. We further conclude that: At the same temperature and humidity, these three fungi are at a disadvantage. Their numbers are slowly declining and could be zero in the future. The most dominant fungus, A. Sub. S, is increasing in number. When $t=15h$, the increasing trend of quantity tends to be stable. The fifth fungus, A. gal5.s, has a slight edge over

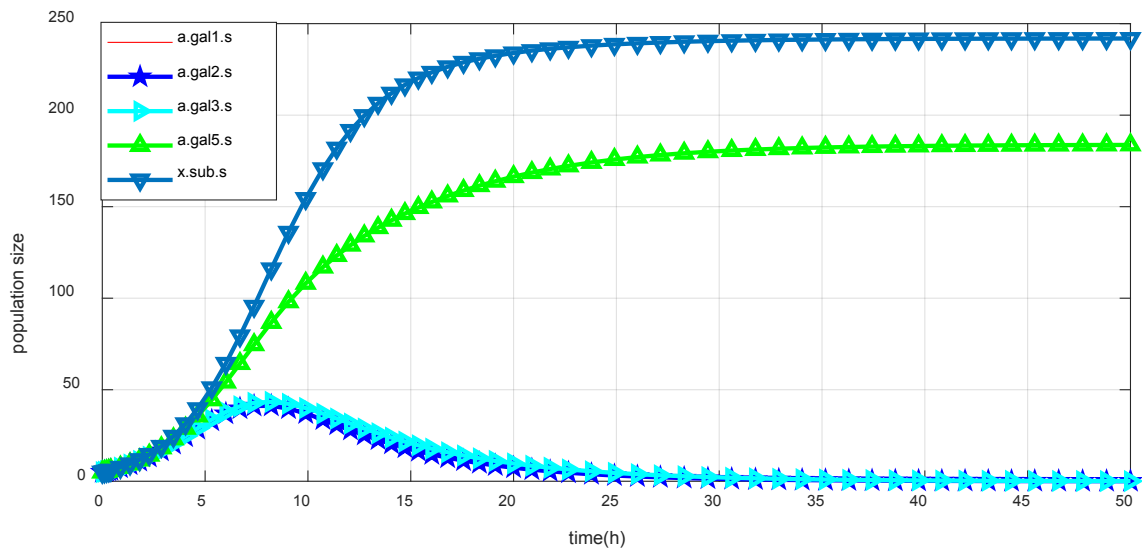


Figure 5. Five kinds of fungi competition simulation diagram

the competition and is slowly increasing in number. When $t=20$, the increase trend of its number tends to be stable. The following table shows the competitive ranking^[12] of the five fungi studied:

Table 5. Compete for league tables

Name	a.gal1.s	a.gal2.s	a.gal3.s	a.gal5.s	a.sub.s
Competitive ranking	0.054	0.054	0.054	0.135	0.243

3.4 Improved Logistic Model of Fungal Growth

3.4.1 Establishment of Improved Logistic Model of Fungal Growth

To solve the problem that the influence of small changes in initial conditions on the evolutionary trend of the community, We consider adding initial environmental variables^[18] to the model to solve this problem. Since

fungi are divided into 5 categories above, we can select a fungus from each category for study. We fit the Fungi data includes optimum humidity and optimum temperature for growth. It is calculated that temperature T and humidity M obey Normal distribution, namely:

$$f(x) = a_1 \cdot e^{\left[-\left(\frac{x-b_1}{c_1}\right)^2\right]}$$

We get the fitting curve, the first five pictures are the fitting curves of temperature and growth rate. The last five pictures are the fitting curves of humidity and growth rate.

Table 6. Table of fitting curve SSE and R^2 values (The temperature)

	aga1	ffom	pharm	probin	psangs
SSE	14.306	18.9621	0.7615	16.0814	11.1826
R^2	0.8162	0.9427	0.9989	0.9047	0.9983

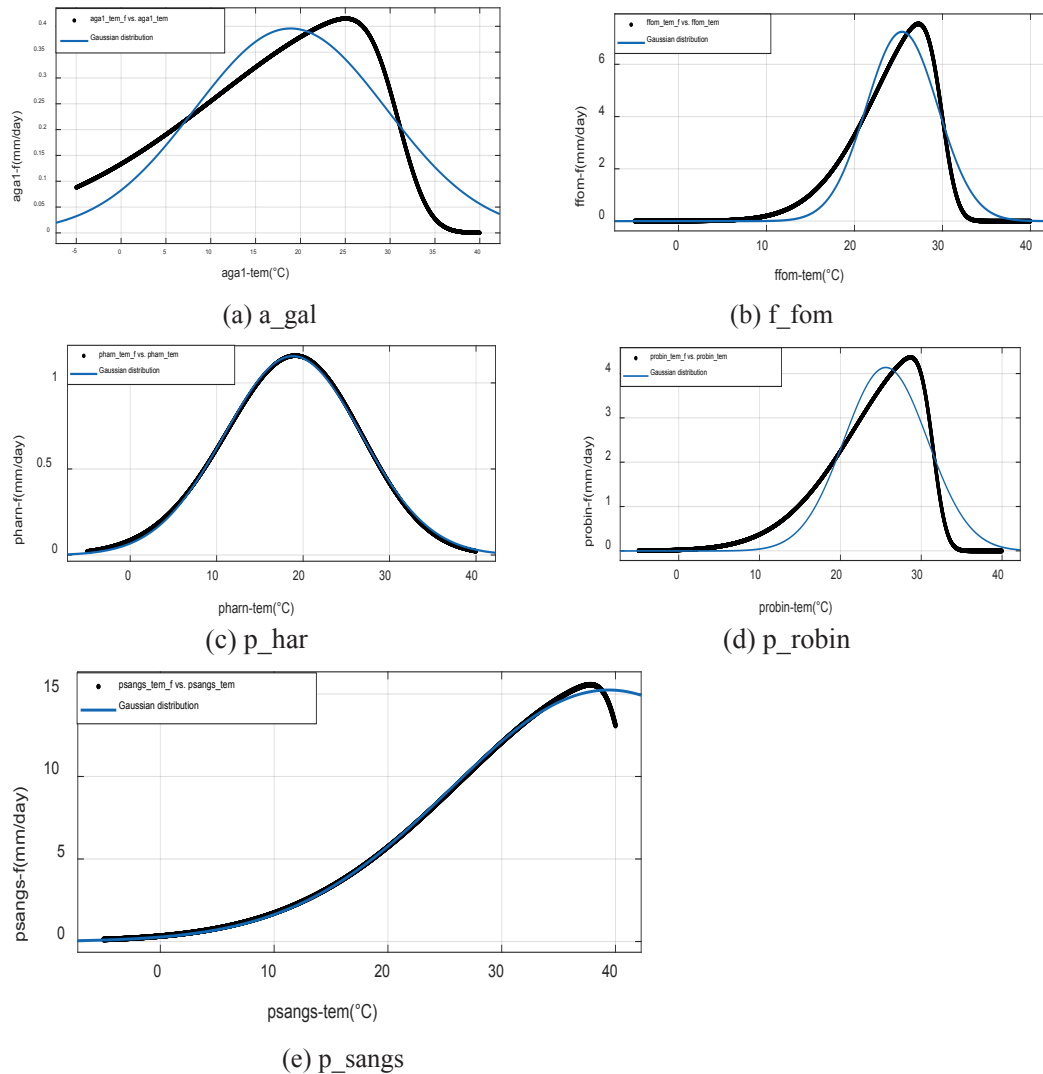


Figure 6. The fitting curves of temperature and growth rate

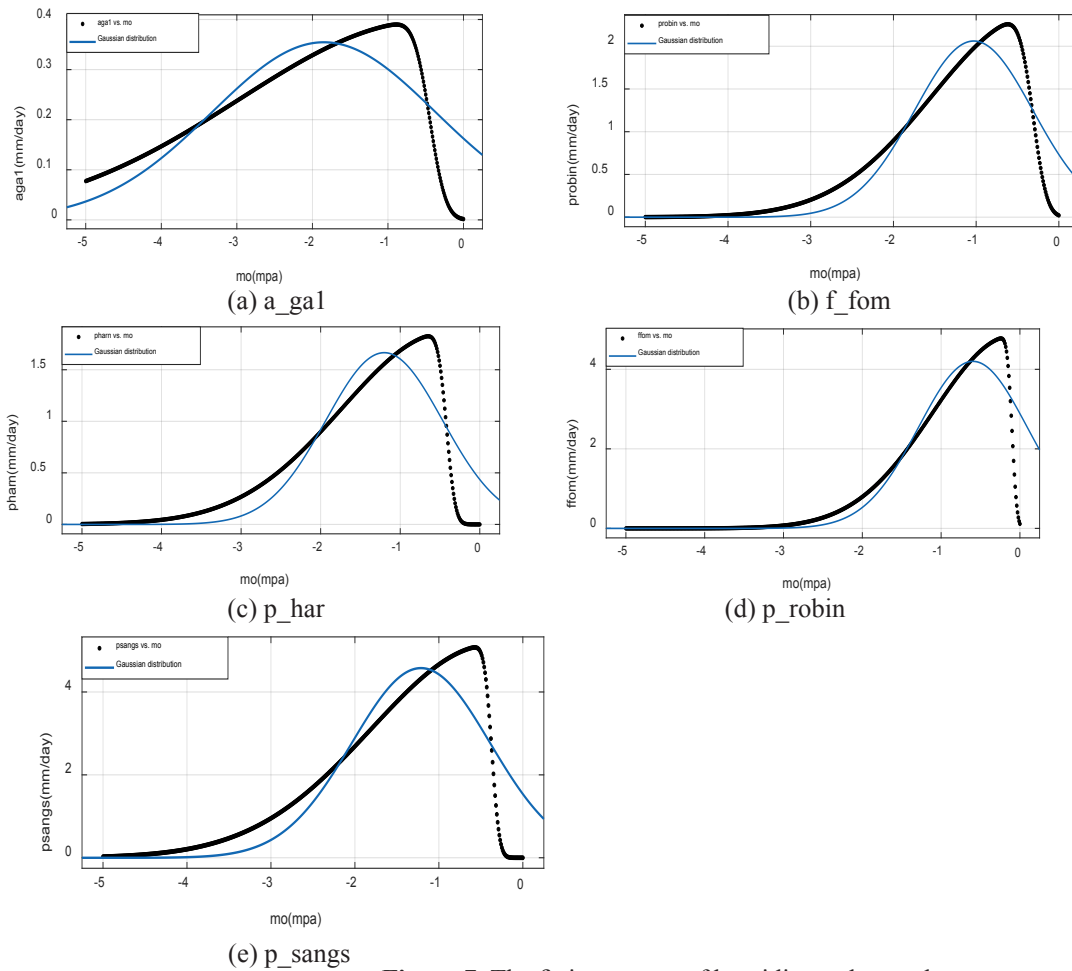


Figure 7. The fitting curves of humidity and growth rate

Table 7. Table of fitting curve SSE and R^2 values (The humidity)

	aga1	ffom	pharm	probin	psangs
SSE	3.4811	8.3632	4.6713	4.6121	0.2508
R^2	0.8026	0.9053	0.9317	0.8561	0.7096

As shown in Table 1 and Table 2, R^2 values tend to 1, and SSE is not very large, indicating a good degree of fitting. In order to further explore the influence of environmental factors such as temperature and humidity^[17] on the model, So let's go ahead and introduce this variable α , Define it as a competing factor after introducing an environment variable, So we get the formula:

$$\begin{cases} \frac{d(x_1)}{dt} = r_1 x_1 \left(1 - \frac{x_1}{N} - a \exp\left(\left(\frac{\alpha - b}{c}\right)^2\right) \sum_{i=2}^n \frac{x_i}{N} \right) \\ \vdots \\ \frac{d(x_n)}{dt} = r_n x_n \left[1 - \frac{x_n}{N} - a \exp\left(\left(\frac{\alpha - b}{c}\right)^2\right) \sum_{i=1}^n \frac{x_i}{N} \right] \end{cases}$$

In the formula, a, b and c are all measured during the growth of fungi in different environments.

3.4.2 Solution of Improved Logistic Model of Fungal Growth

Here we take a fungus and study how it grows in different environments. In Figure 8, the ambient temperature increases in each of these seven conditions(AI1-AI7), We know from the curve change in the Figure 8 above, Under the condition of AI2, the number of fungi changed the most with time, and the last stable number is also the largest. When the temperature increased gradually, the stable number of fungi increased first and then decreased under the corresponding conditions.

3.5 Fungal Habitat Model

After analyzing the competitive relationship between fungal populations, we will focus on the following question: fungal population's growth in different environments including arid, semi-arid temperate, arboreal, and tropical rain forests^[6].

Firstly, we make a numerical conversion of the five envi-

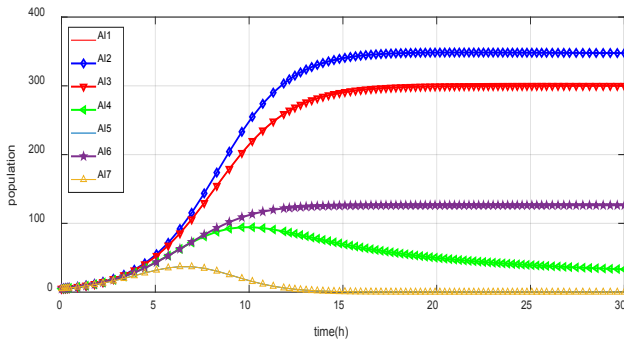


Figure 8. The number of fungi that change temperature conditions

ronments ^[14]. Here we introduce de Martonne dryness index ^[3]: two climate factors, temperature and precipitation, are used as indexes to measure five environments numerically.

$$AI = \frac{P}{T + 10}$$

AI: de Martonne Aridity index, P: The mean precipitation (mm), T: The mean temperature (°C)

The standard of measurement of AI is:

Table 8. AI measure standard

AI	<10	10~20	20~30	30~40	>40
environments	arid	semi-arid	temperate	arboreal	tropical rain forests

According to the standard of measurement of AI, we get five environments' Aridity index:

Table 9. Aridity index of 5 different environments

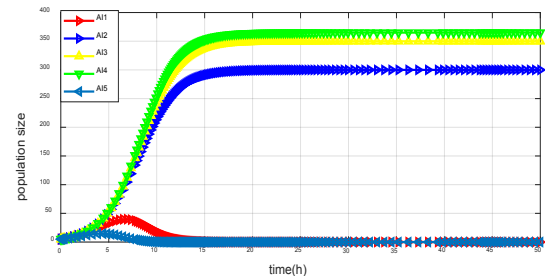
environments	T/°C	P/mm	AI
arid	28	180	4.7
semi-arid	25	350	14
temperate	16	750	25
arboreal	18	950	33.9
tropical rain forests	26	2500	69.4

We will predict whether different species fungi can coexist in different environments. We continue to choose the five fungus representatives: a_gal, f_fom, p_harm, p_robin, and p_sangs, as our research objects. The predicting outcomes as follows:

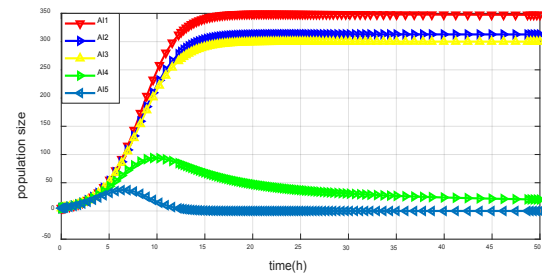
Table 10. Aridity index of 5 different environments

Environments	a_gal	f_fom	p_harm	p_robin	p_sangs
Dari	0	0	0	0	0
Semi-arid	1	1	1	0	0
Temperate	1	1	1	1	0
Arboreal	1	1	1	1	1
Tropical rain forest	0	0	0	1	0

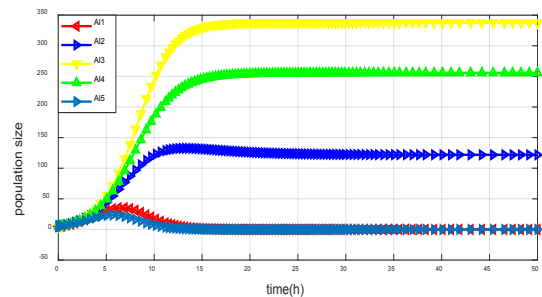
To sum up, whether fungi can coexist with each other is mainly determined by the external environment and



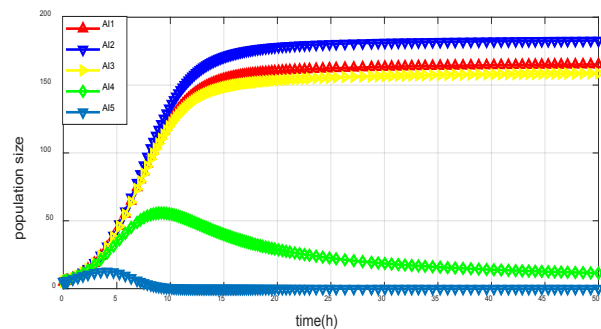
(a) a_gal's



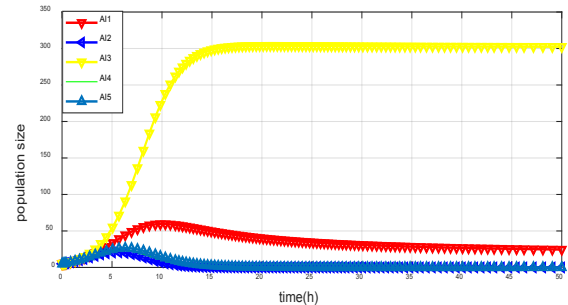
(b) f_fom's



(c) p_harm's



(d) p_robin's



(e) p_sangs's

Figure 9. Predicting outcomes

the competitive level among fungi. When the competitive level is the same, different strains can coexist with each other under the condition of little environmental fluctuations. Therefore, for the best combination of species, it is suggested to choose two species with similar competition grades and similar classes.

3.6 Diversity Analysis

3.6.1 Relationship of Diversity of Fungal and Decomposition Rate

From Logistic-Based Fungal Growth Competition Model, we can know that there are species competition when different kinds of fungi live in a same place. In other words, the diversity of fungal communities of a system will affect the breakdown of ground litter.

According to the research of Douglas Yu et al.^[9], the relationship between fungal diversity and CO₂ emissions from the breakdown of ground litter is a negative correlation. The higher the fungal diversity in deadwood is, the slower the decomposition rate will be^[20].

We use Niche overlap^[11] to explain this conclusion. Niche overlap means the phenomenon of two or more similar species living in a same space and they compete for common resources. As shown in the Figure 10, the overlapping part in the middle area represents the same resources required by two populations living in the same community. The larger the overlapping part is, the larger Niche overlap is, and intense the interspecific competition will be more intense.

All kinds of fungi need to use nutrients in the ground litter to breed. However, these resources are usually limited. That's why there is a competition for food and living space resources among fungal populations^[19].

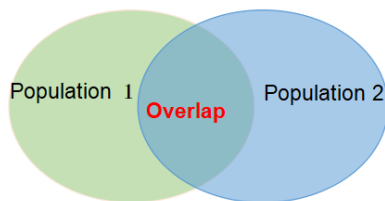


Figure 10. sketch map of the niche overlap

Every year, the world's wood decomposition produces as much CO₂^[10] as the burning of fossil fuels. Luckily, we have learned that the diversity of fungi communities of a system could slow down the decomposition rate of litter and deadwood on the ground^[15]. It has a positive effect on relieving the greenhouse effect.

Fungal diversity is an important part of bio-diversity. It can be closely related to plants through mutualistic symbiosis or parasitism. It is reliable to believe that there is a

coupling relationship between fungal diversity and plant diversity.

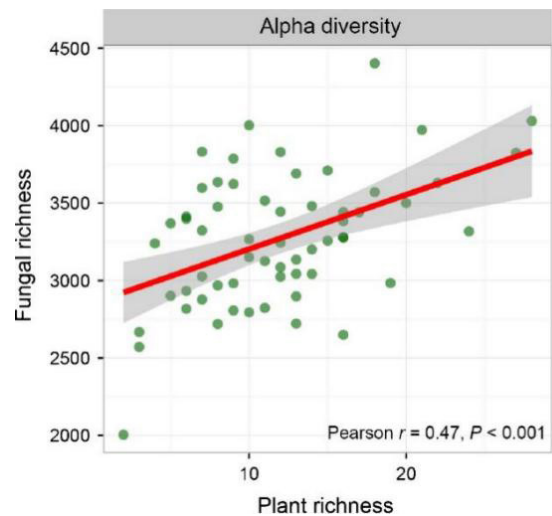


Figure 11. Alpha diversity

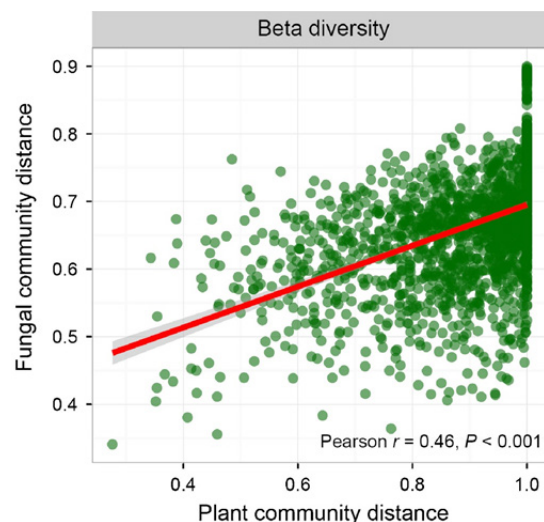


Figure 12. Beta diversity

Through the data of 60 stations in the experiment of Teng Yang et al.^[3], We can get the relationship between plant richness and fungal richness, plant community distance and fungal community distance. The figure shows that there is a positive correlation between fungal diversity and plant diversity. Therefore, in ecosystem, the greater the species richness, the more stable the biological system will be, and the more organisms can be accommodated.

4. Sensitivity Analysis

For the equation we created, the most important parameter is the competition factor, Through the sensitivity test of the parameter of competition factor, the results are as follows:

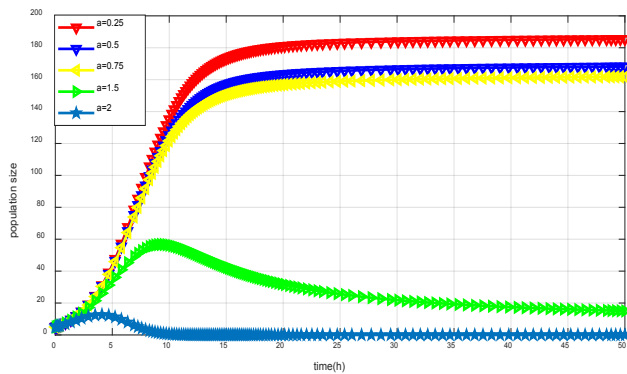


Figure 13. Sensitivity test of competitive factors

By changing the size of the competition factor we observed, that: When the competition factor changes little, the function image changes little. However, when the competition factor changes greatly, the function image changes dramatically. This phenomenon indicates that the competitive factor is sensitive and can accurately reflect the population quantity when the competitive factor changes.

5. Model Evaluation

5.1 Strengths

- During the whole modeling process, we set reasonable assumptions that: Environmental resources are limited, and there is only competition between different species. There is no other relationship. The growth of fungi is affected by many variables, but only the temperature and humidity as well as the moisture tolerance, growth rate and decomposition rate of fungi are considered. This facilitates the construction and resolution of models.
- We innovatively used analogies to add initial environmental factors to the model. This allows us to further understand the effects of weather and climate change on the model.

5.2 Weaknesses

- Our model has a lot of parameters, and the values of those parameters are mostly biological. Due to the diversity and complexity of biology, the values of these parameters can vary considerably. This can also have an impact on the accuracy of the model.

6. Conclusions

Fungi play an important role in the global material cycle, so it will be very meaningful and interesting to study its characteristics and interaction with ecosystem.

For problem 1, we choose the growth rate and the fun-

gus' tolerance to moisture to describe the wood decomposition rate, and established Wood Decomposition Rate Model. We use Multiple linear regression equations to show the relationship between the decomposition rate of wood and the moisture tolerance and growth rate of fungi.

For problem 2, firstly, we divide the fungus samples into five categories based on the optimal growth temperature and growth humidity of each fungus. Secondly, we set up the competitive factor σ to describe the competitive relationship among the fungi population, and established the Fungal Competition Model which shows the competitive ability of various fungi.

For problem 3, we add the environmental factor α to describe fungi's real growing environment, and established the Improved Logistic Model of Fungal Growth. We examine the sensitivity of fungal populations to environmental fluctuations. Through short-term and long-term prediction trend, we can know that with the increase of temperature, the number of fungus population will decrease gradually.

For problem 4, we introduce Aridity index to describe the five habitats of fungi. We establish the Habitat Model of Fungi, and then predict the survival state of the fungal population. Finally, we obtain the best combination of fungi in five habitats.

For problem 5, we use Niche overlap to explain the negative correlation between fungal diversity and the rate of wood decomposition.

In addition, in the sensitivity analysis, we tested the competitive factor σ to analyze the effect of parameter changes on fungal population changes.

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ARTICLE

Ethnobotanical Survey of Two Medicinal Plants (*Heliotropium indicum* L., *Abrus precatorius* L.) Used in Traditional Medicine in West Africa

Farid T. Badé^{1,2} Durand Dah-Nouvlessounon¹ Sina Haziz¹ Cissé Hama² Aude Kelomey¹
Assogba Sylvestre¹ Oladélé Gautier Roko¹ Adjanohoun Adolphe³ Savadogo Aly²
Baba-Moussa Lamine^{1*}

1. Laboratory of Biology and Molecular Typing in Microbiology, Faculty of Science and Technology/University of Abomey-Calavi, Cotonou, Benin
2. Laboratory of Biochemistry and Applied Immunology (LABIA), UFR in Life and Earth Sciences, Doctoral School of Sciences and Technologies, Joseph KI-ZERBO University, Ouagadougou, Burkina Faso
3. South Agricultural Research Center, National Agricultural Research Institute of Benin, Attogon, Benin

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ABSTRACT

Since the time of our ancestors, natural products issued from plant play a therapeutic crucial role. About 25-30% of all medicines (drugs) available for the treatment of diseases are derived from natural products (from plants, animals, bacteria and fungi) or are derivatives of natural products. The aim of this research was to scientifically identify and supply tangible documentation on these two plants employed in the traditional medicine. From November 2020 to February 2021, an ethnobotanical survey was conducted within four markets at the south of Benin, employing a semi-structured questionnaire. Two hundred respondents including 80% of females and 20% of males were interviewed. The 2 studied plants are mainly used for different types of sickness related to infections. Females' herbalists are the most represented. From this research, it appears that the 2 plants are widely used for the treatment of severe infections. On the market, 95% of the leafy steam are sold against 5% of the roots for both plants. The main preparation way is decoction. Oral use is reported to be common in all region. The value of samples sold varies from 200F CFA (Financial Cooperation of Africa) to 1000F CFA. The decoctions are usually obtained through one of a mix of different types of plants. Traditional knowledge is transmitted from one generation to another by oral education. Till today there was no record found. During our study, we did no record prohibition or side effect related to these plants' use. These medicinal plants occupy a crucial place within the therapeutic arsenal of west Africa. Our results constitute a vital tool to determine the true potentials of these plants. These results could lead to new improved traditional medicine.

*Corresponding Author:

Baba-Moussa Lamine,

Laboratory of Biology and Molecular Typing in Microbiology, Faculty of Science and Technology/University of Abomey-Calavi, Cotonou, Benin;

Email: laminesaid@yahoo.fr

1. Introduction

Since the time of our ancestors, vegetable resources have always been considered vital to humankind. Nowadays, about 25-30% of all drugs available for the treatment of diseases are derived from or are derivatives of plants, animals, bacteria and fungi ^[1]. Despite this, in recent decades, mainly because of the advance of synthetic chemistry, natural market research within the pharmaceutical industry has been in slow decline. However, evidence from the pharmaceutical industry shows that, for a few complex diseases, natural products still represent a particularly valuable source for the assembly of latest chemical entities. As they represent preferred structures selected by evolutionary mechanisms over a period of innumerable years ^[2]. Plants, as vital elements of biological diversity, serve essentially for human well-being ^[3]. After a protracted struggle with traditional medicine, doctors and health organizations are now more fascinated by the values and effectiveness of plant treatments. Medicinal plants have always had a crucial place within the therapeutic arsenal of humanity. Numerous scientific studies are undertaken to check the botanical and therapeutic aspects of plants and to integrate their medicinal properties into a contemporary health system by exploiting their active ingredients ^[4]. Approximately 80% of the world's population and over 90% of the population in developing countries depend on them for basic health care ^[5-9]. Urgent attention must be paid to many species as possible on earth that haven't yet been studied scientifically. This is to determine their phytochemical and pharmacological properties, and also assess their qualities, safety and efficacy. This green heritage thus represents an infinite reservoir of compounds waiting to be discovered ^[10]. Ethnobotanical surveys are proving to be one in all the foremost reliable approaches for the invention of the latest drugs ^[11]. Today, numerous studies distributed within the field of ethnopharmacology show us that the plants employed in traditional medicine and which are tested are often effective plants in pharmacological models. On the opposite hand, they would be practically nontoxic ^[12]. The rummage around for new medicinal molecules of natural origin is predicated on the distribution of medicinal plants and on ethnobotanical studies. These studies allow inventories of plants in a locality or country to be made, followed by photochemical and pharmacological studies. As a result, the valorization of natural resources is becoming an increasingly important concern in many countries.

We therefore propose during this present work; to hold out an ethnobotanical study within the communes of Abomey-Calavi, Cotonou, Porto-Novo and Pobe ; to spot

the various usages of Two medicinal plants (*Heliotropium indicum* L., *Abrus precatorius* L.) utilized in traditional medicine in this geographical region.

2. Material and Methods

2.1 Material

The Benin's analytical flora ^[13] served as a base to identify and confirm the studied plants. An audio recorder has been used for the interviews, a camera for the pictures and some nylon bags for the collections of the samples.

2.2 Method

2.2.1 Study Area

Four communes at the south of Benin has been investigated during this study see Figure 1.

These communes have the particularity to concentrate various tribal groups originated from different parts of the world. The marketing of traditional medicine is considered to be an identity business hand over by ancestors. The study area is located at the level of Guinea Gulf, between 110° 0' and 140° 0' W, 60°0 'S and 80°0'N with two seasons of rainfall per year (April to June and September to November). The annual average is 1200 mm. All over the year, the temperature varies between 25 °C and 29 °C with a ratio between 69% and 97% ^[14]. In the study area, agricultural practices impacted heavily the forest coverage area ^[15].

Four departments are involved in our study. It is the:

- **Atlantic department** with equatorial climate marked by two rainy seasons and two dry seasons. One type of soil is observed in the south; it is the ferrallitic soil.
- **Coastal department** extended over a length of 121 km. The width varies from 3 km to 10 km (West to East) with 50 metres altitudes ^[13]. Along the oceans, different types of barriers could be observed separated by lagoons and fluvial-lacustrine complex ^[13].
- **OUEME department** marked by ferruginous soil of red colour; forest relics formed by clay, grass and others. We also noticed the presence of mangroves and raphia ^[13].
- **Plateau department** is characterized by sudano-guinean climate with a shrubby savannah vegetation. A presence of the relic's forests is also noted followed by the dominance of *Daniellia oliveri* ^[16].

2.2.2 Exploratory Investigation

After the paperwork's step, the geographic distribution of the plants was established in prelude followed by prospective research. The main idea was to get in touch

with referenced people, capable to feed us with tangible information in traditional medicine. That permits us to strengthen our questionnaires in order to obtain convincing results after our survey.

Ethno-ecological approach was employed. In each department, three markets were surveyed.

2.2.3 Ethnobotanical Survey

Three markets per communes were surveyed using the methodology of structured interview ^[9,17] see Table 1.

Table 1. Departments, communes and markets selected for the study.

Departments	Communes	Markets
Atlantic	Abomey-Calavi	- Akassato
		- Glo
		- Calavi-kpota
Coastline	Cotonou	- Gbgamey
		- Vedoko
		- Dantokpa
Plateau	Porto-Novo	- Agbokou
		- Adjara
		- Ouando
Oueme	Pobe	- Odja Obada
		- Odja Oho
		- Odja Igana

To gain real and tangible information from the herbalist, a previous discussion has been made with them to explain the importance of this study for humankind. This was followed by the registration of herbalists which were ready to share their knowledge with us. The richness of the shop influenced our choice.

Four local languages were used for the interview:

- **Fon** for the herbalist living in Abomey-Calavi (Benin)
- **Mina** for the herbalist coming from Togo and Ghana
- **Goun** for the herbalist living in Porto-Novo (Benin)
- **Yoruba** for the herbalist selling in Pobe and the ones coming from Nigeria.

The survey took into account the age, the sex, and the level of alphabetization.

The local name, the preparation and administration mode, prohibitions, side effects, and other necessary information were collected during the survey.

2.2.4 Socio-economic Survey

The methodology of structured interview described by ^[9,17] was used to conduct the survey. The sales' prices and the storage's condition were registered.

2.2.5 Data Processing

The collected data were coded and inserted in excel 2020 databases then analysed by the software Minitab

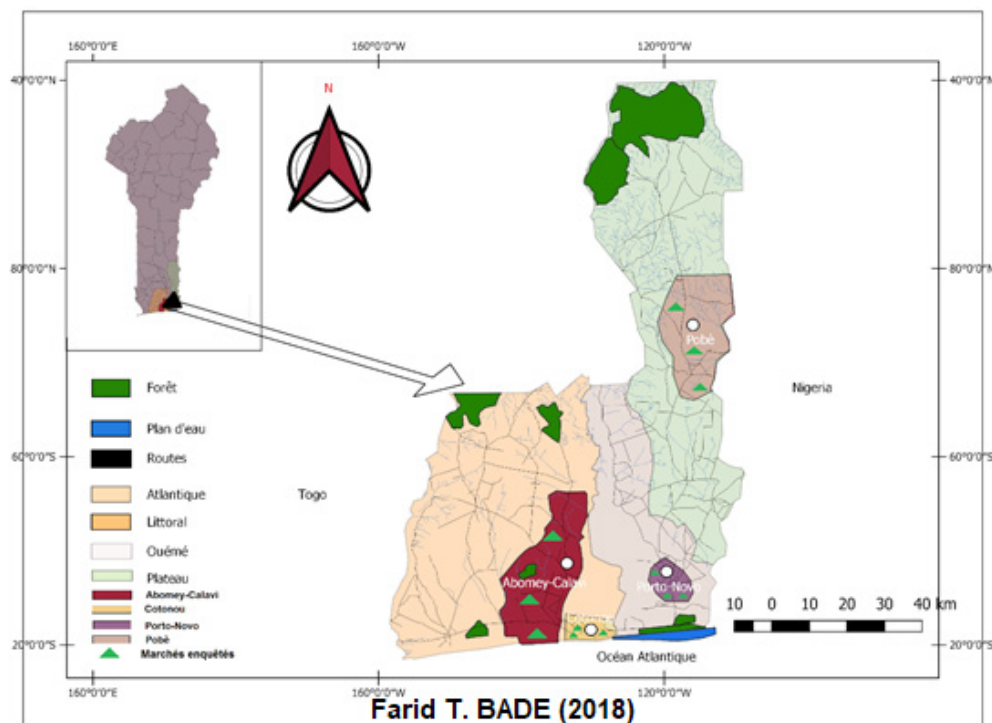


Figure 1. Map showing the study area's departments and their respective communes involved in the survey (Source: Farid T. BADE 2018)

17.0 and Graph pad 2019.

The frequency of citation (Fc) of every plant was resolved by the formula:

$$Fc = \frac{\text{number of citation of the plant}}{\text{Number of citation of all plante}} \times 100$$

3. Results and Discussion

3.1 Strengths and Weaknesses of the Survey Method Used in This Study

The method used in this research was retrospective. It was based on the capacity of the herbalist to remember their ancestral knowledge^[18]. This could lead to biases due to their personal emotions. So, the value attributed to these plants depends on the individual's appreciations, taking into account their experience.

In spite of this, the retrospective method is widely used by many authors^[19-21] and, has the privilege of giving convincing results, when the people involved are highly implicated in traditional treatments.

3.2 Sociodemographic Characteristics of the Respondents

The results concerning the age, the sex, and the level of alphabetization are displayed in table 2. The analyse of this table showed that 80% of herbalists present in the study area are female against 20% of males. The identical observation had been made by^[22] and^[23] who realized that during their different study, females' herbalists are more dominants. This could be due to the fact that nowadays,

in west Africa's market, women prefer soft works, like selling in the market while men preferred hard works. The herbalist interviewed were aged from 30 to 95 years. The subjects of 60 years old and more are more dominants, followed by the ones in the range of 50 to 60 years old. These results could be explained by the fact that in Africa, young people prefer activities with fast and important revenue instead of these kinds of activities with low incomes. It could also be due to the new generation youths that are not patient enough to receive the precious ancestral knowledge from the elders. Analphabets were more represented in our survey results. This data is closed the national data of PNUD BENIN who stipulated that the use and the commercialization of traditional medicine is the privilege of the poor and illiterate.

Forty percent of the herbalists are Gouns while 8 % are Minas. The majority of Goun obtained could be justified by the location of the study area. It appears from our survey that the Goun are the most represented tribe in the south. They are also present in Nigeria and are involved in all types of business. In contrary the Minas were in minority, because these activities are not seen as an important source of revenue for them, they prefer importing commodities from Togo and Ghana to Benin, in order to make better profit.

Species used the study area

Two major plants were identified. There were:

Heliotropium indicum L., and *Abrus precatorius L.* (Table 3). These species are the most sold for the treatments of severe infections and other complications. The citation of each species varies according to the department

Table 2. Sociodemographic characteristics of herbalists

Characteristics	Modality	Herbalist %				
		ATLANTIC	COASTLINE	OUEME	PLATEAU	Mean
Sex	Male	20	10	30	20	20
	Female	80	90	70	80	80
Age	[30-40]	30	18	15,50	22,22	21,43
	[40-50]	10	15	3	10,08	9,52
	[50-60]	40	25	30	38,2	33,30
	[60-95]	20	42	51,5	29,5	35,75
Level of alphabetization	Analphabet	92	84	92	100	92
	Primary	8	16	8	0	8
	Secondary	0	0	0	0	0
Religion	Animist	72	40	88	80	70
	Christian	16	48	6	10	20
	Muslim	12	12	6	10	10
Tribal group	Fon	45	25	10	0	20
	Mina	15	17	0	0	8
	Yoruba	20	18	30	60	32
	Goun	20	40	60	40	40

surveyed. Nevertheless, there is no significant difference between the citations of the species. Other authors like ^[22] noticed that *Heliotropium indicum* L., was more present in the commune of Abomey-Calavi during a census of medicinal plants used in the treatment of gestational diabetes. These observations show that *Heliotropium indicum* L., could be the most dominant and the one with the high frequency of use compared to the other. On the other hands *Abrus precatorius* L. was more cited in Pobe. This could be probably due to soil and other traditional interest. According to ^[13], *Abrus precatorius* L. grows easily in savannah forest and sandy area. The presence of forest in this community could justify the high frequency of citation.

The co-dominance of *Abrus precatorius* L., and *Heliotropium indicum* L. could be justified by their importance in traditional medicine. While *Abrus precatorius* L., is used to relieve pains, fever and caught, *Heliotropium indicum* L., is generally used in the treatment of severe infections.

Table 3. Citation frequency of *Abrus precatorius* L., and *Heliotropium indicum* L. In the study area.

Commune	Citation frequency (%)	
	<i>Abrus precatorius</i> L.	<i>Heliotropium indicum</i> L.
Abomey - Calavi	60	40
Porto-Novo	50	50
Cotonou	60	40
Pobe	51	49
Local name	<i>Viviman</i>	<i>koklossou dinkpadja</i>

Different uses of *Abrus precatorius* L., and *Heliotropium indicum* L.

The phytochemical analysis of the leaves of *abrus precatorius* L. ^[24] showed a heterogeneity of the following chemical groups: alkaloids, tannins, flavones, coumarin, saponins, sterols, triterpenes and reducing compounds, responsible for its attributed therapeutic properties. *Abrus precatorius* L. roots contain sterol and terpenes. *Abrus precatorius* L. helps to treat fever, dysentery, stomach disorders, abdominal colic in new-borns with the fresh plant (leaves, stems, roots together without seeds) or dried plant ^[25]. The decoction of the leaves helps in the treatment of diabetes.

Abrus precatorius L., has been classified as an anti-tussive plant and expectorant for centuries ^[26], so it is not surprising that people in places like Madagascar and Senegal are interested in using it to treat childhood coughs, coughs, asthma and bronchitis ^[25,27]. It is also an anti-inflammatory.

Abrus precatorius L. is a galactogenic or galactagogue food that promotes, the production of breast milk. This

plant is administered orally with an extract of its leaves diluted with palm wine (1 glass/day) or the ash of the vine is used as a local application after scarification on the chest ^[28]. Alternatively, the leaves are used in a drink for the treatment of gynaeco-obstetric disorders. In case of asthenia (weakening of the organism, physical fatigue, low libido) it is recommended to decoct it with water, or mixing the powder of its leaves with honey ^[3]. ^[29] publication stated that in Uganda the powdered leaves/roots of *Abrus precatorius* L. or the decoction is taken orally to treat cases of premature ejaculation.

Heliotropium indicum L. has multiple therapeutic uses due to its natural composition of active's elements on human biology. This plant with its slightly bitter taste is rich in polyphenols, saponosides, flavonoids, gall tannins, catechics, quinones, adrenomimetic substances and alkaloids. The aqueous extract of *Heliotropium indicum* L. has multiple biological properties including the following potentials: gastro-protective against gastric ulcerations for example ^[30], antihypertensive, anti-inflammatory, antimicrobial, vasorelaxant and immunostimulant.

Indeed, with its chemical composition, *Heliotropium indicum* L. leaves can treat several types of eczema, burns, wounds, boils, impetigo in children and even sexually transmitted diseases such as herpes. In Africa, it is also traditionally used in the pharmacopoeia to help treat diarrhoea, constipation and cardiovascular diseases due to the presence of alkaloids that reduce high blood pressure. To treat cases of hypertension in Nigeria, the whole plant of *Heliotropium indicum* L. together with that of *afromomum melegueta*, are roasted and then powdered and administered with hot porridge twice daily in the morning and evening for a week ^[31].

The fresh crushed leaves are applied as a rub and used as an anti-venom for scorpion stings ^[32]. The plant is also used for a number of unspecified eye diseases, but by instillation. For pregnant women, a decoction of *Heliotropium indicum* L. leaves in the form of a bath can reduce swelling of the face, such as pregnancy masks ^[33]. In addition, the decoction of *Heliotropium indicum* L. leaves, is used in various malaria treatments in Nigeria, and the juice of *Heliotropium indicum* L. leaves applied topically is used to treat canker sores in Benin. However, other uses continue to be reported for this incredible plant for amenorrhoea, vomiting and various spiritual treatments.

Decoction is the main way of preparation. Since no intoxication has been reported, the medicine is taking orally.

The preparation is consisted of single plant (30%) or a combination of several plants (70%). The parts of the plant mostly used are the leaves and the leafy stem (Figure 2).

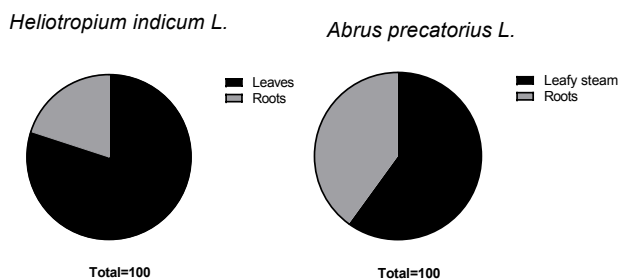


Figure 2. part of the plant used for decoction

Socio-economic values

The species sold within the market are available as leafy stems and roots. For *Heliotropium indicum* L. the massive sales of the leafy stem are up to 80% while for the other the massive sales are up to 40%. The difference obtained is justified by the use of each plant. In the case of *Abrus precatorius* L. the roots are regularly used to lower fever and relieve pains.

The supply of plant materials has significantly decreased over the years. This is due to the fast demographic advance. This is confirmed by more than 87% of our respondents. But the availability of species varies according to people preference and the species. In fact, in some area, people consider *Heliotropium indicum* L. as bad bush and easily get rid of it. This observation is thanks to fast urbanization of the study area. The common purchase and selling prices of every plant recorded during the study period are still low. The gains varied significantly according to the actors of the sectors. In general, the gains range from 3000 F CFA to 4000 F CFA per bag of 50 kg. The producers get more benefits than others. Their benefits range from 1000f to 3000f daily. For others (wholesalers, semi-wholesalers and retailers) involved in well selling, prices vary between 100f and 200f. They get a much bigger profit when selling in detail. This business represents an important source of income for actors involved.

4. Conclusions

The vital role of herbalists in the treatments of different types of sickness has been highlighted in this study. The 2 plants play a significant role in West African traditional medicine. Frequently cited diseases have been: dysentery, stomach disorders, abdominal colic, eczema, burns, wounds, boils, impetigo in children and even sexually transmitted diseases such as herpes. These results require deep laboratory research to determine and isolate the bioactive compounds present in the plants. A new generation of improved traditional medicine could appear with a significant beneficial effect for humankind.

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ARTICLE

Evaluation of Germplasm of Pearl Millet (*Penisetum glaucum* L.) for Agronomic, Physiological and Biochemical Traits under Semi-arid Conditions of Hamelmalo

Habteslase Teklu Tesfagiorgis* **Woldeamlak Araia** **N.N. Angiras***

Department of Agronomy, Hamelmalo Agricultural College, Keren, Eritrea

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ABSTRACT

A field experiment was conducted at the experimental farm of Hamelmalo Agricultural College during summer 2017, to evaluate the agronomic, physiological, and biochemical performance of the collected Eritrean germplasm of pearl millet. A total of 16 accessions were tested, out of which 2 were improved varieties included as a check. The experiment was laid out in 4 x 4 Simple Lattice Design with Randomized Block using 4 replications with a gross plot size of 3.0 m x 1.2 m, row to row spacing of 75 cm and plant to plant spacing of 30 cm. The data collected were Agronomic parameters (growth, development, yield, and yield contributing characters); Physiological parameters (Relative water content and Water Use Efficiency); and Biochemical parameters (crude fat, crude fiber, protein content, TSS, and ash content). The data were analyzed using GENSTAT software and correlation analysis was worked to see the positive and negative contribution of agronomic, physiological, and biochemical attributes. The results of the study showed that Bariyay908 and Kona being statistically at par with Bariyay 910, Hagaz, Zibedi, Shleti, Delkata, Tokroray, and Kunama produced significantly higher grain yield. However, among these Bariyay908 because of its superior agronomic characteristics, lower incidence of downy mildew, relatively higher water use efficiency and higher crude protein content were found to be comparatively superior to the check improved varieties Kona and Hagaz. Grain yield has shown a positive and significant correlation with harvest index, number of seeds per panicle, panicle length, leaf area and water use efficiency. These promising accessions need to be further tested for future breeding programs to develop varieties higher in productivity and resistant to downy mildew under semi-arid conditions of Eritrea.

1. Introduction

Pearl millet (*Pennisetum glaucum* L.) is known by different common names all over the world such as Cattail

millet, Bullrush millet, Candle millet, and Penicillaria in English, Bultug in Eritrea and Bajra in India. It is the world's fourth most important cereal crop in the tropics. It is small-seeded hardy grass that grows well in dry zones

**Corresponding Author:*

N.N. Angiras,

Department of Agronomy, Hamelmalo Agricultural College, Keren, Eritrea;

Email: angirasnsk@gmail.com

Habteslase Teklu Tesfagiorgis,

Department of Agronomy, Hamelmalo Agricultural College, Keren, Eritrea;

Email: habtishagro@gmail.com

under rain-fed conditions, in areas with marginal soil fertility conditions and moisture ^[1] which makes it one of the preferred cereal crops in drier areas. Millet is one of the oldest food crops known to humans and possibly the first cereal grain to be used for domestic purposes ^[2]. It is considered an orphan crop that is widely grown for food and fodder in Africa and India. Among the most important grain crops in the world, Pearl millet is widely grown in the semi-arid regions of Africa and Asia as a staple food crop by the poorest people living in the most difficult production environment ^[3]. It has multiple uses especially its ability to cope up with harsh climatic conditions and will continue to feed the world's expanding populations. Moreover, it will be the crop of the future due to the changing global climatic trends and the increase in the use of marginal lands for crop production ^[4].

In Eritrea, pearl millet grains are used for making a variety of foodstuffs commonly known as *Injera*, *Kicha*, and *Ge'at* while the stalks are used for animal fodder, house construction and fuel. It is widely grown in the lowlands under an arid and semi-arid climate of Eritrea; especially in areas with rainfall shortages where other crops survive the least.

Pearl millet is grown in an area of 36,288 million hectares in the world with average total production of 298,006 tons and average productivity of 821 kg per hectare. In Africa, it is cultivated in an area of 20774 hectares with a total production of 14606 tons and productivity of 703 kg per hectare. In Eritrea, pearl millet production has declined due to land degradation; the use of traditional farm implements and global climate change. Moreover, drought is the major cause of the under-production of the crop. In Eritrea, the total area occupied by Pearl millet during the year 2014 was 85,856 ha (16.3%) with a production of 44,772 (8.8%) tons. But in 2015, the total area occupied decreased to 66,920 ha (15.4%) with a production of 10,348 tons (8.7%) and productivity of 0.3 to 0.5 t/ha, which is very low ^[5]. The average productivity of Pearl millet in Eritrea is much less than its productivity in the African continent which is 703 kg ha⁻¹ and that of the world with 821 kg ha⁻¹. The major constraints of the low productivity in Eritrea are mono-cropping, poor soil fertility, imbalanced use of fertilizers, low and erratic distribution of rainfall, shortage of quality seeds, infestation by weeds, attack of diseases (downy mildew and smut), and insect pests.

Out of the total cultivated area in Zoba Anseba (60,000 ha) of Eritrea, pearl millet occupies 28080 ha with an average production of 23494.9 tons and average productivity of 960 kg ha⁻¹. Whereas in sub- Zoba Hamelmalo of Zoba Anseba out of the total cultivated area (9252 ha), pearl millet occupies 5210 hectares with a total average produc-

tion of 5595.8 tons and average productivity of 1070 kg ha⁻¹. Therefore, pearl millet is the first important crop followed by the sorghum in the Anseba region in terms of total area coverage ^[6]. In Hamelmalo, sorghum mono-cropping has resulted in the infestation of Striga weed in the crop fields hence farmers are shifting to pearl millet which is relatively immune to Striga. Due to this reason, there is a change in total area and production in Hamelmalo area where pearl millet is becoming the most important cereal crop.

Farmers in Eritrea use landraces of pearl millet that have been grown for generations. These landraces have been selected and maintained by the farmers over a longer period of time and have made the necessary adjustments to the environmental conditions and specific requirements of the area. Because of their different morphological, physiological, and biochemical characteristics, they provide an important genetic resources for the development of improved varieties having drought and pest resistance. Some of the varieties released before a longer period of time have deteriorated in their performance because of mechanical mixtures (at planting, harvesting and threshing), out crossing, attack from new races of diseases, etc. Apart from these, genetic erosion has also been caused by land degradation due to loss of soil fertility, drought or moisture stress, weed and disease infestation, and changes in agricultural practices over a period of time.

The National Agricultural Research Institute of the country has collected and preserved the biodiversity of the available germplasm of pearl millet in the gene bank. The pearl millet germplasm collected is expected to be a source of variability of different characters that are useful for crop improvement programs. But their evaluation for agronomical, physiological, and biochemical characteristics for specific environmental conditions has not been attempted to date. Furthermore, it is important to identify pearl millet land races with valuable traits to be used for the future breeding programs and to be screened in future advanced yield trials. Therefore, the present investigation was carried out to evaluate the agronomical, physiological, and biochemical characteristics of some of the pearl millet landraces out of the germplasm conserved in the gene bank for higher productivity under semi- arid conditions of Hamelmalo.

2. Materials and Methods

A field experiment was conducted at the experimental farm of Hamelmalo Agricultural College located at latitude of 15° 52' 18" N, longitude of 38° 27' 55" E and an altitude of 1280 m a.m.s.l. during summer rainy season of 2017. Topography of the area is medium flat and hilly, which is undulated as well as exposed to erosion. The soil type ranges from sandy to sandy loam. The rainfall in the area is low and erratic in distribution. In most of

the years rainfall starts around mid-June and ends up by mid-September. The area receives a mean annual rainfall of 430 mm, which is a typical amount of rainfall obtained in semi-arid regions. The total amount of rainfall in 2017 was 549.6 mm with an average maximum and minimum temperature of 33.7 °C and 13.9 °C, respectively. There was no variation in evapo-transpiration rate during the main growing period of the crop from July to September ranging from 5.8 to 5.9 mm^[7].

A total of 16 pearl millet genotypes were tested out of which 14 accessions are from the Eritrean pearl millet germplasm collection and 2 standard checks (Hagaz and Kona) (Table 2). The germplasm were obtained from the Genetic Resource Division of the National Agricultural Research Institute (NARI). The details of the accessions evaluated in the study were as follows:

Treatment	Acc. No.	Name
T1	EG-1078	Kunama
T2	EG-1094	Gundmay
T3	EG-1200	Bartu
T4	EG-1197	BultugNara
T5	EG-947	Mensura
T6	EG-907	Zibedi
T7	EG-904	Shleti
T8	EG-117	Jengeren
T9	EG-908	Baryay1
T10	EG-203	Anseba
T11	EG-910	Baryay2
T12	EG-205	Delakda
T13	EG-935	Tokriray
T14	EG-148	Ferdeghi
T15	Check (Improved)	Kona
T16	Check (Improved)	Hagaz

Note: T= treatment; EG= Eritrean germplasm

The experiment was laid out in 4 x 4 Simple Lattice Design with Randomized Block using 4 replications with a gross plot size of 3.0 m x 1.2 m, row to row spacing of 75 cm and plant to plant spacing of 30 cm. All other agronomic practices like seed bed preparation, fertilizer application, and weed management were uniform in all the experimental plots.

The following agronomical, physiological, and biochemical characteristics of each of the accessions under study were recorded as per the methodology mentioned against each.

Agronomic parameters

Phenological and growth parameters

Plant count: Number of seedlings emerged in the plot and plants that reached maturity were counted and recorded in percent.

Plant height: It was determined from 5 randomly selected plants at 40 DAF (Days after flowering) by measuring the height from ground level to the base of the youngest fully opened leaf. After panicle emergence, height was recorded from the base of the plant to the tip of the panicle at physiological maturity and expressed in a centimeter.

The number of fertile tillers: A number of basal fertile tillers was counted at 40 DAF.

The number of green leaves (NGL) and number of senescence leaves (NSL): It was determined from 5 randomly selected plants. A number of green leaves having more than 50 % green portion were counted. The number of senescence leaves was counted when more than 50% of the leaf area had senesced. The measurements of both parameters were done at the same time.

Green Leaf Area (cm²): Leaf area of 5 tagged plants was recorded at 40DAF by measuring length (L) from the leaf base to the tip and maximum breadth (B) of fully opened leaf lamina. The product of leaf length, breadth, and correction factor (CF) 0.747^[8] were used to express the leaf area in cm² per plant as given below by taking an average of five plants:

$$\text{Leaf area (cm}^2\text{)} = L \times B \times CF$$

Leaf area index: It was obtained by dividing leaf area per plant by area covered under one plant.

Days to 75% Flowering: The number of days taken to 75% anthesis (flowering) was recorded when 75% of the plants flowered in the two central rows in each plot and expressed in days from sowing up to flowering.

Days to maturity: The date when 90% of the plants reaching maturity were recorded from the central two rows and the number of days taken was counted from sowing up to maturity.

Yield and yield components

Yield components such as Panicle length (cm), Panicle weight (g), Number of grains per panicle, and Thousand-grain weight (g) were recorded immediately after harvest of the crop. Grain yield (kg/ha) was recorded after threshing of the total biomass after recording its dry weight. The harvest index was calculated by dividing the grain yield by the biomass yield of each plot.

Physiological parameters

Relative Water Content: Second or third fully expanded leaf from the top was collected at 30 DAF in polyethylene bags and kept in an ice box after transporting from the field. Immediately, twenty leaf discs were weighted on an electronic balance to determine the fresh weight (FW). The weighted leaf discs were floated overnight in a Petri-dish containing distilled water and subsequently blotted gently and weighted again (TW= turgid weight). After taking turgid weight, the discs were oven-dried at 80°C for

28 hours and dry weight (DW) was recorded separately. The RWC was calculated using the following formula and expressed in percent.

Relative water content (%) = $(FW-DW) / (TW-DW) * 100$

Water use efficiency (WUE): It was calculated by dividing the grain yield by the amount of rainfall received during the growing season by using the following formulae.

$$WUE (kg/mm) = \frac{\text{Grain yield (Kg)}}{\text{Amount of rainfall during the season(mm)}}$$

Biochemical parameters

The analysis for biochemical attributes was carried out in Villaggio, National Animal and Plant Health Laboratory (NAPHL). A composite sample of each landrace in four replications was taken as a representative sample due to unavoidable reasons. There were a total of 16 samples used. The grain samples were dried and powdered to 1 mm particle size. Total soluble sugar content, Fat contents, Fiber content, Total nitrogen content, and Ash content were analyzed from these processed samples.

Protein content was determined by multiplying the nitrogen content in per cent with the Conversion factor (5.83).

Downy mildew infestation

The number of infected plants plot⁻¹ due to downy mildew (DM) was counted and calculated as :

$$DM \text{ incidence}\% = n/N * 100$$

Where N is the total number of observed plants, n is the total number of diseased plants ^[9].

Statistical Analysis

GENSTAT software was used to compile and analyze the data. The mean comparison was estimated using LSD at 5%. Correlation analysis among the characters was carried out using GENSTAT software.

3. Results and Discussion

Growth parameters

The growth parameters averaged over the post- flowering periods for all the accessions tests are given in Table 1.

Plant height

Overall, there were significant differences among the pearl millet accessions in plant height when averaged over the post- flowering periods (Table 1). The plant height ranged from 168.3 to 256.4 cm. The accession Jengeren (256.4 cm) being statistically at par with Anseba was significantly taller as compared to all other accessions. Kona (check), Bartu and Bultug Nara being statistically at par were shorter compared to the other accessions. This is in agreement with the findings of ^[10], ^[11] and ^[12], who reported that there was a variation in plant height among

the varieties of pearl millet. The work done by ^[13] on pearl millet also showed that Kona was short to medium (160-200 cm) in height depending on the location and the plant height is within the range as reported by other researchers.

Leaf Area

There was a significant difference in leaf area among the pearl millet accessions when averaged over the post-flowering stage (Table 1). A significantly higher leaf area was recorded from Delakda (190.1 cm²), Ferdeghi (188.9 cm²), Bariyay908 (188.8 cm²), Bariyay910 (188.5 cm²) Tokriray (187.3 cm²), Zibedi (185.4 cm²), Gudmay (172.1) and Shelti (165.1) over the remaining accessions. A significantly lower leaf area was recorded from Bartu, Bultug Nara, Anseba, and Jengeren. Pawar ^[14] reported that there was significant difference in green leaf area among sorghum accessions which is in agreement with the current study.

Leaf Area Index

There was a significant difference in Leaf Area Index among the accessions when averaged over the post-flowering periods (Table 1). Delakda, Fedeghi, Bariyay908, Bariyay910, Zibedi, Tokriray, Shelti, Gudmay, and Mansurea being statistically at par resulted in significantly higher Leaf Area Index. But significantly lower LAI was recorded in Bartu, Bultug Nara, Jengera, Anseba, and Kunama accessions which are statistically at par.

Number of Fertile Tillers

There was a significant difference in a number of fertile tillers among the accessions of pearl millet when the values taken during post-flowering period were averaged (Table 1). A significantly highest number of fertile tillers was obtained from Kunama followed by Bultug Nara, and Bartu compared to the other accessions. But significantly lower fertile tillers were produced by Anseba, Bariyay910, Delakda, Tokriray, Ferdeghi, Jengren, and Bariyay910 accessions which were statistically at par. The two improved varieties, Hagaz and Kona produced relatively less effective tillers but the panicle size was large enough which is expected to compensate the grain yield. The accessions with more fertile tillers had relatively smaller panicles which resulted in lower grain yield. The finding on fertile tillering capacity is in agreement with the report of several authors who indicated that there was significant difference in the number of fertile tillers per plant among the pearl millet varieties ^[15,16].

Number of Green leaves

There was a significant difference in a number of green leaves (NGL) among the accessions of pearl millet when the values were averaged on the different periods of post-flowering (Table 1). The accessions such as Jengeren, Anseba, and Ferdeghi had significantly lower number of

green leaves. Kunama (33.36) had significantly highest number of leaves per plant. Bariyay908 (25.14), Bartu (24.26), Bultug Nara and Mensura (23.4), Shelti and Ferdeghe being at par were the next higher in a number of green leaves compared to the other accessions indicating that they stayed green for a longer period during post-flowering stage.

This could be attributed to more number of tillers produced by these accessions resulting in a higher number of green leaves. According to ^[17] genotypes with a higher number of green leaves stayed green for a longer period of time and retained chlorophyll in their leaves with the ability to carry out photosynthesis for a longer period resulting in higher yield compared to those with the lower number of green leaves.

Number of Senescence Leaves

There was a significant difference in the number of senescence leaves among the pearl millet accessions when the values were averaged on the post-flowering period (Table 1). The number of senescence leaves increased with time but it was significantly lower in Kona Torrey, Bariyay910, and Hagaz (check variety). A significantly higher number of senescent leaves were observed in Anseba and Jengeren accessions these two accessions were very late- maturing types that were affected by drought during the post-flowering period.

Per cent plant count, Crop Phenology and Disease incidence

The results on per cent plant count; crop phenology and downy mildew disease incidence as influenced by accessions were significant and are presented in Table 2.

Per cent plant count

The Plant count for all the accessions was satisfactory except for Ferdeghe (50.25%) which showed the lowest crop stand (Table 2). The reason for the lower crop stand was due to heavy rainfall at that time resulting in water logged conditions. This is in contrary to the report of ^[18] that did not show any significant difference in Plant count of pearl millet variety in terms of Plant count (in 2010 and 2011 cropping seasons) but were satisfactory in a number of Plant count. The current study is in agreement with the findings of ^[19] who reported that in cereals, the Plant count for both pearl millet and sorghum is hardly affected significantly by the type of a variety when both environmental and soil conditions are favorable for the crop.

Number of Days to 75% Flowering

Accessions showed significant differences in number of days to flowering. Among the accessions Kona (check), Bartu and Bultug Nara, Kunama, and Hagaz (check) took fewer number of days to flowering ranging from 49 to 55 days. It was further noted that Jengeren and Anseba took a significantly higher number of days to flowering (79 days)

Table 1. Effect of pearl millet accessions on growth parameters at post-flowering stage.

Treatment	Plant height (cm)	Leaf Area (cm ²)	LAI	Number of Fertile tillers	Number of Green leaves	Number of Senescence leaves
Kunama	183.3	138.6	0.061	7.5	33.4	11.5
Gudmay	225.6	172.1	0.076	4.0	17.4	11.5
Bartu	168.8	112.1	0.049	6.4	24.3	13.0
Bultug Nara	168.4	116.0	0.051	6.4	23.4	12.1
Mensura	201.6	163.6	0.074	4.7	23.4	11.0
Zibedi	207.7	185.4	0.083	4.2	19.7	10.9
Shleti	203.4	165.1	0.073	4.3	22.6	11.1
Jengeren	256.4	124.5	0.055	3.4	9.3	22.2
Bariyay908	215.8	188.8	0.084	4.8	25.1	12.2
Anseba	248.9	118.7	0.054	3.9	12.4	23.2
Bariyay910	214.8	188.5	0.084	3.6	16.3	9.2
Delakda	230.1	190.1	0.084	3.9	18.2	12.3
Tokriray	209.4	187.3	0.083	3.3	16.6	8.4
Ferdeghe	206.0	188.9	0.085	3.8	15.7	10.9
Kona	168.3	134.5	0.060	4.2	16.9	6.6
Hagaz	192.4	159.8	0.071	4.6	22.5	10.2
Mean	206.6	158.4	0.070	4.6	19.8	12.3
LSD (5%)	18.78	24.98	0.012	0.76	6.57	4.2
CV(%)	6.4	11.1	12	1.5	23.3	24.1

compared to all the accessions. In the current study, there was a variation in the number of days to flowering among the accessions with a difference of 30 days between the earliest and the latest which is very big (Table 2). This is in contradiction with ^[15,20,11] who reported that the pearl millet varieties they tested did not show a significant difference in days to flowering. The same result was reported by ^[21]. On the other hand, ^[22] tested eight varieties of sorghum and confirmed that there was a significant difference in days to flowering among the varieties. ^[23] also stated that the two new improved varieties of Pearl millet in Eritrea showed earliness in flowering compared to the local accessions.

Days to maturity

There was a significant difference in days to maturity among the accessions of pearl millet. The days to maturity ranged from 78 to 113 days. Among these Kunama, Bartu, Kona and Bultug Nara being at par were significantly earliest (78 days) in maturity. Significantly late-maturing accessions were Jengereen and Anseba which took 113 and 108 days, respectively (Table 2).

The two late-maturing accessions (Jengerren and Anseba) taller took more time for vegetative growth resulting in delayed maturity. This is in conformity with ^[23] who found a significant difference in days to maturity in sorghum varieties. Studies have shown that Kona is earlier

in days to maturity compared to the other local landraces (Tokroray) ^[24].

Downy mildew infestation

In general, the infestation of downy mildew was higher in all the accessions except Bariyay908 compared to recommended varieties (check) Kona and Hagaz. Significantly higher downy mildew incidence was noted in Gudmay (66.6%), Jengerren (61%), Mensura (49%), and Ferdeghi (48%) accessions. The improved variety Kona (check) was free from downy mildew incidence. This finding in this study agrees with that of ^[25] who indicated that there was a significant difference in downy mildew among the pearl millet varieties and similarly with the finding of Downy mildew survey Research in Eritrea ^[26] who reported its wide distribution in Eritrea with 30-50% infection rate in Zoba Anseba and Gash Barka during the survey period.

Yield components

All the yield components viz. panicle weight, panicle length, thousand grain weight, number of seeds per panicle, and number of fertile tillers were significantly affected by different accessions under study (Table 3).

Panicle weight

Pearl millet accessions Delakda (23.45 g), Bariyay908 (22.35 g), Tokriray (22.25 g), and Anseba (22 g) resulted in significantly higher panicle weight as compared to oth-

Table 2. Effect of pearl millet accessions on per cent plant count, days to 75% flowering, days to maturity and downy mildew disease.

Treatment	Plant count (%)	Days to 75%flowering	Days to maturity	Downy Mildew %
Kunama	100	53	78	55.5
Gudmay	100	58	89	66.6
Bartu	94	52	78	37.8
Bultug Nara	99	52.	78	46.3
Mensura	100	55	81	49.0
Zibedi	94	57	85	21.9
Shleti	99	55	82	26.1
Jengerren	100	79	113	61.0
Bariyay908	82	56	85	19.7
Anseba	100	79	108	35.8
Bariyay910	100	56	85	33.7
Delakda	100	57	86	34.6
Tokriray	100	56	85	30.7
Ferdeghi	50	57	88	48.0
Kona	93	49	78	0.0
Hagaz	100	55	88	16.1
Mean	94	58	87	36.4
LSD (5%)	11	2	1	19.15
CV(%)	8	2.8	1	36.9

er accessions under study. On the other hand Bartu (15.35 g), Bultug Nara (15.45 g), and Kunama (16.9 g) were the accessions with significantly lower panicle weight. The accessions also had different forms of panicle having compact and loose panicles. This is in agreement with [27] who found out that pearl millet variety with variations on panicle weight for grain yield and yield components.

Panicle Length

Accessions Hagaz (37.5 cm), Tokriray (34.5 cm), Bariyay908 (34.25 cm), Bariyay910 (33.5 cm), Zibedi (33.25), Kona (32 cm), Gundmay (30.75 cm), Delkado (30.75 cm) and Shleti (29.25 cm) being at par produced significantly longer panicles than other accessions under study. On the other hand accessions Jengeren (5.75 cm) and Bultug Nara (13.25 cm) had the lower panicle length. Jengeren recorded lowest panicle length and it was late in flowering and maturity which is an indication that the panicle length was affected by moisture stress (Table 3). [28] and [11] also described on the variation in panicle length among the pearl millet accessions which goes in line with this study.

Thousand grain weight

A significantly higher thousand-grain weight was recorded in checks varieties, Kona (2.25 g) and Hagaz (2.08 g) but were at par with Zibedi (1.68 g), Anseba (1.62 g), and Ferdeghi (1.60 g). The accessions Bariyay910 (0.40 g) and Mensura (0.82 g) showed the lowest thousand- grain

weight (Table 3). [11] reported that there was a significant difference among varieties of pearl millet in thousand-grain weight which agrees with the findings of the current study.

Number of grains panicle⁻¹

A significantly higher number of seeds per panicle were recorded from accession Gudmay but were at par with Bariyay908, Zibedi, Shleti, Bariyay910, Delakda, Tokriray, and Hagaz due to their large panicle size but small seed size. The accessions Jengeren produced significantly the lowest number of grains per panicle but accessions Anseba, Bultug Nara, Bartu, and Kunama were also low in grain number but were superior to it (Table 3). The accessions Anseba and Jengeren were late maturing types with small number of seeds per panicle. [29] reported a significant difference in the number of grains per panicle among accessions in sorghum and the same was observed in the number of grain per panicle with significant difference among the tested genotypes of pearl millet.

It can be inferred that among accessions under study, all the yield components of accessions Bariyay908, Delakda, Tokriray, Zibedi, Shleti, and Gundmay were almost at par with recommended variety Hagaz.

Grain Yield, Biomass yield and Harvest Index

Grain yield, biomass yield and harvest index were significantly influenced by different accessions under study

Table 3. Effect of pearl millet accessions on yield components

Treatment	Panicle weight (g)	Panicle length (cm)	1000 grain weight (g)	Number of grains/panicle
Kunama	16.90	17.25	1.32	9061
Gundmay	20.60	30.75	1.25	16299
Bartu	15.35	16.50	1.27	8914
Bultug Nara	15.45	13.25	1.27	7817
Mensura	21.20	26.00	0.82	10731
Zibedi	20.55	33.25	1.68	13783
Shleti	21.35	29.25	1.57	13220
Jengeren	20.75	5.75	1.57	2375
Bariyay908	22.35	34.25	1.57	15128
Anseba	22.00	16.75	1.62	7384
Bariyay910	20.15	33.50	0.40	13651
Delakda	23.45	30.75	1.45	13678
Tokriray	22.25	34.50	1.57	14277
Ferdeghi	21.25	25.75	1.60	10728
Kona	18.35	32.00	2.25	10240
Hagaz	20.65	37.50	2.08	13032
Mean	20.16	26.06	1.46	11270
LSD(5%)	1.687	9.605	1.46	4205.0
CV(%)	5.9	25.9	22.8	26.2

(Table 4).

Grain Yield

Accessions Bariyay908 (2.9 t ha⁻¹) and Kona (2.8 t ha⁻¹) being statistically at par with Bariyay 910 (2.6 t ha⁻¹), Hagaz (2.5 t ha⁻¹), Zibedi (2.5 t ha⁻¹), Shleti (2.4 t ha⁻¹), Delkata (2.4 t ha⁻¹), Tokroray (2.4 t ha⁻¹) and Kunama (2.1 t ha⁻¹) produced a significantly higher grain yield (Table 4) because of their higher growth in terms of leaf area, LAI, green leaves etc. (Table 1), higher plant population, early development and lower attack of downy mildew (Table 2) higher yield components (Table 3). Jengeren and Anseba were significantly lowest yielding accessions because both had lower leaf area, LAI, number of green leaves (Table 1), late in maturity and were affected by drought during post-flowering period (Table 2), high incidence of downy mildew (Table 2) and poor in yield components (Table 3). Accessions like Bultug Nara, Bartu, and Kunama had smaller panicle lengths resulting in lower yields. According to [22] and [30] pearl millet varieties showed a significant difference in grain yield which agrees with the current study.

Biomass yield

The higher biomass yield was produced in Anseba (20.3 t/ha), Jengeren (19.3 t/ha), and Bariyay908 (18.6 t/ha). The accessions Anseba and Jengeren gave maximum biomass yield but not higher grain yield. These two accessions were tall in plant height compared to the other accessions and varieties resulting in much higher biomass. On the other hand, Kona (improved variety), Bultug Nara, Bartu, and Kunama gave the lowest biomass yield (Table 4) but higher grain yield because of more translocation of the photosynthates to well-developed sink. This is in agreement with [12] and [30] who reported that there was a highly significant difference among pearl millet varieties in biomass yield and also agrees with [22] who indicated that sorghum varieties differed significantly in biomass yield.

Harvest index

The highest harvest index of 41% was obtained from the Kona variety. A higher harvest index means higher grain yield due to better translocation of photosynthates from the leaves to the good development of sinks even with relatively lower biomass yield (Table 4). In food crops, accessions or varieties with higher harvest index are selected but for their use as forage crop lower harvest index is needed. The other accessions such as Bartu, Kunama, Hagaz (check), Mensura and Bariyay 910 gave harvest index between 20% and 22%. The accessions Anseba and Jengeren gave the lowest harvest index which means that the proportion of grain yield compared to biomass yield is very low due to the effect of drought stress. [31] reported that pearl millet varieties have shown a significant difference in harvest index which is similar to the

current study. Furthermore [32] also mentioned that drought stress contributes towards lower harvest index.

Table 4. Effect of pearl millet accessions on biomass yield, grain Yield and harvest index.

Treatment	Grain yield (t ha ⁻¹)	Biomass yield (t ha ⁻¹)	Harvest index (%)
Kunama	2.083	9.444	22.06
Gundmay	1.944	11.389	17.07
Bartu	1.528	7.222	21.16
Bultug Nara	1.250	6.944	18.00
Mensura	1.944	8.889	21.87
Zibedi	2.500	13.611	18.37
Shleti	2.361	12.361	19.10
Jengeren	0.278	20.278	1.37
Bariyay908	2.917	18.611	15.67
Anseba	1.111	19.306	5.75
Bariyay910	2.639	13.056	20.21
Delakda	2.361	13.889	17.00
Tokriray	2.361	11.250	20.99
Ferdeghi	1.250	9.583	13.04
Kona	2.778	6.944	40.01
Hagaz	2.500	11.389	21.95
Mean	1.988	12.135	18.35
LSD (5%)	0.968	3.729	0.068
CV (%)	34.2	21.6	25.6

Physiological Parameters

The effect of pearl millet concessions on Relative Water Content and Water Use Efficiency is shown in Table 5.

Relative Water Content

There was no significant difference in Relative Water Content among the accessions. Numerically, Ferdeghi (59.78%), Shleti (55.98), Hagaz (53.93%), and Gudmay (53%) accessions had a higher relative water content. This is an indication that the accessions stayed green and maintained better water status in the plant system. The next best accessions were Tokriray (52.58%), Delakda (51.45%), Anseba (51.15%), Bartu (51.35%), and Mensura (51.33%). This could be attributed to the maintenance of better water status. There were accessions that showed lower Relative Water Content such as Jengeren (45.48%), Bariyay910 (46.18%), Kunama (47.7%) and Kona (48.95%) which was relatively lower compared to the other accessions (Table 5). The difference in Relative Water Content between accessions even though is not significant among the accessions signifies the resistance to terminal drought and adaptation of the materials to the local conditions.

Water Use efficiency

There was a significant difference in water use efficiency among the accession. Accession Bariyay908 (8.03 kg/mm of

water) being statistically at par with Kona (7.65 kg/mm of water), Bariyay910 (7.25 kg/mm of water), Zibedi (6.90 kg/mm of water), Hagaz (6.85 kg/mm of water), Tokriray (6.50 kg/mm of water), Shleti and Delakda (both 6.48 kg/mm of water), Kunama (5.73 kg/mm of water) and Mensura (5.46 kg/mm of water) because of their higher grain yields gave a significantly higher water use efficiency. Because of lower grain yield accessions Jengeren (0.78 kg/mm of water), Anseba (3.03 kg/mm of water), Ferdeghe (3.43 kg/mm of water) and Bultug Nara (3.48 kg/mm of water) resulted in significantly lower water use efficiency. Water Use Efficiency gives a clue on the amount of water used to produce a kg of seed and the accessions that produced the highest kg of seed per mm of water is the most efficient in terms of water use.

According to [28], sorghum accessions showed a significant difference in water use efficiency which is in agreement with the current study on pearl millet.

Biochemical attributes

The results of biochemical attributes like ash, crude protein, total soluble sugar, nitrogen, crude fiber, and crude fat are shown in Table 6.

Ash

The ash content ranged from 1.62% to 2.48%. It was numerically higher for Bartu (2.48%), Anseba (2.46%) Bariyay908 (2.43%), Jengeren (2.27%), Shleti 2.21%), Gudmay (2.13%), Delakda (2.07%), and Bariyay910 (2.05%) while the minimum values of ash content were obtained from Ferdeghe (1.62%) and the improved varieties Kona (1.71%) and Hagaz (1.79%).

Crude protein

The crude protein ranged from 11.09% to 13.53%. The protein content was numerically higher in Bariyay908 (13.53%) and Kunama (13.12%) accessions as compared to the other materials tested. The level of crude protein in descending order was noted for Ferdeghe (12.73%), Zibedi, and Mensura both with the value of 12.29%, Bartu (12.22%), Gudmay (12.19%), and Hagaz (12.01%). The crude protein was the lowest in Tokriray (11.09%) (Table 6).

Total soluble sugar

Table 5. Effect of pearl millet accessions on physiological parameters.

Treatment	Relative Water Content (%)	Water Use Efficiency (kg grain/mm of water)
Kunama	47.70	5.73
Gundmay	53.93	5.35
Bartu	51.33	4.23
Bultug Nara	50.40	3.43
Mensura	51.33	5.46
Zibedi	50.03	6.90
Shleti	55.98	6.48
Jengeren	45.48	0.78
Bariyay908	49.33	8.03
Anseba	51.15	3.05
Bariyay910	46.18	7.25
Delakda	51.45	6.48
Tokriray	52.58	6.50
Ferdeghe	59.78	3.43
Kona	48.95	7.65
Hagaz	53.00	6.85
Mean	51.16	5.47
LSD (5%)	NS	2.65
CV (%)	10.2	34

Table 6. Effect of pearl millet accessions on biochemical parameters.

Treatment	Ash (%)	Crude protein (%)	Total sol.sugar (%)	Nitrogen (%)	Crude fiber (%)	Crude fat (%)
Kunama	1.94	13.12	77.95	2.25	1.15	5.84
Gundmay	2.13	12.19	79.58	2.09	1.08	5.01
Bartu	2.48	12.22	78.33	2.10	1.05	5.93
Bultug.N NnnNara	1.99	11.34	81.13	1.95	0.98	4.56
Mensura	1.91	12.29	80.01	2.11	1.15	4.64
Zibedi	1.99	12.29	80.16	2.11	1.22	4.34
Shleti	2.21	11.67	79.58	2.00	1.11	5.43
Jengeren	2.27	11.84	80.73	2.03	1.03	5.13
Bariyay908	2.43	13.53	78.13	2.32	0.95	4.96
Anseba	2.46	11.99	80.28	2.06	1.15	4.12
Bariyay910	2.05	11.46	81.41	1.97	0.75	4.33
Delakda	2.07	11.68	80.32	2.00	1.09	4.84
Tokriray	1.95	11.09	80.19	1.90	1.35	5.42
Ferdeghe	1.62	12.73	78.72	2.18	1.58	5.35
Kona	1.71	11.93	79.01	2.05	1.04	6.33
Hagaz	1.79	12.01	80.15	2.06	1.17	4.88

Total soluble sugar ranged from 78.13% to 81.41% with numerically higher values of 81.41% and 81.13% in Bariyay910 and Bultug Nara, respectively. The lowest total soluble sugar was recorded in Kunama (77.95). In the present study, the highest yielding types such as Kona, Hagaz and Bariyay 908 did not show a high level of total soluble sugar (Table 6). In contrary, [34] mentioned that the development of leaf water deficit in pearl millet leaves resulted in an increased amount of glucose, sucrose and fructose. Furthermore, [14] noted that genotypes with higher accumulated total sugars resulted in higher grain yields compared to other types, thus soluble sugar content proved to be a better marker for selecting improvement of drought tolerance in different crops. However, it was not reflected in the present study.

Nitrogen content

The nitrogen content ranged from 1.90 to 2.32 per cent. It followed a similar trend as that of protein content as protein content is calculated from the nitrogen content. Like protein content accessions Bariyay908 (2.32%) and Kunama (2.25%) gave the higher nitrogen content among the accessions. The nitrogen content was numerically

lower in Jengeren (2.03%) and the improved variety Kona (2.05%).

Crude fiber

The crude fiber ranged from 0.75% to 1.58% with Ferdeghe (1.58%) giving the highest crude fiber and Bariyay 910 with the lowest (0.75%) crude fiber. The other accessions with relatively better crude fiber were Tokriray (1.35%), Zibedi (1.22%) Hagaz (1.17%), Anseba (1.15%), Kunama (1.15%), and Mensura (1.15%).

Crude fat

The crude fat ranged from 4.12% to 6.33% with Kona (improved variety) giving the highest (6.33%) and Anseba the lowest (4.12%) crude fat.

These results reveal that biochemical parameters can be taken as one of the parameters for the selection of qualitatively nutritious accessions for further breeding programs.

Correlation studies

The correlation between biomass yield, grain yield and harvest index with agronomic characters is presented in Table 7 while the relationship between biomass yield, grain yield, and harvest index with physiological and biochemical attributes is shown in Table 8.

Table 7. Correlation analysis between agronomic parameters, biomass, and grain yield and harvest index

Agronomic parameters	Biomass	Grain yield	Harvest Index
Plant count	0.090 (NS)	0.540 (NS)	0.094 (NS)
Days to Flowering	0.806 (**)	-0.630 (**)	-0.823 (**)
Days to maturity	0.811 (**)	-0.605 (*)	-0.795 (**)
Downy Mildew	0.059 (NS)	-0.781(**)	-0.570 (*)
Panicle weight	0.631 (**)	0.182 (NS)	-0.341 (NS)
Panicle length	-0.107 (NS)	0.789 (**)	0.508 (*)
Thousand Grain Weight	0.057 (NS)	0.132 (NS)	0.185 (NS)
Plant height	0.878 (**)	-0.367 (NS)	-0.766 (**)
Number of Fertile Tillers	-0.462 (NS)	0.046 (NS)	0.267 (NS)
Grain yield	-0.177 (NS)	—	0.669 (**)
Biomass	—	-0.177 (NS)	-0.732 (**)
Harvest Index	-0.732 (**)	0.669 (**)	—
Number of Seeds/Panicle	-0.123 (NS)	0.650 (**)	0.374 (NS)
Leaf Area	0.139 (NS)	0.520 (*)	0.061 (NS)
Leaf Area Index	0.019 (NS)	0.449 (NS)	0.103 (NS)
Number of Green Leaves	-0.469 (NS)	0.410 (NS)	0.414 (NS)
Number of Senescent Leaves	0.701 (**)	-0.708 (**)	-0.834 (**)

Table 8. The correlation analysis between physiological, biochemical versus biomass, grain yield and harvest index

Physiological/Biochemical parameters	Biomass	Grain yield	Harvest index
Relative Water Content	-0.303 (NS)	-0.041 (NS)	0.018 (NS)
Water Use Efficiency	-0.166 (NS)	0.947 (**)	0.700 (**)
Ash	0.575 (*)	-0.252 (NS)	-0.513 (*)
Crude protein	0.137 (NS)	0.101 (NS)	-0.050 (NS)
Total soluble sugar	0.214 (NS)	-0.165 (NS)	-0.267 (NS)
Crude fiber	-0.175 (NS)	-0.141 (NS)	-0.124 (NS)
Crude fat	-0.479 (NS)	0.117 (NS)	0.522 (*)

Days to flowering, days to maturity, plant height, and number of senescence leaves showed a positive and highly significant relationship with biomass yield. This indicates that the increase in the value of these characters resulted in an increase in biomass yield. However, these characteristics showed a highly significant negative correlation with grain yield and harvest index. [34] stated that plant height had a direct correlation with biomass yield and according to [35] days to 75% flowering was positively and significantly correlated with biomass yield which has similarity with this study. However, [30] who studied open pollinating strains of pearl millet mentioned the positive and significant correlation of biomass with harvest index and grain yield.

Similarly, downy mildew disease had a significant but negative correlation with grain yield and harvest index indicating this disease restrict the formation of grains due to its effect on senescence of leaves. [36] and [37] noted the negative and significant correlation between downy mildew incidence and grain yield in pearl millet which is in agreement to this study. On the other hand, [38] did not find any significant correlation between disease incidence and loss in grain yield which is contrary with this study. Panicle length and number of seeds per panicle had significant and positive correlation with grain yield and harvest index. According to [30] panicle length and grain yield were positively and significantly correlated with harvest index which goes in line with the current study. The rest of the agronomic characters did not show a significant correlation with biomass yield, grain yield and harvest index.

The data in Table 8 show that among the physiological parameters, only Water use efficiency had a significant and positive correlation with grain yield and harvest index, indicating accessions which have agronomic characteristics to use the rain water efficiently under semi-arid conditions were able to produce significantly higher yield and harvest index. The higher-yielding varieties such as Bariyay908 Baryay910, Kona, Hagaz, Zibedi, etc. had higher Water Use Efficiency and higher grain yield in the present study.

Out of the biochemical parameters, crude protein and crude fat were the only characters that showed a positive correlation with grain yield but it was not significant. Among the biochemical characteristics, while crude fat had a significant and positive correlation with the harvest index, the ash content was negatively correlated with the harvest index. None of the other biochemical constituents showed a significant correlation with biomass yield, grain yield, and harvest index.

There was a negative and non-significant correlation between grain yield and chemical composition like ash

content, total soluble sugar and crude fiber (Table 8).

4. Conclusions and Recommendation

Conclusions

It can be concluded that among the accessions under study, Bariyay908 and Kona being statistically at par with Bariyay910, Hagaz, Zibedi, Shleti, Delkata, Tokroray, and Kunama produced significantly higher grain yield because of their higher growth in terms of leaf area, LAI, green leaves, early development and lower attack of downy mildew and higher yield contributing components. However, among these Baryay908 because of its superior agronomic characteristics, lower incidence of downy mildew, relatively higher water use efficiency and higher crude protein content were found to be comparatively superior to the check improved varieties Kona and Hagaz. Bariyay910 was found to be the next best accession having higher total soluble sugar and grain yield higher than the improved variety Hagaz.

Recommendation

It is recommended to test these promising accessions which have been found to be at par or superior to the improved check varieties in further studies to come up with suitable varieties for Downy mildew resistance and further improvement for higher productivity under semi-arid conditions.

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ARTICLE

Slackening of Food Supply Chain during COVID-19 and Affecting Livelihood - A Global Concern

Ambika Prasad Mishra¹ Jyoti Prakash Sahoo^{2*}

1. Department of Soil Science, Faculty of Agriculture, Sri Sri University, Cuttack, Odisha, India

2. Department of Agricultural Biotechnology, Odisha University of Agriculture and Technology, Bhubaneswar, India

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ABSTRACT

The outbreak of COVID-19 has brought about another age on world as the human civilization is restricted in many aspects of everyday lives. There is no exception in the sector of food production and the supply chain of food. Due to constraints on demand, shutting of food production facilities, financial limitations, enterprise operations and delivery of different food items have been interrupted in the food supply chain. Every nation must comprehend the importance of the situation according to the spreading scenario of the ongoing pandemic. The probability of transmission via the food sector is regarded inconsequential, and the public authorities do not believe it necessary to follow COVID into workplaces. The unfavourable effects on the climate, the food framework and the people of the foodstuffs network are evident. An installation for the food supply chain should focus on amenities such as maintaining the safety and health of employees and changing working circumstances. This paper aims at discussing the effects of COVID-19 on the socio-economic status of human being including the negative impacts on the agriculture and food supply chain.

1. Introduction

A pandemic is not a novel phenomenon in human history, since mankind has experienced a variety of pandemics throughout history. Considering one of the major areas of the economy, the food supply chain, COVID-19 has an influence on the complete process from the field to the consumer. Due to the recent issues of COVID-19 lockdown, the food production, processing, distribution and demand have become a source of substantial worry in the food supply chain. COVID-19 has led to limits on the migration of employees, changes in consumer demand, closure of food production facilities, limited rules on the trade of food products and financial constraints on the food supply chain. Governments should therefore promote workers' and agri-food migration. Furthermore, financial help should be given to smallholder farmers or needy persons. On 11 March 2020 speech, the WHO called on nations to plan preventive and reactive action in line with the Global Strategic Preparedness and Response Plan, which identified the fast spreading COVID-19 as pandemic^[1,2].

WHO noted that this outbreak is not only a crisis of

**Corresponding Author:*

Jyoti Prakash Sahoo,

Department of Agricultural Biotechnology, Odisha University of Agriculture and Technology, Bhubaneswar, India;

Email: jyotiprakashsahoo2010@gmail.com

public health, but also a problem affecting all sectors. Each industry and each individual should thus participate in this fight against COVID-19 ^[3]. On March 11, 2020, WHO proclaimed the emergence of COVID-19 to be a worldwide pandemic ^[4]. Many people are affected by the virus, if the world scenario is considered (Figure 1). COVID-19 is anticipated to have a greater impact on the global economy.

Agriculture is one of the most significant industries in global economy. Food safety and human development are vital for agriculture. More than 60% of the world's population is estimated by FAO to rely on agriculture for survival ^[5]. In the current worldwide COVID-19 pandemic, the impact of COVID-19 on food and agriculture is crucial and enormous. COVID-19 influenced all the procedures connecting agricultural production to the end consumer. In addition, the food system and the value chain appear to be striking. The negative effects of the pandemic on food supplies and demand might challenge food safety. The recession that has already started in Europe and the Unit-

ed States is projected to depress economic activity across developed countries by 6% on average in 2020, despite an expected rebound later in the year as social distancing measures are lifted and stimulus measures take effect. This recession will spill over to the rest of the world through lower demand for trade and lower commodity prices. Developing economies will be hurt by the economic fallout caused by their own social distancing measures and by increased morbidity affecting the labor supply for farming and other business activity. For developing countries as a group, the economic fallout would lead to a decline of their aggregate GDP of 3.6% (Figure 2), but economies in Africa south of the Sahara, Southeast Asia, and Latin America would be hit much harder due to their relatively high dependence on trade and primary commodity exports ^[6]. The recession is expected to be less severe in China and the rest of East Asia, where we expect the economic recovery to start sooner with the earlier lifting of containment measures ^[6]. This review aims at examining the consequences of COVID-19 on the socio-economic condition

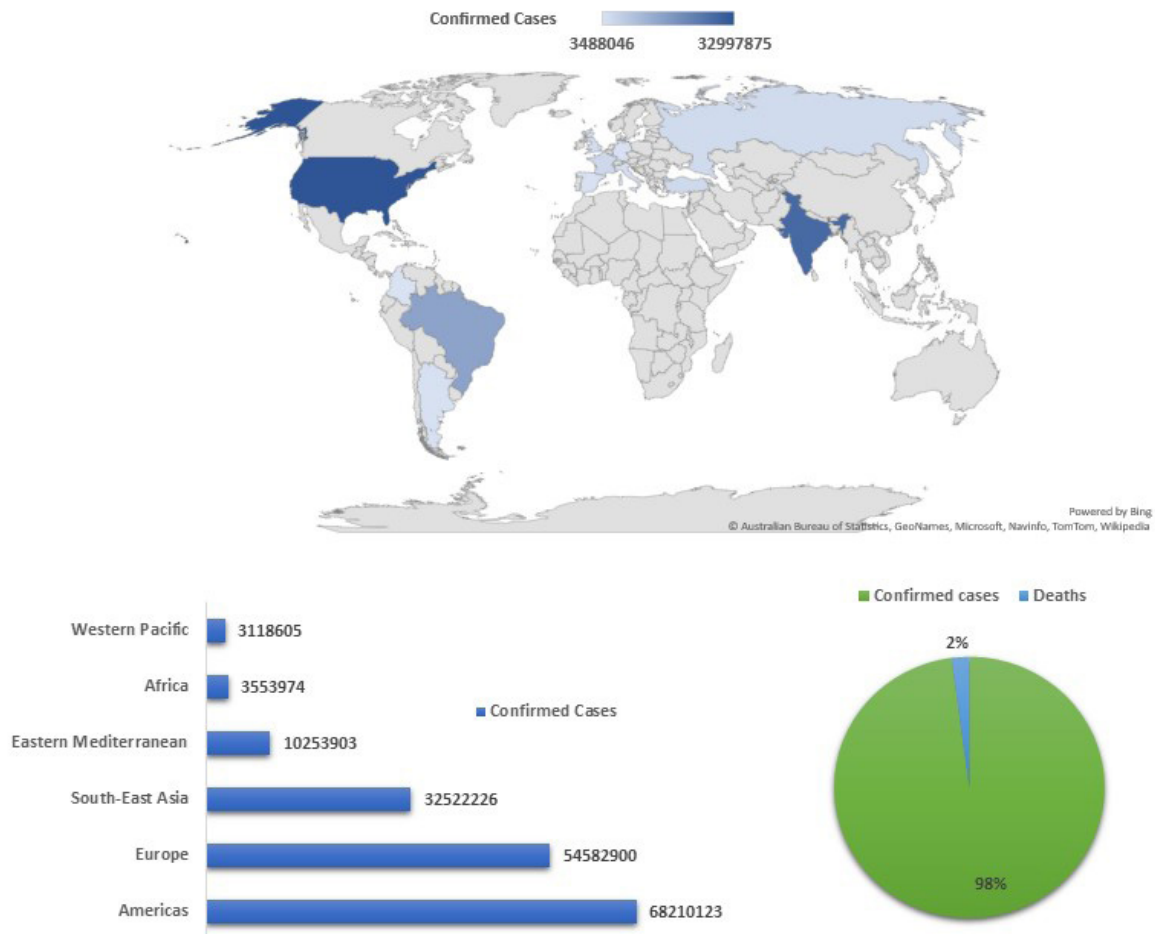


Figure 1. Globally scenario of COVID-19 till 5th June, 2021

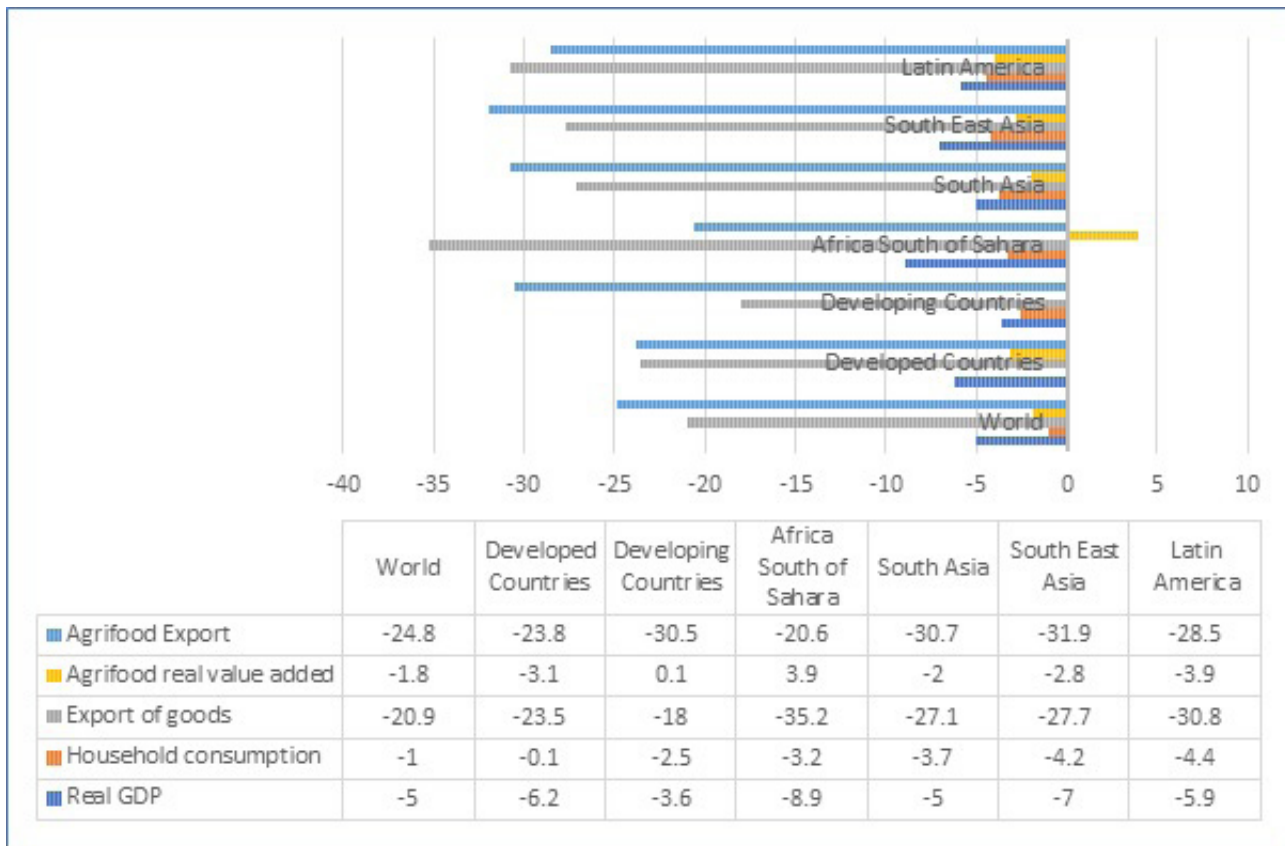


Figure 2. COVID-19 global economic recession in 2020 (% change from base year values) ^[6]

of human being including the detrimental effects on the agricultural and food supply chain.

2. Impact of COVID-19 on Food Production and Distribution

Most governments across globe have taken steps to restrict the infection rate, such as home quarantine, travel bans and the shutdown protocols. This limitation of mobility has a significant influence on food distribution throughout all the stages of the food supply chain (Figure 3). The world market in goods is expected to fall from COVID-19 by 13 percent to 22 percent ^[7]. Different agricultural sectors have suffered severe pandemics, including crops, animals and fisheries. Owing to limited availability of animal feed and a scarcity of work in India, COVID-19 has a greater impact on livestock production. Fish is an essential protein and energy source and accounting for more than 3 million individuals for more than 20 percent of animal protein. In the same way, the marketing of milk has been hindered by prolonged lockdown, coupled with closing hotels and restaurants.

During the lockdown, milk cooperatives are thus unable to supply milk to dairy producers. Farmers lack fundamental inputs such as seeds, fertilisers and insecti-

cides because of global trade disturbances. China is one of the world's largest manufacturers of fertilisers and exports. The Chinese lockdown has a major impact on global commerce in fertilizers ^[8]. Spring crops such as maize, sunflower, spring wheat, barley, canola, open field vegetables have been harmed by this pandemic. In *kharif* season, scientists claim that, India requires 250 lakh quintals of seed for cultivation practices ^[9]. So, if the pandemic continues, sowing of *rabi* and *kharif* seasonal crops might be adversely affected. In the farming business, health care and labour shortages for workers have been of great concern with the high incidence of transmission of COVID-19. Low and intermediate workers in nations lack adequate health and social protection services and, owing to a little amount of savings or no savings, many informal agriculturists are obligated to work during the COVID-19 epidemic, despite the self-isolation protocol as there is a substantial risk of the COVID-19 for these workers ^[10]. Most agricultural producers have a scarcity of labour. Employment losses are growing rapidly worldwide. Many Government and NGOs perform their part in keeping the food supply chain constant to overcome these eventualities. Currently the FAO is focusing on maintaining the food value chain and maintaining the food supply. This is

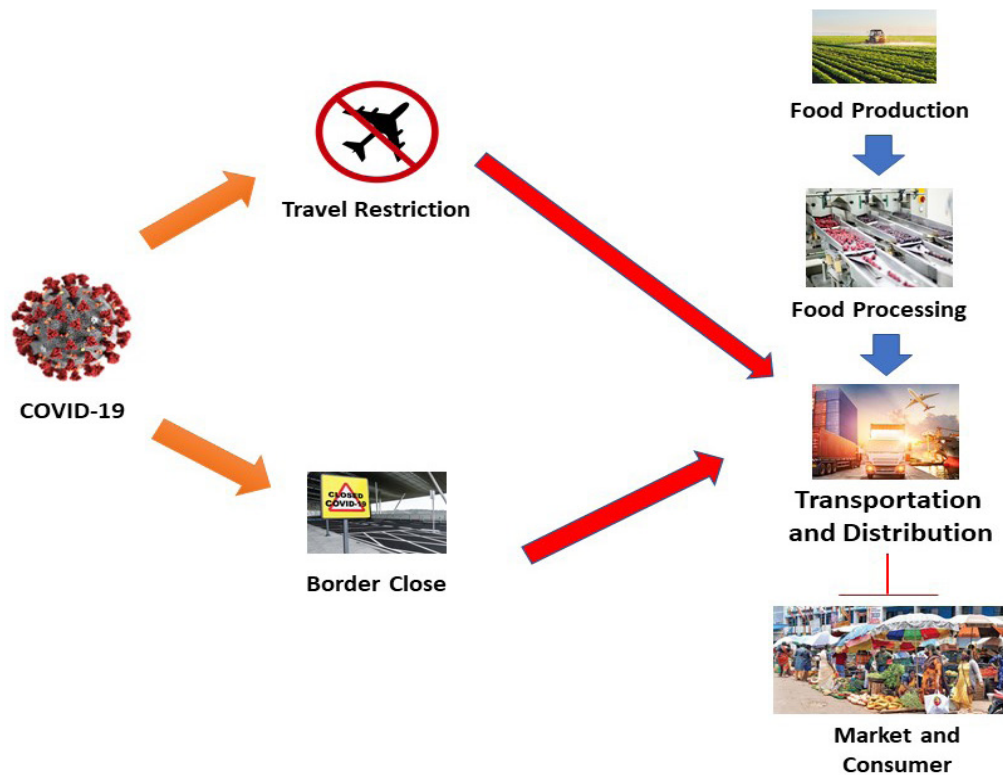


Figure 3. COVID-19 affecting food supply chain with major impact on food transport and distribution

the major purpose of the FAO. The major problems in the foodstuff supply chain are the procurement and continuation of food chains from manufacturers to end consumers^[11]. The challenges threaten the capacity of farmers to continue their business as usual, and can adversely affect the quality of food, freshness and food safety, and prevent market access and cost^[12].

3. Impact of COVID-19 on Food Demand and Food Security

Food safety only refers to the continuous availability and accessibility of enough healthy food. Food insecurity might emerge as a result of a reduction in international commerce, food supply chain disruption and food production. The FAO has stated that it might be difficult for small-scale farmers and fishermen to buy their product that would in turn lower their revenue and capability. In the lowest and vulnerable sectors of population, the food insecurity increased by the COVID-19 would be heavily affected^[13]. Currently, 820 million people suffer from chronic starvation, while 113 million suffer from acute insecurity^[14]. Thus, food availability disturbances caused by the pandemic severely affect these people. Approximately 10 million youngsters rely on food to meet their dietary needs. However, while schools are closed and school meal programmes suspended, these youngsters will no longer

have regular school meals, which can diminish their illness capacity^[15]. The use of animal protein has reduced considerably in the current circumstances as a result of a mistaken view of the animal as a viral reservoir. The supply chain affects manufacturers, distributors and consumers as well as labour-intensive food processing factories. Production in numerous facilities was decreased, suspended and temporarily stopped because of employees who were tested COVID positive and were unwilling to go to work, believing that they were sick at work, mostly in enterprises producing meat products during the epidemic.

For these reasons, pork production capacity in late April was projected to drop by around 25 per cent^[16,17]. Closing of food plants has generated a food supply chain ripple effect. Greater demand on the part of consumers resulted in bare shelves and a reduction in the availability of meat items prompted increased prices. Some marketplaces have restricted the quantity of products a buyer wishes to buy, such as beef and pork. Another element that caused food chains disruption during the COVID-19 pandemic is centralised production of food. This paradigm has helped to improve productivity and cut expenses for the food processors. However, there are certain negatives to centralization, such as tight and long supply chains. Furthermore, the use of the small number of really large production facilities to satisfy demand may generate challenges^[18]. COVID-19 is spreading through the developing

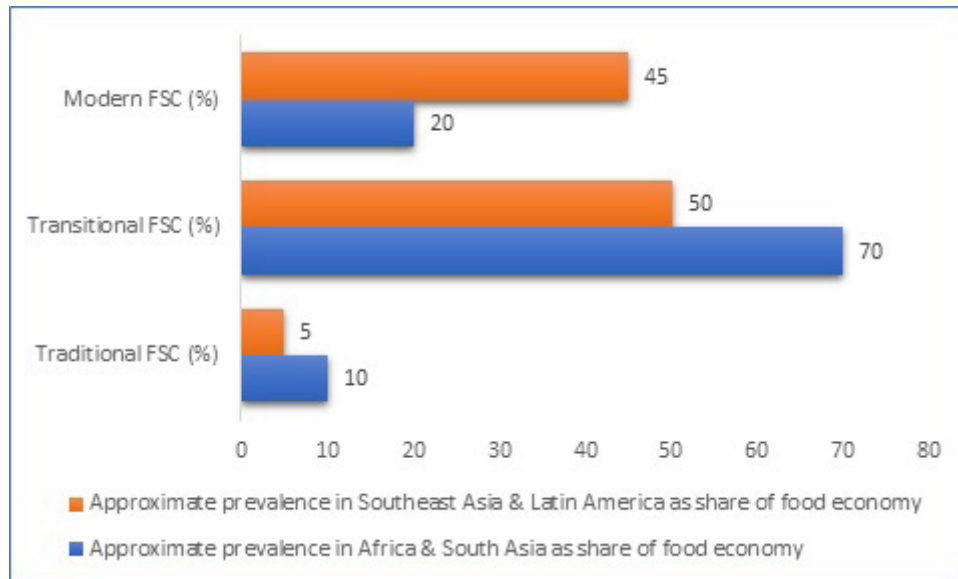


Figure 4. The three stages of food supply chains and their prevalence in the food economy

world. Many low- and middle-income countries are now reporting growing numbers of cases and imposing rigorous lockdown regulations in response, which impact all aspects of the economy. Most urban and rural consumers now depend on markets, in contrast to 30 to 40 years ago when a large share of rural populations lived “off the grid” in subsistence agriculture. Consumers purchase 80% of all food consumed in Africa and Asia, and thus FSCs (Food supply Chain) provide 80% of all food consumed. Modern FSCs (dominated by large processing firms and supermarkets, capital-intensive, with relatively low labour-intensity of operations) constitute roughly 30%-50% of the food systems in China, Latin America, and Southeast Asia, and 20% of the food systems in Africa and South Asia. Transitional FSCs (stretching from rural to urban areas, fragmented and dominated by thousands of labour-intensive SMEs - small and medium-sized enterprises) dominate food systems, constituting 50%-80% of the food economies of developing Asia and Africa (Figure 4). SMEs in transitional FSCs in developing countries tend to be found in clusters such as dense sets of food processing SMEs, scores of meal vendors at truck stops, and dense masses of wholesalers and retailers in public wholesale markets and wet markets^[18]. Each of these clusters could have numerous SMEs.

4. Effects of COVID-19 on Consumer Behaviour

Outreach COVID-19 scenario is disturbing the everyday routine. Furthermore, confinement has caused individuals' tension and driven them towards succulent food for a great sensation. Due to their capacity to promote serotonin synthesis, carbohydrate-rich meals can be em-

ployed as self-medical components. This improper eating pattern however can lead to obesity associated with chronic inflammation and significant COVID-19 problems^[19]. The shutdown of restaurants and restricted food service venues altered food or buying patterns and led to an unexpected shift of demand from food to retail. Reports have shown that the ratio of food purchases and food services to supermarkets was 50% before the pandemic, while for supermarkets it is approximately 100%. There have been reduced numbers of visitors to the food store, yet grocery expenditure has been risen. During COVID-19 shutdown, consumers saw a decreased supply of several food categories. Interestingly, on the grocery shelves bread and baked items held their position. Consumers rely on long-preserveable items, such as dry or canned food, pasta, milk and milk replacements, convenience frozen meals and everyday home cooking. Those food materials were stuck at home due to the shift towards home-baking and faithful myths or misinformation. In fact, the lack of eggs was fascinating not only because of increasing demand but also because of the absence of retail packaging. COVID-19 concerns are wide-ranging, covering both health and financial problems.

In a research conducted in 18 different nations, it has proven that consumers have altered their behaviour as a result of their readiness to eat more healthy food, but to do so at the same time without exceeding the typical budget. Consumers have taken a core approach to return to natural foods and drinks that offer nutrient supplements such as fruits and vegetables, beans, grains or olive oil. At the same time, the influence of COVID-19 on their mental condition worries most customers, which is the reason

why many customers hunt for dietary products to boost this mood^[20]. The behaviour of the Italian public on food choices and behaviour was studied by a recent poll of the Italian Agricultural Research and Economic Council (CREA) under COVID-19 quarantine. About 2.900 individuals have answered from all areas of Italy. The findings show healthy eating and drinking: rise for veggies (33 percent), fruit (29 percent), vegetables (26.5 percent), and extra-virgin olive oil (21.5 percent). However, 44.5 percent of them were found to have more sweet drinks and 16 percent to drink more wine. The intake of more calories and poor physical exercise revealed a 44 percent weight increase. 37 percent of respondents said their diet should be adapted to reduce weight^[21].

Another research indicated that 42 percent of consumers favoured packaging food more than normal among 1000 persons over 18, while another part of this ratio indicated the pandemic had not changed their position on packaging food. 82 percent of customers believe food they buy is safe to consume during the epidemic. However, a part of the food they buy is unlikely to be safe to buy. A total of 77 percent say food producers can offer sufficient food to suit the requirements of consumers and 16 percent say they cannot afford it^[22]. Consumers playing a major role in the food supply chain have profoundly influenced the supply chain as changes in consumer behaviour. The outbreak of COVID-19 led to substantial food price increases due to continuous lockdown constraints as well as interruptions of the food supply chains^[23]. Some customers will focus more on reducing food waste in order

to improve food safety^[24]. However, the contrary is also conceivable since, the shutdown of schools, restaurants or processing facility, most of the perishable food was wasted or dispelled. Moreover, transit challenges during the locking or over-commercial purchase of perishable foods caused a higher levels of food waste^[25,26]. Changing requests also modify the materials or design of packaging, transportation alternatives and storage conditions^[27].

5. Effects of COVID-19 on Global Food Trade

Although present conditions appear to be extraordinary, a long way before the COVID-19 crisis has been shown in the sensitivity of food systems to climatic issues and illnesses. Indeed, the food systems were unstable due to multiple occurrences prior to the oil crisis in the 1970s, the SARS and Ebola epidemic and the food crisis of 2007-08. Africa Swine Fever sickness crisis just a year ago, a gradual outbreak in East Europe and Asia, has sparked global commodities markets. China, the world's greatest pork producer (with one third of the world's market) and the world's top exporter, lost 37% of its pigs by 2019^[28]. Ebola has a major detrimental influence on various African countries' agricultural output, marketing and trade industries. Farmers have restricted access to supplies such as seeds, fertilisers, and pesticides on the production side owing to road restrictions, and most regions are facing job shortages (Figure 5)^[28]. More than 40% of agricultural land was not farmed for this reason. However, output was not affected by the epidemic since farming regions were

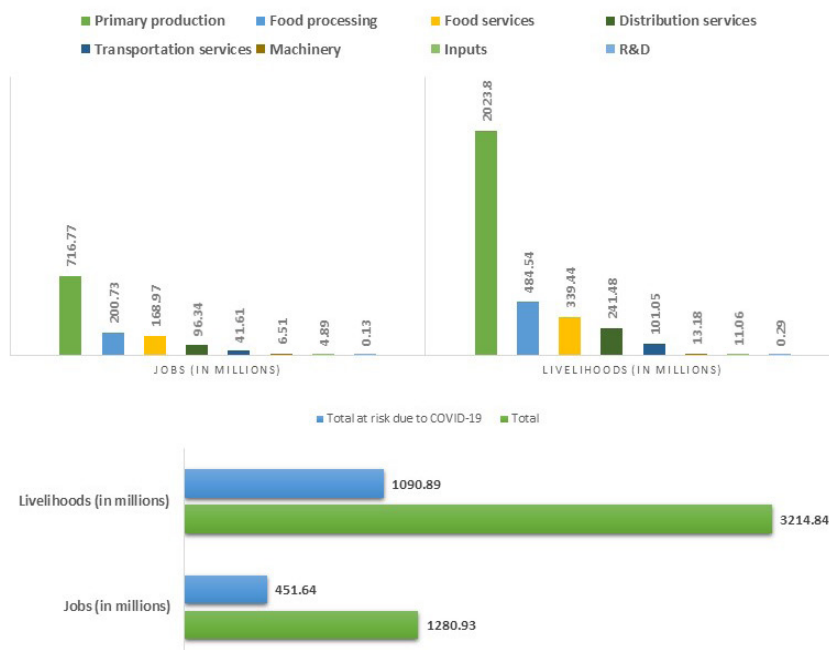


Figure 5. Formal jobs at risk in food systems during this COVID-19 pandemic^[28]

frequently remote from urban populations in geographical areas^[29,30].

The current COVID-19 issue has affected several nations' food trade policy to reduce exports and facilitate imports. It is mainly because governments apply export restraints that the quantity of items on the local market is maintained. Although this results in the short-term export limitation, it also has some negative impacts. First, export limitations lead domestic prices to fall, hurting farmers to lose crop output financially and reducing incentives in the business. Secondly, by losing their position in international markets, countries would lose their competitive edge. Thirdly, constraints on exports degrade the reputation of exporters and urge importers to diminish world market confidence, therefore diminishing their faith in international commerce and damaging future business possibilities for exporters^[31,32]. The COVID-19 pandemic has led to major food trade impacts as a result of the export restrictions, and disruption in the food supply chain. Since export-limited policies have driven up stable food prices such as wheat, maize, and rice and reduced the quality and amount of food eaten^[33]. The product which is not cultivated or manufactured nationwide could not also be found by customers. Local vendors might not find consumers and result in excess supply and economic losses when export restricting regulations were implemented. Foods that were not cultivated locally but required to be processed, due to constraints and the use of food plants to respond to demand, were also affected badly^[34-36].

6. Business Strategies to Tackle COVID-19 Pandemic

A crisis committee should be set up to emphasise COVID-19's impact on the food value chain while not waiting too long for some plans and actions to be implemented by the countries. The Committee should be a major player in monitoring progress and proposing measures to lessen the impact of COVID-19 on agricultural production and food supply chain. It is crucial for the committee to work with the business sector to ensure the initiatives are implemented adequately^[37]. COVID-19, consisting of seven academicians and two members of the Ministry of Agriculture and Forestry, has been set up by the Minister of Agriculture and Forestry in Turkey to take actions and suggestions in respect of agriculture and food under this ongoing pandemic^[38]. In Turkey, the Ministry of Agriculture and Forestry has informed farmers, production facilities or shops such the slaughterhouses, greenhouses and bakeries about measures and financial aid programmes. Furthermore, the Interior Ministry released lockdown instructions that allow farmers and food manufacturing

enterprises to maintain operations at lockdowns^[38,39].

Canada has created an Agriculture Response Program that covers 50-75% of funding that must not be reimbursed as regards health protocols, marketing, transport of products, distribution, strategic initiatives, slaughter efficiency and development^[40]. In the US, the Department of Agriculture has committed programmes and flexibility to support agricultural farmers associated to the COVID-19 pandemic by providing food aid, supply chain for milk, crop insurance, farmer loans, commodity credit, crop acreage, animal death wages and financial harm^[40]. In order to reduce the effect of restrictions on migrant labour local residents or jobless might be taught in agricultural operations like planting, weeding or harvesting. In order to make connectivity between locals and farmers, online platforms should be leveraged^[41]. Unemployed persons or local workers should be encouraged to be agricultural workers by boosting salaries as local employees do not want to work on agriculture since they have a chance to discover better non-agricultural options^[42]. Outbreak COVID-19 indicated the greatest possible solution to resolve labour shortages over the medium and long term is through working mechanisation policy^[41]. In order to determine shortages or surpluses that may emerge due to import prohibitions and export limitations, rapid yield forecasting and determination of domestic food supplies must be established. Better food stock management in various locations should be addressed and non-food utilisation of agricultural products (e.g., biofuel) should be minimised^[42]. Models of crop production information can be employed to help governments decide on food safety or marketing of agricultural products.

In short, as the duration of the COVID-19 is unknown, farmer business models have begun to alter. The development of infrastructure that might be used for the agricultural and food industry should be given considerable attention to companies. Financial incentive packages must also be provided based on the needs of companies^[43]. Understanding the effects of COVID-19 behind restriction rules is especially significant since the availability levels of food are high and the major production projection is strong. Although these conditions are favourable, governments seek to assure food security because of increased consumer demand and to protect disadvantaged individuals from price rises. However, learning from previous experiences show that avoiding trade restriction regulations can be as beneficial as direct promotion actions to safeguard consumers and agricultural earnings^[44,45,46]. Therefore, choices and methods for agricultural trade should be altered to reduce the medium-term consequences of the pandemic of COVID-19.

7. Conclusions

During the COVID-19 pandemic a continuous flow of food supply is crucial to prevent the food crisis and minimizing the detrimental impact on the world economy by strengthening agriculture and the food sector, which is one of the most significant sectors combined with health care. Consequently, the seriousness of the crisis must be realised by each nation and, in some cases, it should strengthen or relax the pandemic-dependent measures. The supply network should also be sufficiently flexible to adapt to the food supply chain issues. This is thus determined that the influence of COVID-19 is not excluded from food and agriculture. This pandemic is damaging crops, livestock and fisheries. Today's worldwide scenario needs food safety and security. Concerning the food safety for the most vulnerable sector of the population, the food supply chain has been severely damaged due to COVID-19. Furthermore, most migrant, informal, seasonal farm labour lose their employment that might influence food demand. Therefore, without affecting the food supply chain and taking the food security of the citizens into account, the government of different countries across the globe should use steps to limit the pandemic issue. Each government should establish its own policy to identify the impact and significance of modifying specific trade strategy features on agricultural inputs. This is particularly crucial if domestic agricultural production capacity is restricted and there is an increase in costs for certain foodstuffs.

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ARTICLE

Ethnobotanical Study and Vulnerability of *Uvariodendron molundense* (Annonaceae) in Gbado-Lite City (Ubangi Eco-region), Democratic Republic of the Congo

Ruphin Djolu Djoza¹ Colette Masengo Ashande¹ Koto-te-Nyiwa Ngbolua^{1,2*} Mawunu Monizi³ Jeff Iteku Bekomo² Damien Sha-T. Tshibangu⁴ Dorothée Dinangayi Tshilanda⁴ Pius T. Mpiana⁴ Mudogo Virima⁴

1. Département de l'Environnement, Faculté des Sciences, Université de Gbado-Lite, Gbado-Lite, République Démocratique du Congo

2. Département de Biologie, Faculté des Sciences, Université de Kinshasa, Kinshasa, République Démocratique du Congo

3. Department of Agronomy, Polytechnical Higher Institute of Uíge, Kimpa Vita University, Republic of Angola

4. Département de Chimie, Faculté des Sciences, Université de Kinshasa, Kinshasa, République Démocratique du Congo

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ABSTRACT

Democratic Republic of the Congo is a real reservoir of medicinal plants. These plants play a major role in the treatment of certain common pathologies in tropical regions. The aim of this study was to list the ethnomedicinal uses of *Uvariodendron molundense*, a medicinal and aromatic plant from the Ubangi ecoregion. The ethnobotanical survey was carried out in Gbado-Lite with 200 people using stratified probability sampling. The respondents were interviewed individually on the basis of free consent. The study revealed that the majority of respondents were men (72%) and had a secondary education (37%), followed respectively by illiterates (34%) and those with a primary education (28%), and finally, university graduates represented only 1% of the respondents. 83% of the respondents were farmers, while 79% of the respondents were married. The leaf is the most used organ (81%) followed by stem and root bark. *U. molundense* is used both as food and medicine. The plant treats eight diseases (pain, malaria, cold, hypertension, gastritis, infection, headache and rheumatism). The calculated value of the informant consensus factor is 0.96 and indicates that there is a high degree of consensus among informants regarding the use of *U. molundense* against these diseases in Gbado-Lite. Decoction is the most commonly used method of preparation (89%) and 50% of the respondents stated that the species is currently not very abundant, while 31% of the respondents felt that the plant was rare. The calculated value of the vulnerability index shows that *U. molundense* is very vulnerable in its natural environment ($Iv > 2.5$).

**Corresponding Author:*

Koto-te-Nyiwa Ngbolua,

Département de l'Environnement, Faculté des Sciences, Université de Gbado-Lite, Gbado-Lite, République Démocratique du Congo;

Département de Biologie, Faculté des Sciences, Université de Kinshasa, Kinshasa, République Démocratique du Congo;

Email: jpngbolua@unikin.ac.cd

1. Introduction

Democratic Republic of the Congo (DRC) is a real reservoir of medicinal plants. These play a major role in the treatment of certain common tropical diseases^[1]. According to the WHO (World Health Organization), more than 80% of the populations in Africa in general and in the DRC in particular, use Traditional Medicine (TM) to solve the problem of primary health care^[2,3]. The use of medicinal plants for various health problems is not only a choice, but is also reportedly linked to poverty and the high costs of modern medicines^[4,5]. WHO defines TM as the sum of knowledge, skills and practices that are grounded in the theories, beliefs and experiences of a given culture and that are used to maintain human health or to prevent, diagnose, treat and cure disease^[3]. Based on scientific evidence, research on renewed TM aims at the production and distribution of improved traditional medicines (ITMs) formulated from these medicinal plants in order to contribute to the achievement of MDGs 3 (health), 12 (sustainable consumption) and 15 (life on earth).

In recent years, a few studies on the ethnobotany of

local wild medicinal and/or food plants have been carried out in Kinshasa and in the province of North-Ubangi in the DRC, including those by Masengo *et al.*^[6,7], Ngbolua *et al.*^[8], Ngbolua *et al.*^[9]. It should be noted, however, that data specifically on aromatic medicinal plants remain very fragmentary. Thus, the present study was initiated with the aim of cataloguing the ethno-medical uses of an aromatic plant from the Ubangi ecoregion, *Uvariadendron molundense*. The specific objectives of this study are to determine the socio-demographic characteristics of the respondents (sex, age, level of education, profession, family situation) who use *U. molundense* in Gbado-Lite; to identify the most commonly used organs of the plant and the diseases treated, as well as the different ways in which medicinal recipes derived from the plant are prepared, and the population's perception of the frequency of use of the species over the last 10 years.

Thus, the documentation of local naturalist knowledge on *U. molundense* is essential because bio-resource management policies can only be sustainable if they integrate the social, cultural and economic values that local communities associate with them^[6,7].

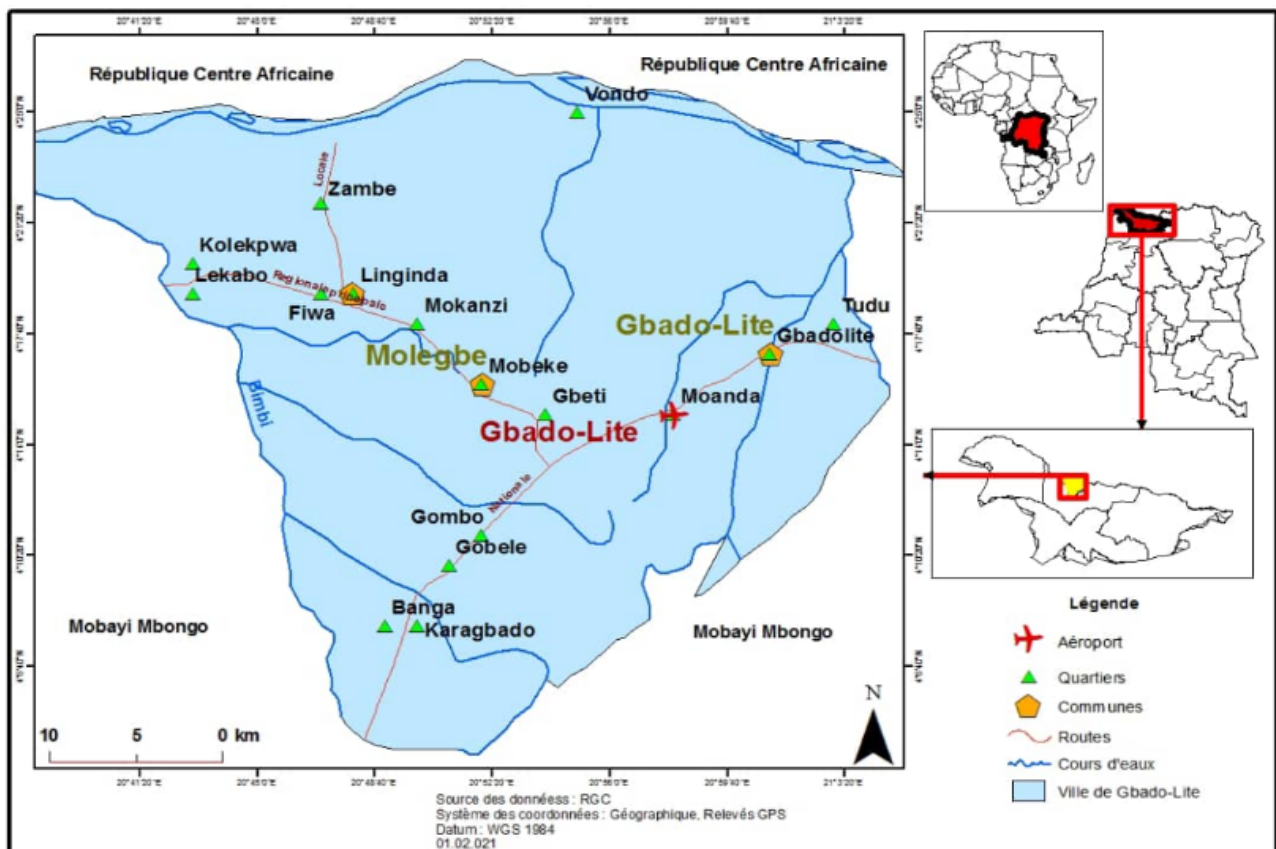


Figure 1. Geographical location of the town of Gbado-Lite and its surroundings (North Ubangi Province, Democratic Republic of Congo)

2. Materials and Methods

2.1 Study Area

The present study was carried out in Gbado-Lite (Latitude: 4° 16' 41" North; Longitude: 21° 00' 18" East; Altitude: 300-500 m above sea level). The town of Gbado-Lite (Figure 1) is located in the Ubangi eco-region, a subset of the *Northeastern Congolian lowland forests*. This eco-region is one of the 200 global priority terrestrial eco-regions known as the "G200". It has an area of 278 km² and an estimated population of 198,839 ^[10-15].

2.2 Methods

The ethnobotanical survey was conducted in Gbado-Lite city with 200 people using the stratified probability sampling method as previously described ^[1,6,7,16]. To collect the ethnobotanical data, this sample of 200 people was randomly drawn. The respondents were interviewed individually on the basis of a survey form. The main data collected were socio-demographic data (sex, age, socio-cultural group, level of education, occupation and marital status) and ethnobotanical data (vernacular name, part used, diseases treated, category of use and method of preparation of medicinal recipes, etc.). The survey was carried out according to the principles of the Helsinki Declaration (free consent of respondents, etc.) and in the local language (Lingala).

The vulnerability index was calculated according to the ECOFAC (Central African Forest Ecosystems) method based on the identification of a certain number of characteristics or constraints of the species, namely frequency of use (c1), plant organ used (c2), stage of plant development (c3), mode of collection (c4), pharmaceutical form (c5), biotope (c6), mode of diaspora dissemination (c7), morphological types (c8) and perceived abundance (c9) ^[1].

3. Results and Discussion

The results of this study show that the majority of respondents are men (72% vs. 28% of women). The majority of respondents had a secondary education (37%), followed respectively by illiterates (34%) and those with a primary education (28%), and finally, university graduates represented only 1% of the respondents. 83% of respondents were farmers. They are followed respectively by students (10%), civil servants (5%) and teachers (2%). 79% of the respondents were married compared to 21% who were single.

Table 1 gives the socio-demographic parameters of the respondents.

The fact that the main activity of the respondents is

Table 1. Socio-demographic parameters of respondents

Socio demographic parameters	Number	Frequency (%)
1. Sex		
Male	144	72
Female	56	28
Total	200	100
2. Age		
18-35 years	70	35
36-50 years	70	35
>50 years	60	30
Total	200	100
3. Education level		
Primary	56	28
Secondary	74	37
Universitary	2	1
Illiteracy	68	34
Total	200	100
4. Profession		
Farmers	166	83
Elèves	20	10
Teachers	4	2
Civil servants	10	5
Total	200	100
5. Marital status		
Single	42	21
Married	158	79
Total	200	100

traditional slash-and-burn agriculture can have a negative impact on the environment, particularly forest ecosystems. Indeed, it has been shown that the practice of traditional slash-and-burn agriculture in the province of North Ubangi in DRC is the main cause of deforestation and forest degradation. The latter are converted into agricultural space leading to the disappearance of forest and non-timber products (NTFPs) that generate income for poor households in the town of Gbado-Lite ^[17]. This is why it is essential to extend agricultural activity to the domestication of NTFPs in order to develop reasoned, multifunctional and sustainable peasant agriculture and thus ensure the resilience of the population in the face of current changes.

The education level of the population has a very significant impact on the adoption of innovations and/or the transfer of knowledge and technology to increase productivity in all sectors of activity and in decision making ^[18]. The present study reveals that the majority of the respondents have a secondary education. This justifies the need to strengthen their capacity in NTFP management. Thus, agro-ecology, defined as the science of natural resource

management for the benefit of the poorest people facing an unfavorable environment, is a discipline to be developed and popularized in North Ubangi Province^[19].

Figure 2 shows the different vegetative organs (parts) used in the plant.

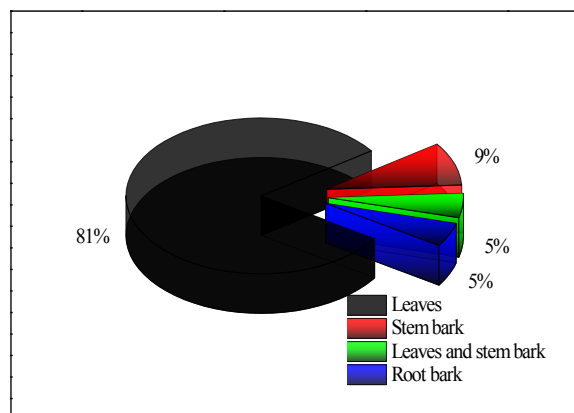


Figure 2. Different used vegetative organs (parts) of the plant

The Figure 2 shows that the most commonly used part of the plant is the leaf (81%), followed by stem bark (9%), leaves and stem bark and root bark (5% each).

These results corroborate those found by^[9,20,21]. The use of these organs is justified by the simple fact that they are rich in bioactive secondary metabolites that give the plant its therapeutic virtues. It should be noted, however, that harvesting practices such as debarking and uprooting of plants are dangerous as they prevent the plant from reaching flowering, promote infections and are the cause of the threat of species extinction^[22]. Similarly, stem removal is an ecologically unsustainable practice that results in the immediate loss of the medicinal plant taxon.

Figure 3 shows the categories of use of the plant.

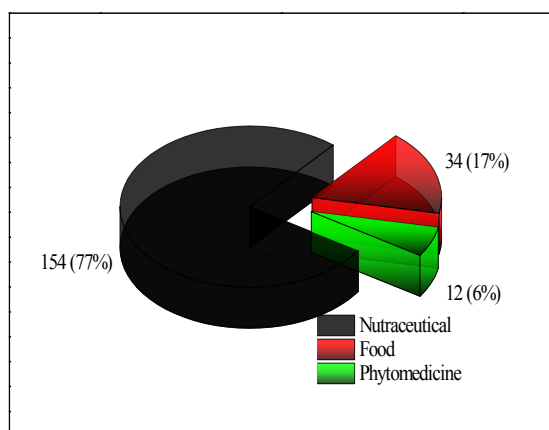


Figure 3. Categories of use of the plant

Figure 3 shows that the plant *Uvariadendron molundense* is a nutraceutical, i.e. it is used as both food and medicine.

It is thus well known that in tropical Africa, wild medicinal plants are the most exploited resources in rural areas^[23,24,25]. However, these plants are increasingly being abandoned by the local population in favor of so-called exotic plants, mainly due to their scarcity, but also their lack of knowledge and the absence of scientific evidence on their toxicity and other pharmaco-biological evidence^[8].

However, wild plants are currently of great importance in nutritherapy due to their medicinal and nutritive properties. In a study on the evaluation of the chemical composition and bioactivity of *U. molundense* against sickle cell disease and associated bacterial pathogens, the results revealed that the leaves and stem bark contain various secondary metabolites (total phenols, flavonoids, anthocyanins, tannins, quinones, saponins, alkaloids, steroids, terpenoids and leucoanthocyanins) and are endowed with anti-sickle cell activity in vitro. At 100 µg/mL, the normalization rate was 89% for the total organic acid extract (ED₅₀ = 0.391 µg/mL) and 82% for the anthocyanin extract (ED₅₀ = 0.659 µg/mL). The antibacterial activity of the tested extracts was very good against *Staphylococcus aureus* (MIC ≤ 31.25 µg/mL) whereas, for *Escherichia coli*, only the extraction of total organic acids presented an interesting activity (MIC = 31.25 µg/mL)^[26]. Thus, despite its nutritional properties, this plant can be useful for sickle cell patients.

Figure 4 shows the frequency of diseases treated by the plant *Uvariadendron molundense*.

The figure shows that this plant cures eight diseases, of which pain, malaria and colds are the most frequently cited, followed by hypertension and gastritis, infection, headaches and rheumatism respectively.

The calculated value of the informant consensus factor (number of citations Nr minus number of diseases treated Na divided by number of citations Nr minus 1)^[1] is 0.96 and indicates that there is a high consensus among informants regarding the use of *U. molundense* against these diseases in Gbado-Lite city. Indeed, according to the WHO (World Health Organization), more than 80% of the population in Africa and other poor regions of the world rely on traditional medicine for the treatment of common diseases^[4,5].

Figure 5 shows the different modes of preparing the plant. The figure shows that decoction is the most commonly used preparation method (89%), while expression accounts for only 11%. Either processes or modes of preparation are also reported by Masunda *et al.*^[27] in Central Kongo Province, Ngbolua *et al.*^[9,20,21] in Kinshasa. Decoction is most commonly used as an oral drink (per os). Consumption is often done in a fresh state so as not to alter the properties of the bioactive molecules.

Figure 6 gives the population's perception of the fre-

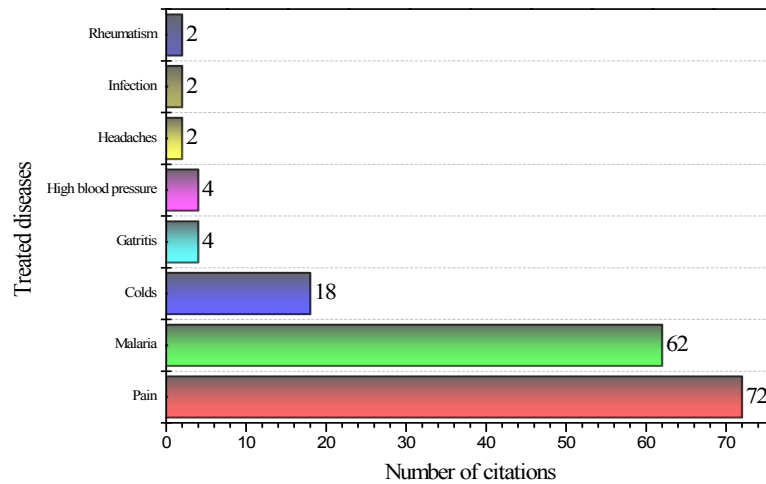


Figure 4. Diseases treated by the plant *Uvariodendron molundense*

quency of the species over the last 10 years.

With regard to the population's perception of the frequency of the species, the majority of respondents stated

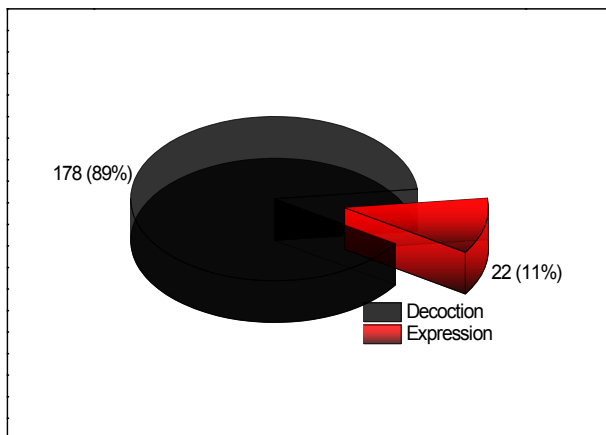


Figure 5. Different methods of preparation of plant-based recipes

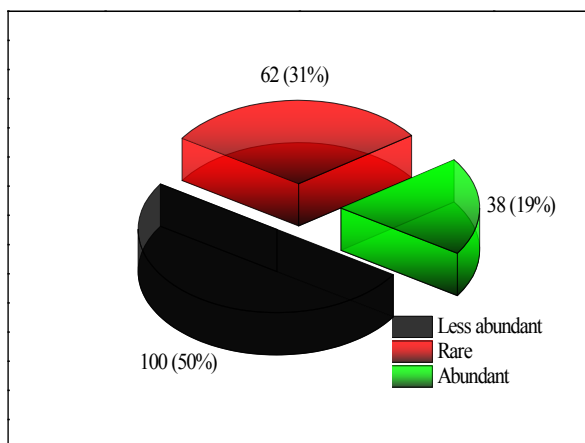


Figure 6. People's perception of the frequency of the species

that the species is not very abundant (50%), while 31% of respondents considered the plant to be rare, compared to 19% who thought that it was abundant.

According to the work of Mongeke et al. [28], medicinal plant genetic resources constitute goods for humanity and require sustainable management with a view to their valorization according to the principle of access and benefit sharing (ABS). Indeed, these bio-resources are sources of natural bioactive substances that can be used as hit molecules or for the development of standardized phyto-drugs that are less costly and easily accessible to the population. Hence the need for participatory management, a strategy to combine socio-economic development and nature conservation, in order to prevent the erosion of biodiversity and limit the impact of agriculture on the environment [29].

The vulnerability index of *Uvariodendron molundense* is given in Table 2 below.

Table 2. Vulnerability index of *U. molundense*

	Characteristics	Vulnerability level
C1	Frequency of use (100% of respondents)	3
C2	Plant organ (leaves, bark, stem and roots)	3
C3	Developmental stage (Adult)	2
C4	Collection (Gathering)	3
C5	Pharmaceutical form (Decoction)	3
C6	Biotope (Forest)	3
C7	Mode of dissemination of diaspores (Sarcochorie)	3
C8	Morphological type (Tree)	2
C9	Abundance (Low)	3
	Vulnerability index (Iv)	2,78

Legend: Level 1: Low vulnerability, Level 2: Medium vulnerability, Level 3: High [1].

The calculated vulnerability index value according to

ECOFAC shows that *U. molundense* is very vulnerable ($Iv > 2.5$) in its natural environment because of its frequency of use and the parts used, its mode of collection by the local population, its pharmaceutical form, its biotope and the mode of dissemination of its diaspores as well as its low abundance in the environment. There is therefore reason to fear the disappearance of *U. molundense* in the wild if no conservation measures are taken in the short term. Indeed, the results of this study indicate that *U. molundense* is a wild food plant with a diversity of uses in Traditional Medicine. Moreover, this plant genetic resource is essentially a product of gathering. Hence, the need for its domestication from a wealth creation perspective as the available data on the properties makes this plant a raw material for the development of a biopharmaceutical industry.

Indeed, Traditional Medicine occupies a key position in the management of both urban and rural diseases in Africa [4,5]. To this end, the domestication of this bioactive medicinal plant can be a strategy to reduce human pressure on natural forests while improving the lives of communities through the creation of a productive ecosystem through the ecological rehabilitation/restoration of degraded peri-urban ecosystems.

4. Conclusions and Suggestions

The aim of this study was to identify the ethno-medical uses of *U. molundense* in Gbado-Lite with a view to its development according to the principle of access and benefit sharing. This study shows that:

- o The majority of respondents is men (72%) and has a secondary education (37%);
- o 83% of respondents are farmers while 79% of respondents are married;
- o The leaf is the most used organ (81%) followed by stem and root barks;
- o *U. molundense* treats pain, malaria, colds, hypertension, gastritis, infections, headaches and rheumatism;
- o The calculated value of the informant consensus factor is 0.96;
- o Decoction is the most used preparation method (89%);
- o *U. molundense* is very vulnerable in its natural environment ($Iv > 2.5$).

It is therefore desirable that further research be carried out to gain a better understanding of the ecology, phytochemistry, pharmaco-biological, toxicological and nutritional properties of this plant species and its domestication in North Ubangi.

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REVIEW

Proteomics and Bioinformatics as Novel Tools in Phytoremediation Technology- An Overview

Monalisa Mohanty*

Department of Biotechnology, Laboratory of Environmental Biotechnology, Rama Devi Women's University, Bhubaneswar, India

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ABSTRACT

Biotechnology plays an important role in mitigation of various pollution in a cost effective manner by using the complex chemistry of living organisms, various cell manipulations and their approaches for environmental cleanup along with environmental sustainability. One such technology is phytoremediation technology or green technology which has emerged and evolved as a novel tool for remediation of toxic contaminants from environment. Plants with its diverse range show a remarkable range of their phytoremediation potentiality for establishing a sustainable environment. There is a huge exploitation of natural resources through expanded industrialization, urbanization, modern agricultural development, energy generation to fulfill the never-ending human desires and need. This disturbs the balance in nature where we reside and leads to progressive deterioration of the environment. There are several biotechnological advances which are employed for combating both the biotic and abiotic stress problems caused due to toxic contaminants in the environment. Various biotechnological interventions such as bioinformatics, proteomics, genomics, metallomics and metabolomics play a crucial role and open new avenue in this context. This omics approach is now integrated with bioinformatics to serve as a novel tool in phytoremediation technology. This smart technology provides insights into the complex behavior of enzymes, proteins and metabolites action and their biochemical pathways for degradation of wastes. This leads towards deriving a sustainable solution for environmental pollution.

1. Introduction

We all are struggling for a safe, contaminant free and clean environment. Our increasing demands for leading a more comfortable and luxurious lifestyle release hazardous substance and expose our environment to a great threat. There are several biotechnological advances which are employed for combating both the biotic and abiotic stress problems caused due to toxic contaminants in the environment. There is a huge exploitation of natural re-

sources through expanded industrialization, urbanization, modern agricultural development, energy generation to fulfill the never-ending human desires and need. This disturbs the balance in nature where we reside and leads to progressive deterioration of the environment.

Biotechnology plays an important role in mitigation of various pollution in a cost effective manner by using the complex chemistry of living organisms, various cell manipulations and their approaches for environmental

**Corresponding Author:*

Monalisa Mohanty,

Department of Biotechnology, Laboratory of Environmental Biotechnology, Rama Devi Women's University, Bhubaneswar, India;

Email: monalisamohanty@rdwu.ac.in

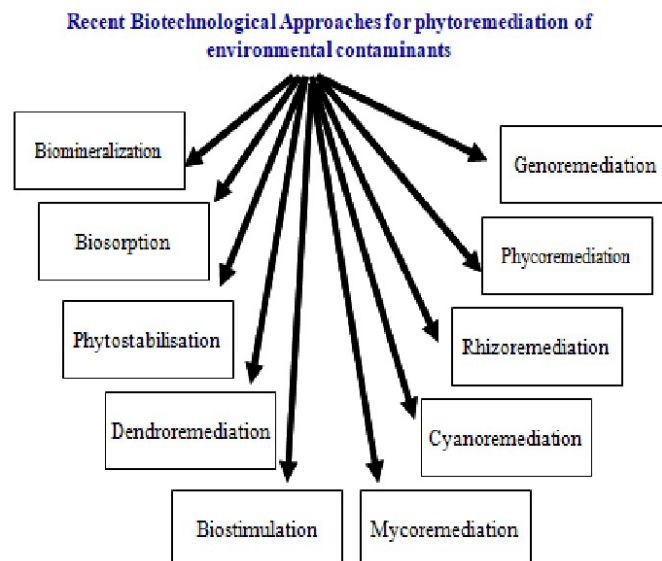


Figure 1. Biotechnological interventions for phytoremediation of environmental contaminants

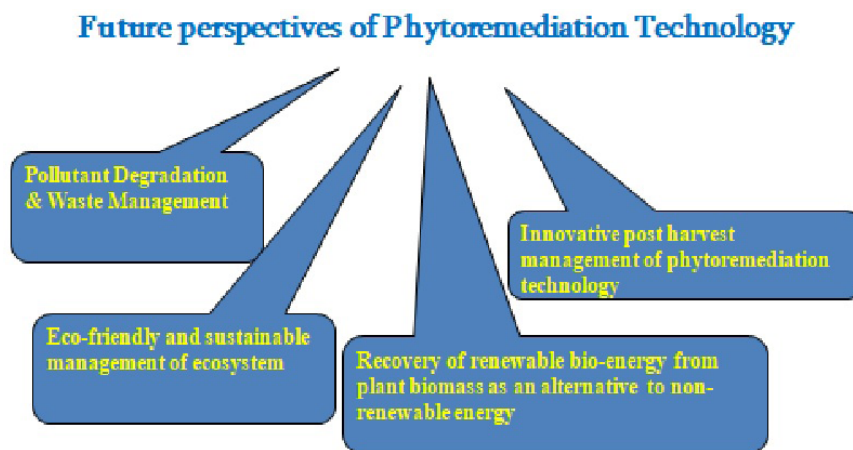


Figure 2. Future prospects of phytoremediation technology

cleanup along with environmental sustainability (Figure 1). One such technology is phytoremediation technology or green technology which has emerged and evolved as a novel tool for remediation of toxic contaminants from environment ^[1] and emerges with a number of future perspectives (Figure 2). Various biotechnological interventions such as bioinformatics, proteomics, genomics, metallomics and metabolomics play a crucial role and open new avenue in this context. This omics approach is now integrated with bioinformatics to serve as a novel tool in phytoremediation technology.

2. Role of Proteomics and Bioinformatics for Phytoremediation

A variety of pollutants such as xenobiotics, polycyclic aromatic hydrocarbons (PAHs), heavy metals, chlorinated

and nitro-aromatic compounds are persistent, highly toxic, mutagenic and carcinogenic for living organisms through bioaccumulation, adsorption and biotransformation ^[2,3]. A number of diverse and versatile plants, with high adaptability in the environment, are considered to be the potential tool among all living organisms to remediate most of the environmental contaminants. These natural agents can reduce wastes and cleanup the environmental contaminants by integrating with bioinformatics and proteomics.

The physiological changes in an organism during Phytoremediation can be best traced by using a proteomic approach, that further provide insight into remediation-related genes and their regulation ^[4]. Gene discovery through the use of computer software has developed advanced methods for the improvement of seed quality, stress tolerant transgenic plants, and engineer plants with phytoremediation capabilities.

Detoxification of pollutants follows a path of uptake followed by metabolism and compartmentation in plants which are controlled by large families of genes and their expression. From expression profiles at the m- RNA level, proteomics provide information on where, when and at what level specific proteins accumulate in response to toxicants [5].

Diverse group of plants show a remarkable range of their phytoremediation potentiality for establishing a sustainable environment. Contaminant induced protein expression studies as well as exploring the protein aggregation complexes like protein-protein interaction (interactomics) enables us for systematic study of plant physiological expressions in response to contaminants.

For example genetically, engineered plants (*Arabidopsis thaliana*) have been used as a tool of phytoextraction of arsenic pollutants and sequestration of As in vacuoles. These plants contain two bacterial genes of which one gene helps in conversion of arsenate into arsenite and the other binds to the arsenite and is finally stored in the vacuoles. In addition to this modified genes synthesizing different functional proteins (enzymes) involved in biochemical reactions in plants include phytoextraction, phytostabilization, phytotransformation, phytostimulation, and phytovolatilization played vital roles in remediation of contaminants [6].

Wojas et al. [7] demonstrated heterologous expression of AtMRP7 in modified *Nicotiana tabacum* var. Xanthi for higher cadmium accumulation, its distribution and tolerance in plants using *Arabidopsis* spp. MRP7 both in the tonoplast and in the plasma membrane of tobacco. The gene overexpression increased Cd tolerance and accumulation in tobacco leaf vacuoles, indicating more efficient detoxification by means of vacuolar storage. Heterologous AtMRP7 expression also led to more efficient retention of Cd in roots, with reduced root-to-shoot translocation.

The genes responsible for synthesis of proteins which help in uptake, sequestration, transportation and bioconcentration of different heavy metals as well as toxic organic and inorganic pollutants have been modified as per the desire which opens its avenue for efficiency of phytoremediation. Although intrinsic or natural phytoremediation is having more advantages than omics engineered phytoremediation, still application of omics based phytoremediation has gained attention of several researchers for stimulated removal of pollutants. Enhanced level of engineered proteins and enzymes will facilitate the mobilization, enhanced transportation in the root cell membrane and facilitate translocation to the shoot, modify, conjugate or degrade pollutants and facilitate tolerance, degradation, sequestration or volatilization. Several researchers inves-

tigated the molecular genetic groundwork for enhanced metal tolerance through characterizing and identifying the genes encoding bacterial inorganic transformation [8-10].

A number of plant species, such as tobacco, yellow poplar, cottonwood, and rice, expressing modified merA genes, have showed ten fold higher resistant to Hg(II) than non-transgenic plants [11]. Lyyra et al. [12] reported that the both merA and merB genes in yellow poplar and cottonwood plants, for their increased potential for Hg phytovolatilization in wetlands. Genetic manipulation to yield metal tolerant plants, metalophore or hyperaccumulators for enhanced metal accumulation and tolerance through over-expression of natural or modified genes encoding antioxidant enzymes, or those that are involved in the biosynthesis of glutathione and other phytochelators have been focused by several researchers and draws their attention. Banuelos et al. [13] reported the efficiency of transgenic *Brassica juncea* plant with higher biomass and accumulation potential for Se and Cd than the wild type

Bioinformatics approach for phytoremediation is one such technique which has created a great revolution in management of huge integrated database created through genome expression, genome profiling, protein profiling, and expression level of proteins.

As per the report of Poirier et al. [14] Cd was the most toxic metal for *Pseudomonas fluorescens* BA3SM1, They showed that the bacterium is able to acquire a metal-resistant phenotype, making the strain BA3SM1 a promising agent for bioremediation processes.

In the recent era Phytoremediation confronts a number of challenges, which needs establishment of efficient integration between different academic areas such as plant physiology, biochemical pathway of contaminant uptake and translocation, biotechnology, ethnobiology, metallomics, genomics, metabolomics and proteomics; improved research practice; practical based experiences as interpretation of results produced and the applied methodologies; and the progress in monitoring programs based on environmental pollution.

Omics based phytoremediation adds value to the processes of phytomining, bioenergy, biomineralization, biostimulation, mycoremediation, cyanoremediation, phytodegradation, phytostabilization, hyperaccumulation and dendroremediation. It focused on improving plant capacity to uptake translocate, stabilize, store and remove specific contaminants from polluted water and soil environments. Potential genes were identified and isolated from microbes and plants and manipulated for enhancing phytoremediation efficiency of plants and thus increase their survival percentage, tolerance level, storage and toxicant degradation capacity.

Practical application of omics in phytoremediation technology has been represented in the Table 1. Integrated omics approaches may reveal information that remains undetected when organisms are examined in isolation as cited by Bell et al. [15]. Different metaorganism subcomponents like microbiome, interactome and plantome contribute to different properties of phytoremediation such as Relationships between gene content, expression, translation, and activity, Intermicrobial interactions, Relative plant:microbe investment in phytoremediation activity, Interkingdom (microbe to plant) gene transfer, Interspecies variability in gene content, expression, and activity, Root exudation patterns, Physiological responses across heterogeneous environments, Physiological responses across contaminant gradients, Physiological responses across heterogeneous environments and Variations in expression between tissues by integrating omics with traditional approach [15].

Multiple scale applications of Omics technologies are used in recent phytoremediation of soil contaminants through plants and microbes. Single organism omics involved cultured microorganisms, Isolated single cells of uncultivated microorganisms, plants. In cultured microorganisms approach complete biotransformation pathways

or contaminant tolerant genes can be revealed from their genome assembly of isolate [15]. In this context, transcriptomic or proteomic approaches are able to identify contaminant tolerant genes or plant metabolites. Omics approach characterize gene, protein, and metabolite in plants, that reveals interplant variability thereby assist in plant selection and cultivation efforts for phytoremediation of contaminants. Mixed microbial communities and Metaorganism omics are involved in multiple-organism omics approach [15].

Different bioinformatics tools those are used for implementation of Bioremediation technology are listed in Table 2.

Different bioinformatic approaches can be effectively used in tracing numerous biodegradation pathways, physiochemical analysis of toxins, prediction of thee levels of toxicity, genomic and proteomic approaches to enzyme system of microbes, prediction of path of degradation , and reaction kinetics for remediation of contaminants. So Bioinformatics hold prospective purpose for the development of phytoremediation technology [16]. Bioinformatics requires the study of plant genomics, proteomics, systems biology, computational biology, phylogenetic trees, data mining and application of major bioinformatics tools for

Table 1. Different Omics approaches, their purpose and instances in context of phytoremediation technology

Omics approach	Purpose	Instances
Comparison of plant genomes with phytoremediation efficiency to identify optimal/novel targets for transgenes	To Improve genetic engineering of plants	Identified genes potentially involved in the detoxification of xenobiotic (RDX) pollutants via transcriptomics
Efficient isolation of remediation related genes	High throughput sequencing of functional metagenomic libraries	Review of function
Determine efficacy of soil amendments Apply amendments over a wide range of environmental conditions and compare omics and functional responses to determine parameters of efficiency Amplicon	targeted metagenomic sequencing showed that diesel degradation efficiency following monoammonium phosphate addition was correlated to organic matter content and promotion of Betaproteobacteria	Determine efficacy of soil amendments Apply amendments over a wide range of environmental conditions and compare omics and functional responses to determine parameters of efficiency Amplicon

Table 2. Different bioinformatics database and their principle of use in bioremediation technology (Source- Khan 2018)

Bioinformatics databases and tool	Use in bioremediation
AutoDock/AutodockVina, DOCK, DockoMatic, FINDSITE LHM, GalaxyDock, GlamDock, Glide, GOLD, GriDock, Haddock, HomDock, Rosetta Ligand , LeadFinder, Molegro Virtual Docker, PAR-3D, ParaDockS, PROCAT, Pocket-finder, rDock, VinaMPI, YASARA Structure	Protein-ligand docking tool
BioCarta and WIT, Biocyc BRENDA, EcoCycsystem, ExPASy, KEGG, MetaCyc, MetaRouter, PANTHER, Roche Biochemical Pathways UM-BBD	Metabolic pathways databases
ChemDplus, Chemogenesis, PubChem	Physical chemical properties related databases
ACD / TOx suite, CAESAR,Comparative Toxicogenomics Database ECOSAR, ECOTOX, GENE-TOX, Hazard Expert , PBT profiler, Toxicity Estimation Tool (TEST)	Toxicity prediction
Database of Biodegradative Oxygenases , KEGG	Catalog of microbes degrading pathways
Phylemon2 , Phylip, Phyloendron, PHYML, T-Rex	Phylogenetic study of the microbes involved in bioremediation

determining the structures and biodegradative pathways of xenobiotic compounds^[4].

Insertion mutagenesis involving populations of T-DNA is one such Molecular genetics approaches, which can be used to identify genes for hyper-accumulation^[17]. Recently, considerable progress has been made though genomics study for identifying metal ion transporter plant genes^[18,19]. Phytoremediation technology is still in its premature development stages which have just indicated efficiency of the plants for toxic metal remediation. Public awareness about this omics approach for phytoremediation technology is considered and clear and precise information is made available to the general public to augment its suitability as a global sustainable technology for wide use^[20]. Recently a new concept on use of symbiotic proteomics tools for better understanding of the molecular bases of cell communication and the regulation of developmental and metabolic pathways in mycorrhizal associations were established for general increase in stress tolerance and health. Chapelo et al.^[21] studied that proteomics gives a better understanding to identify proteins expressed and regulated during the development and functioning of mycorrhizal symbioses, and thus contribute in information for events occurring at the cellular level

The need of the hour is implementation and popularization of proteomics and bioinformatics based phytoremediation technology which is considered as one of the recent biotechnological advancement in this field.

3. Conclusions

The combined science of biology and information technology i.e, called Bioinformatics basically focuses on the biotechnological application at cellular and molecular levels for. Phytoremediation is the novel technology of employing plant's potentiality for degradation of toxic contaminants in soil and water. Different plants display an amazing array of contaminant degradation ability that can efficiently and effectively re-establish a sustainable environment. In this regard different aspects of genomics and proteomics have proved effective in phytoremediation studies. The revolutionary role of proteomics and bioinformatics in phytoremediation of contaminants will be an effective approach for combating environmental stress. Proteomics and bioinformatics based phytoremediation is considered and could be named as smart phytoremediation technology employed for quick recuperation of environment from pollutants and wastes. This smart technology provides insights into the complex behavior of enzymes, proteins and metabolites action and their biochemical pathways for degradation of wastes. This leads towards deriving a sustainable solution for environmental pollution.

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