OPEN ACCESS

African Journal of Agricultural Research

4 October, 2018
ISSN 1991-637X
DOI: 10.5897/AJAR
www.academicjournals.org

ACADEMIC JOURNALS
expand your knowledge

About AJAR

The African Journal of Agricultural Research (AJAR) is a double blind peer reviewed journal. AJAR publishes articles in all areas of agriculture such as arid soil research and rehabilitation, agricultural genomics, stored products research, tree fruit production, pesticide science, post-harvest biology and technology, seed science research, irrigation, agricultural engineering, water resources management, agronomy, animal science, physiology and morphology, aquaculture, crop science, dairy science, forestry, freshwater science, horticulture, soil science, weed biology, agricultural economics and agribusiness.

Indexing

Science Citation Index Expanded (ISI), CAB Abstracts, CABI's Global Health Database
Chemical Abstracts (CAS Source Index), Dimensions Database, Google Scholar
Matrix of Information for The Analysis of Journals (MIAR) Microsoft Academic
ResearchGate, The Essential Electronic Agricultural Library (TEEAL)

Open Access Policy

Open Access is a publication model that enables the dissemination of research articles to the global community without restriction through the internet. All articles published under open access can be accessed by anyone with internet connection.

The African Journal of Agricultural Research is an Open Access journal. Abstracts and full texts of all articles published in this journal are freely accessible to everyone immediately after publication without any form of restriction.

Article License

Article Copyright

Self-Archiving Policy

The African Journal of Agricultural Research is a RoMEO green journal. This permits authors to archive any version of their article they find most suitable, including the published version on their institutional repository and any other suitable website.

Please see http://www.sherpa.ac.uk/romeo/search.php?issn=1684-5315

Digital Archiving Policy

The African Journal of Agricultural Research is committed to the long-term preservation of its content. All articles published by the journal are preserved by Portico. In addition, the journal encourages authors to archive the published version of their articles on their institutional repositories and as well as other appropriate websites.

https://www.portico.org/publishers/ajournals/

Metadata Harvesting

The African Journal of Agricultural Research encourages metadata harvesting of all its content. The journal fully supports and implements the OAI version 2.0, which comes in a standard XML format. See Harvesting Parameter

Memberships and Standards

OPEN ACCESS

Academic Journals strongly supports the Open Access initiative. Abstracts and full texts of all articles published by Academic Journals are freely accessible to everyone immediately after publication.

creative commons

All articles published by Academic Journals are licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0). This permits anyone to copy, redistribute, remix, transmit and adapt the work provided the original work and source is appropriately cited.

Crossref

Crossref is an association of scholarly publishers that developed Digital Object Identification (DOI) system for the unique identification published materials. Academic Journals is a member of Crossref and uses the DOI system. All articles published by Academic Journals are issued DOI.

Similarity Check powered by iThenticate is an initiative started by CrossRef to help its members actively engage in efforts to prevent scholarly and professional plagiarism. Academic Journals is a member of Similarity Check.

CrossRef Cited-by Linking (formerly Forward Linking) is a service that allows you to discover how your publications are being cited and to incorporate that information into your online publication platform. Academic Journals is a member of CrossRef Cited-by.

<idpf>

Academic Journals is a member of the International Digital Publishing Forum (IDPF). The IDPF is the global trade and standards organization dedicated to the development and promotion of electronic publishing and content consumption.

Contact

Editorial Office: ajar@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/AJAR

Submit manuscript online http://ms.academicjournals.org

Academic Journals

73023 Victoria Island, Lagos, Nigeria

ICEA Building, 17th Floor, Kenyatta Avenue, Nairobi, Kenya

Editors

Editorial Board Members

Table of Content

Table of Content

Vol. 13(40), pp. 2087-2097, 4 October, 2018
DOI: 10.5897/AJAR2018.13403
Article Number: 3EAF05558713
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Review

A review of the evaluation of irrigation practice in Nigeria: Past, present and future prospects

Bashir Adelodun and Kyung-Sook Choi*

Department of Agricultural Civil Engineering, Institute of Agricultural Science and Technology, Kyungpook National University, 80 Daehakro Bukgu, Daegu, 702-701 Korea.

Received 21 July, 2018; Accepted 7 September, 2018

Irrigation practice across the world is vital to successful green revolution all year round to achieving sustainable development goals in food security, socio-economic and rural development. However, irrigation practice in Nigeria has not achieved the set goals despite the huge investment involved. Moreover, the level of investment and abundant water resources ought to have expedited the goals of food self-sufficiency and socio-economic development in the country. This review attempts to uncover the underline issues regarding the irrigation practice in Nigeria through the evaluation of past and present practices, and its future prospects. The review showed that the major persistent issues that have been hindering the performance of irrigation practice to achieving the set goals were inconsistent government policies, lack of political commitment, low awareness and lack of technical know-how among the farmers on irrigation farming system, and untimely financial intervention. In addition, the communication gap between the government and the farmers was responsible for some cases of underutilization and abandonment of large-scale irrigation system. The study concluded that to achieve food security and socio-economic development through irrigation systems practice in Nigeria, there is need to provide proper policy framework, appropriate technology, and farmers' awareness and their inclusion in the decision making process.

Key words: Irrigation practice, Green revolution, socio-economic development.

INTRODUCTION

Nigeria is located between Latitudes 4° and 14° N and Longitudes 3° and 15°E on the Gulf of Guinea with a land mass of 923,768 km^2, signifying about 14% of the West African landed area (Balarabe et al., 2016). Approximately, 13,000 km^2 (1.4%) of the land is covered by water and the remaining 98.6% ranges from thick mangrove forests and dense rainforests in the south to a near-desert condition in the north-eastern part of the country (Ibe and Nymphas, 2010). Additionally, the country has a coastline of over 853 km with about 80% in the Niger Delta region. The country is adjoined by four countries including the Republic of Benin in the West, Niger and Chad Republic in the North, the Cameroon Republic in the East, while the Atlantic Ocean forms the southern limits of the territory (FAO-Aquastat, 2016). There are three distinct ecological zones in the country

*Corresponding author. E-mail: ks.choi@knu.ac.kr. Tel: +821068228038.

Table 1. Agro-ecological zones of Nigeria with some climatic characteristics.

Zone description	Percentage of country area	Annual rainfall (mm)	Monthly temperature (°C)		
			Minimum	Normal	Maximum
Semi-arid	4	44 - 600	13	32-33	40
Dry sub-humid	27	600 – 1000	12	21-31	49
Sub-humid	26	1000 – 1300	14	23-30	37
Humid	21	1100 – 1400	18	26-30	37
Very Humid	14	1120 – 2000	21	24-28	37
Ultra Humid (Flood)	2	> 2000	23	25-28	33
Mountainous	4	1400 – 2000	5	14-29	32
Plateau	2	1400 – 1500	14	20-24	36

Source: Kundell (2008).

including Guinea savannah, Northern Sudan savannah and Southern rainforest (Cosmas et al., 2010). However, the agro-ecological zones, governed by the combined effects of rainfall variations, soil, humidity, and temperature, are divided into eight zones for the purpose of irrigation practice (Table 1).

The climate in Nigeria is characterized by relatively high temperature and variations in the amount of precipitation throughout the year with alternating two seasons (rainy and dry) (Ibe and Nymphas, 2010). The rainy season is generally from April to October and the dry season from November to March, with some degrees of spatial and temporal variations in the amount and distribution of rainfall across the agro-ecological zones (Akande et al., 2017; Bibi et al., 2014). The southern part of the country has the highest average annual rainfall, ranging from 1524 to 2035 mm with duration of eight to nine months. The middle belt ranges from 508 to 1524 mm while it is less than 508 mm annually for a period of five to six months in the north and less than four months in the far north (Oriola and Alabi, 2014).

Furthermore, a short dry season is known as “August break” generally comes up in the month of August. The dry season persists from late October to early March. This period witnesses dusty north-east winds (Chineke et al., 2010). However, the Northern Nigeria which experiences short wet season, the dry season is very long, from October to mid-May. Annually, the average temperature ranges from 21 to 32°C in the south while the north has a temperature range of 13 to 41°C. Nigeria, the most populous country in Africa, was estimated to have a population of over 140 million in 2006 and the United Nation estimate in 2015 was roughly 181 million (United Nations, 2017). However, the exponential projection growth in the population has not translated to food sufficiency but rather the agricultural production is on the decline. There is an uneven spatial population distribution with about 65% living in rural areas and the rest in urban areas (Aidi et al., 2016). The major occupation of people in rural areas is agriculture but with a low level of productivity (Dayo et al., 2009). The level of food insecurity in the rural areas of Nigeria is alarming with 84.3 % reported in some communities in the north and about 56% in the south west of the country (Akinyele, 2009). The country relies mostly on the importation of agricultural produce to feed its growing population in spite of her production potential in agriculture. The only way out to address the challenges of food insecurity and rural poverty is to find the solution to agricultural production in the country (Xie et al., 2017).

In Nigeria, agriculture remains the bedrock of the economy as it provides a living for the majority of its populace. World Bank (World Bank, 2014) reported that the agricultural sector alone accounts for 33% of the total GDP of Nigeria and the sector employs around 23% of the total economically active population (FAO, 2014). Agriculture used to be the Nigerian major source of foreign exchange from independence in 1960 up to the mid-1970s when Nigeria was the world’s largest producer of groundnuts, palm oil, and cocoa, and one of the major producers of millet, maize, yam, cassava, coconuts, citrus fruits and sugar cane (Ladan, 2014). However, the sector has been on the neglect and contributed less economically since the early 1970s when attention was shifted to oil revenues. Notwithstanding the reliance of the country’s economy on proceeds from oil export, Nigeria remains agrarian with her endowed substantial natural resources including 68 million hectare of arable land, abundant freshwater resourcess covering about 12 million hactare, and an ecological diversity which enables the country to produce a wide variety of crops and livestock, forestry and fisheries products (Arokoyo, 2012). Moreover, the dry northern savannah is appropriate for sorghum, millet, maize, groundnuts, and cotton while cassava, yam, plantain, maize, and sorghum can successfully be grown in the Middle Belt. Cash crops like oil palm, cocoa and rubber can be grown in the South whereas low-lying and seasonal flooded areas can grow rice (FAO-Aquastat, 2016). The government has acknowledged the need to diversify the country’s economy by giving adequate attention and promoting the development of the agricultural sector in order to shift from a mono-cultural economy of oil exports (Olajide et al., 2012).

Farming system in Nigeria can still be regarded as subsistence-based and it is predominantly rainfed, which makes it overly dependent on weather fluctuations. The irrigated agriculture only accounts for one percent of the cultivated area (FAO-Aquastat, 2017). Many farmers are out of jobs during the dry season and local food prices are on the rise as a result of food scarcity during this period. However, the green revolution requires all-year-round farming. The role of irrigation cannot be ignored as it is the only way to achieve the mandate of "Green Alternative" of the present administration. Hence, there is a need to evaluate the irrigation practices in the country so as to know what has been done in the past, the present status, and how to improve for the future developments.

HISTORY OF IRRIGATION PRACTICES IN NIGERIA

The irrigation practice in Nigeria can be traced back to 700 AD (Olubode-Awosola and Idowu, 2004), however, became more pronounced after the drought of 1970-1975. Sojka et al. (2002) defined irrigation as the practice of applying additional water, beyond what is available from rainfall, to the soil to enable or enhance plant growth and yield, and, in some cases, the quantity of foliage or harvested plant parts. Furthermore, water could be sourced from groundwater through pumping to the surface or surface water diversion from one landscape position to another. The traditional application of water to land for dry season farming was first conceived in northern Nigeria in form of gravity, bucket/calabash and pump methods by farmers without any financial assistance from the government (Yahaya, 2002). Food and Agriculture Organization of the United Nations (FAO) classified irrigation scheme into three, based on land mass size such that large irrigation scheme has over 10,000 ha, between 100 – 1000 ha is classified as medium-scale scheme while the small-scale scheme has less than 100 ha (Moris and Thom, 1990). Figure 1 shows some selected large-scale irrigation schemes across Nigeria.

In Nigeria, irrigation schemes and projects consist of three categories; the public irrigation schemes, which are government-executed schemes, the farmer-owned irrigation scheme, and the floodplains called fadama irrigation scheme. As the dire need for irrigated crop cultivation grew, a study was carried out in 1972 to examine the water resourcess and irrigation development potential in the country. Consequently, the study led to the institution of three models public irrigation schemes; namely the Bakolori scheme, the Chad Basin scheme, and Kano River irrigation scheme (NINCID, 2015). Subsequently, additional eleven more River Basin Development Authorities (RBDAs) were added across the country after the success of the pilot schemes in 1976. These RBDAs include the Niger Basin; Lower Benue Basin, Upper Benue Basin, Lake Chad Basin, Benin-Owena Basin, Sokoto Rima Basin, Hadejia Jama'are Basin, Cross River Basin, Ogun Osun Basin, Anambra-Imo Basin, and Niger Delta Basin. Their mandates among other things were to carry out developmental functions of irrigation infrastructures in their respective agro-ecological zones so as to promote irrigated agriculture in order to enhance food self-sufficiency.

Moreover, the rural water supply function was added to the functions of the established river basins and this brought about the change of name from the initial River Basin Development Authorities (RBDAs) to River Basin and Rural Development Authorities (RBRDAs) in 1995. Figure 2 shows the Map of River basins and their locations in Nigeria. Through the RBRDAs, about 162 dams with 11 billion m^3 reservoir capacity were constructed, with the intention to irrigate about 725,000 ha. However, the expected efficiency and sustainability of these large-scale public irrigation schemes to provide food sufficiency were not met as only about 32% of actually irrigated areas of equipped areas were covered (Table 2). Most of these schemes have become obsolete due to high operating costs, poor maintenance culture by the beneficial of the schemes.

In order to arrest these situations, with the available abundant water resourcess, there was a policy shift to small-scale irrigation through state's Agricultural Development Projects (ADPs) funded by the World Bank. Boreholes and tube wells were constructed across Nigeria's northern states and motor pumps were distributed to lift the water for irrigation (Kimmage, 1991). Inland valley bottoms were explored and executed in phases, Fadama I, II and III, as National Fadama Development Program by providing financial support to farmers for the procurement of irrigation facilities including boreholes, irrigation pumps, and tube wells in such fadama areas (Takeshima and Yamauchi, 2012, Nkonya et al., 2012). Despite these efforts, with large and small-scale irrigation systems combined, the earlier performance of agricultural production in terms of food production and economic growth has not been matched.

Regardless of the combined outputs of the irrigations systems, the private small-scale schemes and improved fadama development program have witnessed improved performances based on the Federal Ministry of water resourcess assessment as presented in Table 3. Kolawole (1988) opined that the declining in the performance of the irrigation schemes is as a result of the combination of technical, economic, social, institutional, and political factors. Moreover, Olowa and Omonona (2008) identified higher value in actually irrigated areas of Hadejia Jama'are in comparison to the equipped areas as a result of importance of irrigation in the region, where the rainfall is very low and there are incidences of drought, compare to the southern parts of the country where the rainfall is

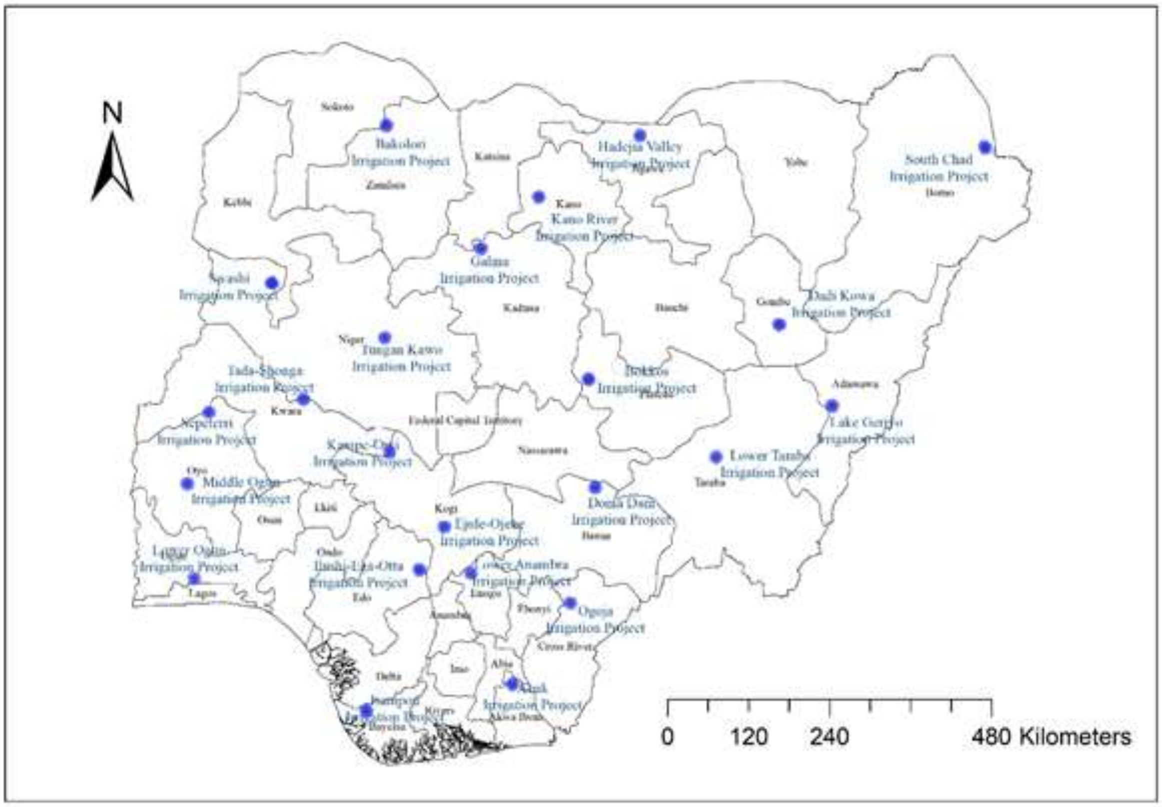

Figure 1. Map of Nigeria showing the locations of some selected major irrigation schemes.

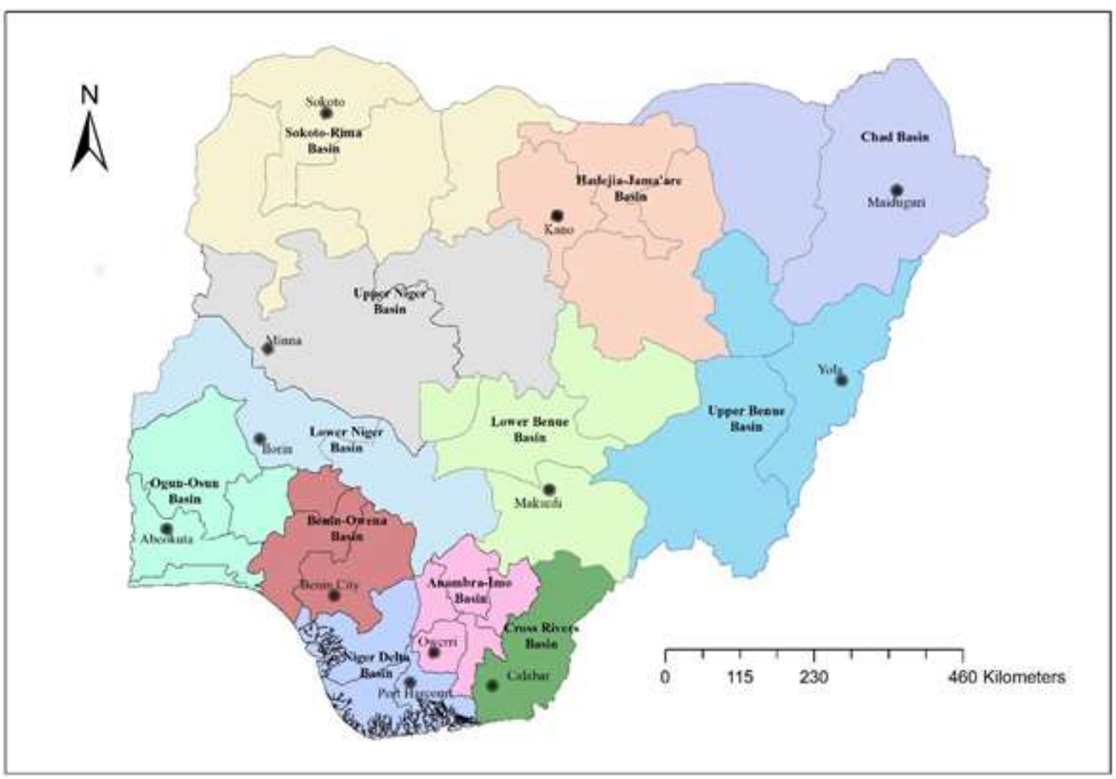

Figure 2. Map of Nigeria showing the River Basins.

Table 2. Equipped and irrigated areas in the River Basin development authorities for the year 2004.

River Basin Development Authority	Equipped area (ha)	Actually irrigated area (ha)	Actually irrigated as a percent of the equipped area (%)
Anambra-Imo	3941	10	0.3
Benin-Owena	317	0	0.0
Chad Basin	26180	1000	3.8
Cross River	364	40	11.0
Hadejia Jama'are (areas outside the equipped area used water from the main canal for irrigation)	18475	21000	113.7
Lower Benue	1310	70	5.3
Niger Delta	187	0	0.0
Lower Niger	1344	115	8.6
Upper Niger	3697	722	19.5
Ogun-Osun	512	110	21.5
Sokoto Rima	27580	5290	19.2
Upper Benue	8410	783	9.3
Total	**92317**	**29140**	**31.6**

Source: FAO-Aquastat (2016).

Table 3. Structure of the irrigation sub-sector in Nigeria for the year 2004.

Scheme type	Equipped area (ha)	Actually irrigated area (ha)	Actually irrigated as percent of the equipped area (%)
River Basin Development Authorities	92317	29140	32
State schemes	12200	6700	55
Private sector-sugar schemes	5600	0	0
Private small scale schemes	128000	128000	100
Improved fadama (equipped low land)	55000	55000	100
Total	**293117**	**218840**	**75**

Source: FAO-Aquastat (2016).

relatively high.

CURRENT CONDITIONS OF IRRIGATION DEVELOPMENT

Irrigation farming allows farmers to produce all year round thereby resulting in higher agricultural outputs and improved farmers income. However, in Nigeria, the current state of irrigation development has not been fully explored. Currently, only 45% of the total irrigation potential of 2.0 million ha, is under irrigation. The northern part of the country where the average rainfall is very low as 70% of the total irrigation potential and about 20% can be found in the humid south with the balance in the central and western plateau areas. The country has huge potentials for irrigation with dam projects spread all over the country. However, most of the dams, the ones that the government has invested in, are either under-utilized for irrigation or abandoned (Yahaya, 2002). Irrigation scheme like the Hadeja-Jama'are river project, the utilization of the project is just about 50% while the Zobe dam in Dutsin-Ma in Katsina, which was constructed 40 years ago, currently has very the little irrigation activities. Also, at the Bakolori irrigation dam in Zamfara State, under the Sokoto Rima Water Project, the area cultivated is not commensurate with the amount of water in the dam.

According to the Federal Ministry of water resourcess (FMWR, 2017), in Nigeria, there are about 264 dams with a combined storage capacity of 33 billion m^3 of water for multipurpose use that includes water supply, irrigation, hydropower, fisheries and eco-tourism, of which 210 are owned by the Federal Government, 34 by the States and 20 by the private organizations. These dams have combined of about 350,000 ha of irrigable land around the vicinities ready for development. Moreover, there are 27 on-going small earth dams nationwide with a total potential irrigable land 2,700 ha. The government is currently making frantic efforts to revive the agricultural

Table 4. Comparative yields of selected crops in rainfed and irrigated agriculture.

Crop	Yield	
	Rainfed (tonnes/ha)	Irrigated (tonnes/ha)
Rice	2.51	3.58
Maize	2.97	3.87
Tomato	6.41	8.42
Pepper	4.25	5.76
Onions	6.10	6.60
Sugarcane	6.50	26.00
Wheat	-	2.80

Sources: Tashikalma et al. (2014) and Kundell (2008).

sector among which is a policy on placing a ban on the importation of some agricultural products like rice, cocoa, vegetable, among others, that can be abundantly produced in the country. This is to enable the farmers to have the confidence to produce more by exploring the available irrigation infrastructures. Tashikalma et al. (2014) investigated the profitability of rice, maize, tomato and pepper under both rainfed and irrigated agriculture for 2007 to 2009 seasons. Similarly, Kundell (2008) compared the yields of selected crops including onions, sugarcane, and wheat for the 1998/1999 season. The result as presented in Table 4 shows that there is an appreciable increase in the yields of agricultural production in irrigated agriculture as compared to rainfed agriculture.

Apart from the provision of irrigation infrastructures, the Nigerian farmers have also recently benefitted financial supports of US$495.3 million under the Transformation Irrigation Management in Nigeria (TRIMING) project from the World Bank (World Bank, 2014). This is to enhance improvement of the existing irrigation on 27,000 hactare and benefit more than 140,000 farmers while mobilizing private sector investment. The project aims to expand food production and spawn economic growth in rural areas through large-scale public irrigation improvement. Currently, the total investment for Nigeria in irrigation projects from 2016 to 2017 is estimated at $443 million (World Bank, 2014). The investment expected to cover small-scale irrigation development, rehabilitation/ modernization of irrigation schemes, and large-scale irrigation development. The source of funding for the project is dominated by public sources such as the Federal and State Government of Nigeria. The project is expected to bring about 34,881 ha under irrigation while the surface benefitting from the rehabilitation of irrigation schemes would be 57,198 ha (World Bank, 2014).

Nigeria agricultural sector has witnessed policies instability by the different administrations over the years. This has not only made the application of policy instruments unstable but also hinders the general developmental objectives of the agricultural sector in the country. A sizeable number of policy documents have been produced ever since Nigeria started dam construction and large-scale irrigation schemes in the 1970s (Ugalahi et al., 2016). National water resourcess (NWR) policy, Draft of National Irrigation Policy, water resourcess infrastructure operation and maintenance policy and financial report of the water resources strategy are examples of policies and documents on irrigation between 1998 and 2007 (World Bank, 2014). Among the recently set up policy frameworks is the project resettlement framework under the need for transforming irrigation management in Nigeria (Elufioye, 2017). The policy is designed to provide the procedures and guidelines that would be followed in taking care of any anticipated resettlements. The farmers are in dire need of this policy to restore the trust and build harmonize the relationship between them and the government. Similarly, a new policy on agricultural promotion (Agricultural Promotion Policy 2016-2020) was recently launched to institutionalize all the stakeholders involving in agricultural production to find a lasting solution to the perceived challenges and implementation plans of the policy framework (Ojong and Anam, 2018).

Furthermore, in 2014, Nigeria government partnered with Food and Agriculture Organization to finalize the 2006 draft of the National Irrigation and Drainage Policy and Strategy (NIPD) which is expected to provide the essential framework that will guide the sustainable irrigation development, create an enabling environment, and stimulate private sector investment in irrigation development.

CHALLENGES OF THE IRRIGATION SYSTEM IN NIGERIA

The performance of agricultural use of irrigation water in sub-Sahara Africa, as compared to Asia, has been characterized by inefficiency and poor management (Nwa, 2003). However, Nigeria irrigation system has recently started receiving due attention and there is an

Tables 5. Comparing fund availability for Kampe-Omi and Tada-Shonga irrigation schemes (2004-2010).

Farming season	Kampe-Omi				Tada-Shonga			
	Land area irrigated (ha)	Fund required ($)	Fund released ($)	% of fund released	Land area irrigated (ha)	Fund required ($)	Fund released ($)	% of fund released
2004/2005	85	4054.05	1790.54	44.16	28	10135.14	N.A	N.A
2005/2006	70	3513.51	1824.32	51.92	28	11486.49	N.A	N.A
2006/2007	105	4054.05	1756.76	43.33	12	5405.41	3378.38	62.5
2007/2008	94	3716.22	1418.92	38.18	15	18457.25	8108.11	43.93
2008/2009	100	4256.76	1689.19	39.68	40	38496.96	16891.89	43.87
2009/2010	92	3378.38	1560.81	46.20	38	37155.41	N.A	N.A

Source: Oriola and Alabi (2014) (with modification) *$1 equivalent to ₦148 (exchange rate), N.A means Not available.

observed facelift in its development. Nevertheless, there are still underline challenges that need to be adequately addressed in other to meet up with its developmental objectives such as contributing substantially to the national economy, and rural development.

Firstly, Nigeria irrigation development has been faced with inconsistent and unstable policies and inappropriate legal framework over the years. Water and agriculture are regarded as separate entities under different ministries (Ugalahi, 2016). These have made the two to have different independent policies formulation. Federal Ministry of water resourcess (FMWR) is saddled with the policy formulation for irrigation development in Nigeria. However, the Federal Ministry of Agriculture and Rural Development (FMARD), State Irrigation Departments, and River Basin Development Authorities (RBDAs) have variant duties regarding the irrigation development in Nigeria. Rather than complementing one another to ensure sustainability of water resourcess for agriculture and consumption in Nigeria, the Ministries and the respective agencies have resulted to a competition among one another which resulted to a fragmented and conflicting approach to irrigation development in the country (Goldface-Irokalibe, 2008, World Bank, 2014). Notwithstanding the unstable policies witnessed in the past, the current government's agricultural transformation agenda and the finalization of the National irrigation and drainage policy and strategy are expected to set things right in the future especially in terms of appropriate framework and policy stability (FMARD, 2011).

Secondly, the funding constraint and farmers' attitudes and awareness towards irrigation systems of crop production. For a successful irrigation scheme, apart from the provision of irrigation infrastructures, there are other required inputs such as operating irrigation equipment, operation and maintenance of irrigation infrastructures, and technical expertise, which government has been responsible for their provision. But, all these are either inadequately provided or are not provided at all. According to Oriola and Alabi (2014), two of the Nigeria irrigation schemes, Kampe-Omi and Tada-Shonga, under Lower Niger River Basin Development Authority, received less than fifty percent of the funds required for their operations between 2004 and 2010 while the status of irrigation equipment is presented in Table 5. Comparatively, more funds were available for Tada-Shonga irrigation scheme than in Kampe-Omi irrigation scheme (Table 5). Furthermore, Tada-Shonga irrigation scheme enjoyed more irrigation equipment than the Kampe-Omi irrigation scheme (Table 6). However, more land is under irrigation in Kampe-Omi compared to Tada-Shonga irrigation scheme. Moreover, the percentage of the funds released compared to what was required did not reflect on the size of the land under irrigation. Oravee (2015) reported that the challenges of inadequate funding of the river basins can be traced back to 1989 which was instrumental to discontinuing of direct involvement in farming activities by some of the River Basins and Rural Development Authorities and consequently leading to the ineffectiveness of the scheme. In conclusion, the attitudes and interests of the participating farmers have a larger role to play when it comes to Nigeria irrigation farming. The government and its agencies in charge of the irrigation systems need to be proactive in discharging their duties and correspondingly provide a platform to encourage and sensitize the farmers on the need to engage in irrigation farming rather than on only rainfed.

In addition, the farmers are not interested in the operation and maintenance of the large-scale irrigation facilities. Adekunle et al. (2015) found out that poor knowledge of irrigation techniques among the farmers was one of the factors affecting their participation in large-scale irrigation scheme. Those that manage to participate are not equipped with the requisite knowledge for the operations and maintenance of the facilities. This problem is one of the current challenges being faced by the large-scale irrigation scheme in Nigeria. The participating farmers see the facilities as government properties which should be maintained by the government. These do not only make the equipment short-lived but have also resulted in the abandonment of irrigation scheme due to lack of irrigation equipment and

Table 6. Status of irrigation equipment in Kampe-omi and Tada-Shonga irrigation schemes.

Equipment	Kampe-Omi			Tada-Shonga		
	Number	Condition	Remark	Number	Condition	Remark
Tractor	6	Good	Not adequate	6	Good	Not adequate
Excavator	1	Good	Not adequate	1	Good	Not adequate
Load loader	1	Good	Not adequate	1	Good	Not adequate
Pale loader	1	Good	Not adequate	1	Good	Not adequate
Grader	1	Good	Not adequate	1	Good	Not adequate
Bulldozer	1	Good	Not adequate	1	Good	Not adequate
Planter	-	None	Not adequate	1	Good	Not adequate
Boom sprayer	-	None	Not adequate	2	Good	Good
Duty vehicle	-	None	Not adequate	2	1 Good	1 for Repair
Motorcycle	-	None	Not adequate	2	1 Good	1 for Repair
Irrigation pump	-	None	Not adequate	4	2 Good	2 for Repair

Not Adequate = NA; No = Number; Source: Oriola and Alabi (2014).

infrastructure to make use of. There has been limited stakeholders' participation as well as inadequate attention to operation and maintenance of irrigation systems. Also, farmers see other agricultural inputs and services such as fertilizers, tractors, harvesters, as more important than agricultural water. They tend to seek more government interventions on these agricultural inputs more than the provision of agricultural water through irrigation facilities.

Moreover, the use of technology in large-scale irrigation systems for agricultural operations including land clearing, land leveling, and excavation of soil for the construction of canals and drains tends to destroy small-scale farming systems and render most of the practicing farmers homeless (Yahaya, 2002). Anyebe (2015) opined that the Sokoto Rima River Basin Development Authority has failed in one of its objectives of flood prevention and control which has resulted in loss of agricultural farmlands and displacement of farmers. Similarly, rice plantation of about 3,200 ha under Tada-Shonga irrigation scheme, one of the schemes under Lower Niger River Basin Development Authority, was inundated by the flood. The current challenge of incessant flooding is a threat to large-scale irrigation farming system to ensuring food security and rural development. However, the farmers, which are the benefits of the irrigation facilities, are not involved in planning and construction of large-scale irrigation systems. Most of their views and concerns in terms of agricultural productivity, relocation, and settlement plans are left unaddressed (Yahaya, 2002). This made most of them abandon the facilities after the completion. The level of awareness of the farmers regarding the large scale-scale irrigation systems is very low in Nigeria.

Furthermore, overestimation of construction cost, high overhead and management cost, inaccurate irrigation cost/benefit analysis, and technical and management problems are some of the factors considered by Carsell (1997), limiting the development of irrigation system in Nigeria. This was corroborated by FAO report in its review that the average cost of large-scale irrigation development in Nigeria with an estimated per capita income of $1000, is estimated at $15000 per ha in 1993 with the annual operation and maintenance cost varying between $50 per ha for gravity systems and up to $800 per ha for sprinkler irrigation system (FAO, 1997).

FUTURE IRRIGATION DEVELOPMENT PROSPECTS

The agricultural sector has been projected as an alternative to the future economic sustainability of the country (Omorogbe et al., 2014). However, its developmental plan cannot be achieved without addressing the challenges being faced by the irrigation systems. water resourcess development for irrigation plays a key role in agricultural and economic growth (Mugagga and Nabaasa, 2016). Since agriculture and irrigation are intertwined, especially in a country like Nigeria where there is a wide spatial-temporal variation of rainfall across the country (Akande et al., 2017; Bibi et al., 2014), every plan towards agricultural development must also be extended to irrigation system development. It is on this premise we reviewed the future prospects of irrigation development in Nigeria under the population growth, resources availability, and government policy.

With the unabated population growth, the dire need to meet the growing food demand and the nutritional requirement of the population require bringing more land under cultivation. Consequently, the opportunities for future irrigation water development as the rainfed agriculture cannot sustain the production of growing food demand (Cosmas et al., 2010; Olayide et al., 2016). According to Takeshima and Adesugba (2015), the average population growth in Nigeria between 1961 and 2013 was 2.6% with continuous growth in agricultural

Table 7. SWOT analysis of the review outcomes.

Strengths	Weaknesses
1. Resources availability There are abundant water resources, arable land, and rural population that can drive the irrigation development (Aidi et al., 2016, Arokoyo, 2012.	1. Farmers' awareness and participation. The level of utilization of the irrigation system is very low compared to the existing irrigation facilities (Yahya, 2002).
2. Policy framework. Government acknowledgment to support irrigation development (Olajide et al., 2012). Provision of resettlement framework for transforming irrigation systems in Nigeria (Elufioye, 2017).	2. Technical know-how and knowledge capacity The farmers' inadequate technical knowledge of the operations and maintenance of irrigation systems limits the extent of irrigation development (Adekunle et al., 2015).
3. Irrigation infrastructure and financial support. The existing irrigation development can transform an irrigation system in Nigeria (Takeshima and Yamauchi, 2012, FMWR, 2017). Financial supports under the Transformation Irrigation Management enhances the improvement of the existing irrigation development and stimulates private sector investment (World Bank, 2014).	3. Irrigation infrastructure and financial support. The exorbitant cost of construction and maintenance of large-scale irrigation systems limits the development of irrigation development in the country (Carsell, 1997; FAO, 1997).
Opportunities	**Threats**
1. The productivity of irrigation systems Irrigation development enhances the productivity of the agricultural land and improves yield (Takeshima and Adeshugba, 2015).	1. Policy framework. The sustainability of the existing framework and political commitment are not guaranteed due to the past failed policies (Ugalahi et al., 2016).
2. Resources availability The land and water resources s are currently underutilize (Lowder et al., 2016; Omorogbe et al., 2014). There is potential for future development of the irrigation systems (Olayide et al., 2016; Cosmas et al., 2010).	2. Management of irrigation scheme The incessant flooding of some of the large-scale irrigation schemes hinders the goals of irrigation development (Anyebe, 2015).
3. Policy framework There is a policy framework that encourages the irrigation development through private sector participation (Arigor et al., 2015; Ogundele, 2007).	3. Operations and maintenance of irrigation systems. Late release of fund and inadequate running costs significantly affect the productivity of most the irrigation schemes (Oravee, 2015)

population at 1.4% which was higher than most of the countries in Asia and South American. This implies that there will be more pressure on the food demand and also on the expansion of irrigated agriculture in the future (NINCID, 2015). Ugalahi et al. (2015) reported that about 2 million irrigated land is required to produce 11 million tonnes of rice demand by 2025 to feed the Nigerian population. Nevertheless, the available resources for agricultural and irrigation development are still underutilized including land, water resourcess, and other agricultural inputs (Mallam et al., 2014). The essential needs, however, are the sustainable irrigation development to meet the future demand for food production (NINCID, 2015).

Currently, the total arable land in the country is estimated at about 34.6 million ha, however, only 40% is under cultivation out of which less than 5% is irrigated (Lowder et al., 2016; Omorogbe et al., 2014). Notwithstanding the abundant land and water resourcess, the availability of land for crop production is under threat due to recently increased conflict of the resource among the farmers and the herders in some selected agro-ecological zones of the country (Dimelu et al., 2017). The productivity of the available land can be enhanced through irrigation systems and other agricultural inputs including fertilizers (Takeshima and Adesugba, 2015). Furthermore, Cosmas et al. (2010) and Xie et al. (2017) are of the opinion that more land can be cultivated by engaging in small-scale irrigation scheme. The potential of future expansion of small-scale irrigation system under baseline conditions was estimated at 1 and 0,65 million ha for dry and rainy seasons, respectively (Xie et al., 2017). The development of small-scale irrigation system will not only improve the performance of the agriculture sector in terms of food production but also allow the participation of private sectors in the development of future irrigation systems. The involvement of private sector investment in future irrigation development is imperative and requires appropriate agricultural policies (Table 7).

On this account, the recent government policy towards increased importation tariff and an outright ban on importation of some staple food like rice has started bringing development to the country's irrigation system as more stakeholders including private sectors and youths are now interested in irrigated agriculture (Arigor et al., 2015; Ogundele, 2007). One of the examples is Kampe-Omi dam project under the Lower Niger River Basin which has been underutilized after the construction. This is now targetted by the Kogi State Government in collaboration with private sectors for massive production of rice. More lands are now under cultivation for food and fiber productions, however, optimum productions cannot be achieved through rainfed practice alone without additional water through irrigation systems. The irrigation development in Nigeria will continue to receive attention now, and in the future, as there will need to increase food production to feed the unabated growing population in the country.

CONCLUSION

This study reviewed the Nigerian irrigation systems development on the basis of historical backgrounds, current conditions of development, challenges, and the future development prospects. There are diverse points of view on the underline problems of the irrigation development in Nigeria. A sizeable number of the authors are of the opinion that investment on large-scale irrigation systems has been resulted in costly failures because of their under-utilization and cases of abandonment when compared to the success recorded in small-scale irrigation system across the country. All the authors agreed that with the appropriate policy framework, political commitment, institutional reform, and sensitization of farmers on the operation and management of the modern irrigation technology. Nigeria irrigation will meet up with its developmental plan on the national economy and rural development.

However, irrigation development in Nigeria, whether small or large-scale, offers some benefits, which also comes with some challenges. Already, considerable amounts of private and public funds have been invested in both large and small-scale irrigation development. Investment in irrigation development should not be an issue of debate but rather on how to improve the performances of various irrigation schemes across the country by addressing the various challenges encountered. Generally, the government is now aware of the significant role of irrigation development and its efficient utilization of food security and economic growth. The confidence of other stakeholders' participation in modern irrigation development and its sustainability also needs to be enhanced. Agriculture needs to be seen as a serious business by both the government and the farmers. Hence, there should be a performance index which must be effectively pursued for each irrigation scheme across the country by the government, non-government organization, and private investors. Specifically, the roles of individual actors in the development of irrigation systems across the country should be well defined and as such should be evaluated from time to time accordingly.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Adekunle OA, Oladipo FO, Busari IZ (2015). Factors Affecting Farmers' Participation in Irrigation Schemes of the Lower Niger River Basin and Rural Development Authority, Kwara State, Nigeria. South African Journal of Agricultural Extension 43(2):42-51.

Aidi HO, Emecheta C, Ngwudiobu IK (2016). Population and Economic Growth in Nigeria: Is There An Empirical Evidence of Casualty? International Journal of Advances in Social Sciences and Humanities 4(2):59-66.

Akande A, Costa CA, Mateu J, Henriques R. (2017). Geospatial Analysis of Extreme Weather Events in Nigeria (1985–2015) Using Self-Organizing Maps. Advances in Meteorology, 11, Article ID 8576150, 11 p.

Akinyele IO (2009). Ensuring Food and Nutrition Security in Rural Nigeria: An Assessment of the Challenges, Information Needs, and Analytical Capacity. Nigeria Strategy Support Program (NSSP). Background Paper No. NSSP 007. International Food Policy Research Institute, Washington D.C.

Anyebe AA (2015). Sokoto Rima River Basin Development Authority (SRRBDA) and Rural Development in Sokoto State, Nigeria. Journal of Economics Bibliography 2(3):134-143.

Arigor AJ, Nyambi NI, Obuo PO (2015). Analysis of Effect of Government's Trade Policy on Rice Supply in Three Local Government Areas of Cross River State, Nigeria. African Journal of Agricultural Research 10(8):829-834.

Arokoyo T (2012). Challenges of Integrating Small-Scale Farmers into the Agricultural Value Chains in Nigeria. Paper Presented at the 2012 Edition of the Annual National Agriculture Show Tagged Promoting Sustainable Investment in Agriculture In Nigeria. October 14.

Balarabe M, Abdullah K, Nawawi M, Khalil AE (2016). Monthly Temporal-Spatial Variability and Estimation of Absorbing Aerosol Index using Ground-Based Meteorological Data in Nigeria. Atmospheric and Climate Sciences 6:425-444.

Bibi MU, Kaduk J, Balzter H (2014). Spatial-Temporal Variation and Prediction of Rainfall in Northeastern Nigeria. Climate 2:206-222.

Carsell G (1997). Agricultural Intensification and Rural Sustainability Livelihoods, 'a think piece'. IDS Working Paper 64. IDS Publication office. Institute of Development Studies, University of Sussex, Brighton, United Kingdom.

Chineke TC, Jagtap SS, Nwofor O (2010). West African monsoon: is the August break "breaking" in the Eastern Humid Zone of Southern Nigeria? Climatic Change 103:555-570.

Cosmas NA, Chinenye CA, Okala ON, Godwin OC (2010). Present and Prospective Roles of Irrigation in National Food Security in Nigeria. International Journal of Applied Agricultural Research 5(4):455–466.

Dayo P, Ephraim N, John P, Omobowale AO (2009). Constraints to Increasing Agricultural Productivity in Nigeria. A Review: Strategy Support Program. Background Paper No NSSP 006. International Food Policy Research Institute. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.225.4572&rep=rep1&type=pdf.

Dimelu MU, Danjuma SE, Mbolle CJ, Achonam EI, Mbadiwe IE (2017). Livelihood issues in herdsmen-farmers' conflict among farming communities in Kogi State, Nigeria. African Journal of Agricultural Research 12(24):2105-2115.

Elufioye A (2017). Nigeria - Transforming Irrigation Management in Nigeria Project: Resettlement Plan (Vol. 2): Resettlement action plan for Kano River Irrigation Scheme in Kano State, Nigeria. http://documents.worldbank.org/curated/en/294751499934041116/Resettlement-action-plan-for-Kano-river-irrigation-scheme-in-Kano-state.

Food and Agricultural Organization (FAO) (1997). Irrigation Potential in Africa. A basin approach. FAO Land and Water Bulletin 4, Rome. Retrieved June 10, 2018, from http://www.fao.org/docrep/W4347E/W4347E00.htm.

Food and Agricultural Organization (FAO) (2014). FAOSTAT Database. Retrieved June 26, 2018, from http://faostat.fao.org/site/291/default.aspx.

FAO-Aquastat 2016. Food and Agriculture Organization. Aquastat Project. FAO. Rome. Retrieved June 26, 2018, from http://www.fao.org/nr/water/aquastat/main/index.stm.

FAO-Aquastat 2017. Food and Agriculture Organization. Regional Report-Nigeria. Retrieved August 10, 2018, from http://www.fao.org/nr/water/aquastat/countries_regions/nga/index.stm

Federal Ministry of Agriculture and Rural Development (FMARD) (2011). Agricultural Transformation Agenda: We will Grow Nigeria's Agricultural Sector. Draft. Abuja, Nigeria. http://unaab.edu.ng/wp-content/uploads/2012/10/Agricultural%20Transformation%20Blue%20Print.pdf

Federal Ministry of water resources (FMWR) (2017). "Dams and Reservoirs Operations." Federal Ministry of water resourcess. Retrieved June 10, 2018, from http://www.waterresources.gov.ng/dams-reservoir/

Goldface-Irokalibe IJ (2008). Water Management in Federal and Federal-Type Countries: Nigerian Perspectives. International Conference on Water Management. Zaragoza, Spain, July 7-9.

Ibe O, Nymphas E (2010). Temperature Variations and Their Effects on Rainfall in Nigeria. In: Dincer I, Hepbasli A, Midilli A, Karakoc T, ed. Global Warming. Green Energy and Technology. Springer, Boston, MA. https://doi.org/10.1007/978-1-4419-1017-2_38.

Kimmage K, (1991). Small-Scale Irrigation Initiations in Nigeria: The Problems of Equity and Sustainability. Applied Geography 11(1):5-20.

Kolawole A, (1988). RBRDAs and Vulnerability to Hunger in Nigeria, the Case of the South Chad Irrigation Project. Food Policy 13(4):5-20.

Kundell J (2008). Water profile of Nigeria (online). Retrieved June 26, 2018, from http://www.eoearth.org/article/water profile of Nigeria.

Ladan SI (2014). An Appraisal of Climate Change and Agriculture in Nigeria. Journal of Geography and Regional Planning 7(9):176-184.

Lowder SK, Bertini R, Karfakis P, Croppenstedt A (2016). Transformation in the Size and Distribution of Farmland Operated by Household and Other Farms in Select Countries of Sub-Saharan Africa. In 2016 AAAE Fifth International Conference, September 23–26, 2016, Addis Ababa, Ethiopia. African Association of Agricultural Economists (AAAE).

Mallam M, Agbo UF, Ebe EF (2014). Resource Use Efficiency among Beneficiaries and Non-beneficiaries of Fadama Rice Project in Niger State. International Journal of Agricultural Research 9:294-303.

Moris JR, Thom DJ (1990). Irrigation Development in Africa: Lessons of Experiment Studies in Water Policy and Management. No 14, West view press Inc, Colorado, USA.

Mugagga F, Nabaasa BB (2016). The Centrality of water resourcess to the Realization of Sustainable Development Goals (SDG). A Review of Potentials and Constraints on the African Continent. International Soil and Water Conservation Research 4:215-223.

Nigeria National Committee on Irrigation and Drainage (NINCID) (2015). Country Profile - Nigeria. Federal Ministry of Agriculture & water resources. Abuja, Nigeria. Retrieved June 12, 2018, from www.NINCID.org/cp_nigeria.html.

Nkonya E, Phillip D, Mogue T, Pender J, Kato E (2012). Impacts of Community-driven Development Programs on Income and Asset Acquisition in Africa: The Case of Nigeria. World Development 40(9):1824-1838.

Nwa EU (2003). History of Irrigation, Drainage and Flood Control in Nigeria from Pre-Colonial Time to 1999. Spectrum Books Limited, Ibadan, Nigeria.

Ogundele F (2007). Trade Liberalization and Import Demand for Rice in Nigeria: A Dynamic Modelling. Journal of Rural Economic and Development 16(1):34-45.

Ojong EF, Anam EB (2018). Agriculture Promotion Policy 2016-2020 and Rural Development in Nigeria: Challenges and Prospects. Journal of Humanities and Social Sciences 23(2):24-29.

Olajide O, Akinlabi B, Tijani A (2012). Agricultural Resource and Economic Growth in Nigeria. European Scientific Journal 8(22):103-115.

Olayide EO, Tetteh KI, Popoola L (2016). Differential impacts of rainfall and irrigation on agricultural production in Nigeria: Any lessons for climate-smart agriculture? Agricultural Water Management 178:30-36.

Olowa OW, Omonona BT (2008). water resourcess Development: Opportunities for Increased Agricultural Production in Nigeria. Agricultural Journal 3(5):366-374.

Olubode-Awosola OO, Idowu EO (2004). Social-Economic Performance of Sepeteri Irrigation Project in Nigeria. water resourcess of Arid Areas 287-299. Proceedings of International Conference on water resourcess of Arid and Semi-Arid Regions of Africa, Gaborone, Botswana, 3-6, August 2004.

Omorogbe O, Jelena Z, Fatima A (2014). The Role of Agriculture in the Economic Development of Nigeria. European Scientific Journal 10(4):133-147.

Oravee A (2015). Lower and Upper Benue River Basin Development Authorities and Rural Development: A Comparative Study. Research on Humanities and Social Sciences 5(13):11-16.

Oriola EO, Alabi MO (2014). Assessing River Basin System Potentials to Enhance Sustainable Irrigation Farming Operations and Management in Nigeria. Journal of Environmental Research and Development 8(3):515-522.

Sojka RE, Bjorneberg DL, Entry JA (2002). Irrigation: An Historical Perspective. In: Lal R, ed. Encyclopedia of Soil Science (1st Edition): pp. 745-749.

Takeshima H, Adesugba M (2015). Irrigation Potential in Nigeria: Some Perspectives Based on Factor Endowments, Tropical Nature, and Patterns in Favorable Areas. IFPRI Discussion Paper 01399. Washington, DC: International Food Policy Research Institute.

Takeshima H, Yamauchi F (2012). Irrigation Pumps and Milling Machines as Insurance against Rainfall and Price Risks in Nigeria. IFPRI NSSP Policy Note 33. http://www.ifpri.org/publication/irrigation-pumps-and-milling-machines-insurance-against-rainfall-and-price-risks-nigeria.

Tashikalma KA, Sani MR, Giroh YD (2014). Comparative Profitability Analysis of Selected Rainfed and Irrigated Food Crops in Adamawa State, Nigeria. Global Journal of Pure and Applied Sciences 20:77-87.

Ugalahi UB, Adeoye SO, Agbonlahor UM (2016). Irrigation Potentials and Rice Self-sufficiency in Nigeria: A Review. African Journal of Agricultural Research 11(5):298-309.

United Nations (2017). World Population Prospects: The 2017 Revision, Volume I: Comprehensive Tables (ST/ESA/SER.A/399). https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_Volume-I_Comprehensive-Tables.pdf.

World Bank (2014). Transforming Irrigation Management in Nigeria. World Bank indicators. Retrieved June 31, 2018, from http://data.worldbank.org/indicator.

Xie H, You L, Takeshima H (2017). Invest in Small-scale Irrigated Agriculture: A National Assessment on Potential to Expand Small-scale Irrigation in Nigeria. Agricultural Water Management 193:251-264.

Yahaya MK (2002). Development and Challenges of Bakolori Irrigation Project in Sokoto State, Nigeria. Nordic Journal of African Studies 11(3):411-430.

Vol. 13(40), pp. 2098-2103, 4 October, 2018
DOI: 10.5897/AJAR2018.13352
Article Number: 86A165E58715
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Review

Corynespora leaf fall of *Hevea brasilensis*: Challenges and prospect

Umoh Florence[1*] and Fashoranti Ebenezer L. [2]

[1]Rubber Research Institute of Nigeria, P. M. B. 1049, Benin city, Edo State, Nigeria.
[2]International Institute of Tropical Agriculture, P. M. B 5320, Ibadan, Oyo State, Nigeria.

Received 27 June, 2018; Accepted 21 August, 2018

Hevea brasiliensis **is the major source of natural rubber. Natural rubber being a unique biopolymer of strategic importance needs to be continuously well managed and protected against biotic damages. Many rubber producing countries include South East Asia, Africa and Latin America among others.** ***Corynespora*** **leaf fall caused by** ***Corynespora cassiicola*** **is currently considered as the most destructive leaf disease of** ***Hevea*** **rubber in Asian and African continents causing about 45% of yield loss. It had caused great loss to the rubber industry in various countries, thus the need for prompt action against the disease. The rubber breeding over the years have been on the development of clones with high yield combined with the desirable secondary traits. The resistance of rubber clones to** ***C. cassiicolla*** **depends on its ability to neutralize the toxin or its use of the hypersensitive response of the clone. The major objective of this review was to awaken the consciousness to** ***C. cassiicolla,*** **having in mind that rubber clones once tolerant to the disease had later become susceptible.**

Key words: Bio polymer, *Corynespora cassiicolla, Hevea brasiliensis,* natural rubber, tolerant.

INTRODUCTION

Rubber tree (*Hevea brasiliensis*) is a deciduous plant that belongs to the Euphorbiaceae family. The common names are Pará rubber tree, in Spanish it is called ‘sharinga’ tree, ‘seringueira’, ‘jebe’. The Portuguese call it ‘seringueira-rosada’, ‘seringueira-verdadeira’ while Italian and Malay call it ‘della gomma’ and ‘pokok getah’, respectively (Heuzé and Tran, 2017). Amazon basin is the centre of diversity for major commercial rubber in the world. *H. brasiliensis* was introduced to tropical Asia in 1876 through Kew garden, from the seeds brought from Rio Tapajo’z region of the upper Amazon region of Brazil by Sir Henry Wickam (Dijkman, 1951). There, the planting materials were assembled from the native land, propagated and then distributed to other botanical gardens around the world (Baulkwill, 1989). The successful transfer of *H. brasiliensis* to Asia and the subsequent establishment of rubber plantations were successful due to the demand for its raw material (Venkatachalam et al., 2013). Natural rubber is produced from the Para rubber tree, which is of the height of 30 to 40 m in the Amazonian forest (its natural habitat) (Venkatachalam et al., 2013).

Cultivated trees are usually smaller because the tapping activity reduces its growth and they are cut after

*Corresponding author. E-mail: umohflorencem1@gmail.com.

30 years due to decline latex production (Döring, 2018). The bark has patches of white and gray. The leaves are trifoliate and spirally arranged. The tree starts its productive phase from 5 to 8 years, after planting it has a productive life span of 25 to 30 years (HAL, 2014).

Flowers are monoecious and small with no petals. It is a pungent bright or cream-yellow coloured flower pollinated by insects, mostly midges and thrips (Priyadarsha, 2017). The fruit is a capsule that contains three large seeds (Blackley, 1997)

Natural rubber is synthesized from 2000 plant species confined to 300 genera of seven families which consist of Euphorbiaceae, Apocynaceae, Asclepiadaceae, Asteraceae, Moraceae, Papaveraceae and Sapotaceae (Cornish et al., 1993). Only three species of the genus namely *H. brasiliensis*, *Hevea guianensis* and *Hevea benthamiana* yield usable rubber (Sharpe, 2017). Other species have excessively high resin to rubber ratio in their latex (Mekonnen, 2015). The major content of latex is cis1-4 polyisoprene (94%), while protein and fatty acids make up 6% (Sakdapipanich, 2007). Cis-1, 4-polyisoprene biopolymers are made up of C5 monomeric isopentenyl diphosphate (IPP), units and are formed by sequential condensation on the surface of rubber particles. The rubber chain elongation is catalyzed by cis-prenyltransferases (CPTs), known as rubber polymerases (Asawatreratanakul et al., 2003). The molecular weight of the resulting polymer is an important determinant of rubber quality (Rahman et al., 2013). Latex contains some stress and plant defense-related proteins called *hevein* and *hevein amine* (Yeang et al., 2002). However, latex preparations are often contaminated with allergens. These allergens are carried through the manufacturing process and are present in the finished products (Flaherty, 2012). Latex has multiple commercial uses and is commonly found in a number of products (Sando et al., 2008).

H. brasiliensis is the primary source of natural rubber (NR) (Rahman et al., 2013) and also the only species planted commercially (Kew Science, 2017). According to the International Rubber Study Group (www.rubberstudy.com), global production of NR got to almost 11 million tons in 2011 and its demand is steadily on the increase over the years. NR is a latex polymer with high elasticity, flexibility, resilience, impact resistance, and efficient heat dispersion (Mooibroek and Cornish, 2000). These useful properties are due to the large and complex molecular structure of rubber (Milliken et al., 2009). The natural rubber obtained from the Para rubber tree (*H. brasiliensis*) is a unique bio-polymer of great importance. Thus, it cannot be replaced by synthetic rubber alternatives because of its significant applications (Venkatachalam et al., 2013). No other synthetic substitute has comparable elasticity, resilience and resistance to high temperature (Davis, 1997). Also, natural rubber is a renewable (green) elastomer and its production requires less oil than that of synthetic rubber (one-sixth) (Jules, 2007).

South-East Asia produces 92% of natural rubber, followed by Africa and Latin America with 6 and 2%, respectively. Major rubber producing countries includes Vietnam, Thailand, Indonesia, India, Malaysia, China, Côte d'Ivoire, Liberia, Sri-Lanka, Brazil, Philippines, Cameroon, Nigeria, Cambodia, Guatemala, Myanmar, Ghana, Democratic Republic of Congo, Gabon and Papua New Guinea (Saha and Priyadarshan, 2012).

Other products obtained from *H. brasiliensis* include seed oil and wood. Rubber wood has generated a profitable industry not only in Malaysia and Thailand, but also in India, Vietnam, Indonesia, Cambodia (Venkatachalam et al., 2013) and Nigeria. Its natural light colour and excellent physical properties make it suitable for flooring, household furniture, boards and packing boxes (FAO, 2001). Owing to the value of this product, several superior latex-timber clones have been developed (Rahman et al., 2013).

Wood quality has been associated with several lignocellulose biosynthesis genes (Dillon et al., 2010). Lignin, a heteropolymer of monolignols, determines the texture and hardness of the wood. Para rubber seeds are sources of seed oil, recommended for manufacturing soap, paints, leather (Ohikhena, 2006), biofuel or compression engines (Ikwuagwu, 2000; Ramadhas et al., 2005), wood polish (Bello and Otu, 2015) among others.

BACKGROUND AND DAMAGE CAUSED BY *CORYNESPORA* LEAF FALL DISEASES (CLFD)

Diseases are the major constraints of Para rubber tree. These include the abnormal leaf fall caused by *Phytophthora* species, *Colletotrichium* leaf fall caused by *Colletotrichum acutatum*, powdery mildew caused by *Oidium heveae* and C*orynespora* leaf fall caused by *Corynespora cassiicola* (Manju et al., 2002). The scientific classification of *C. cassiicola* is shown in Table 1. In Nigeria, the most devastating diseases of rubber seedlings and budded plants in the nursery are the leaf diseases (Begho, 1995; Omorusi et al., 2011); while in some countries like The United States of America, the South American Leaf Blight (SALB) ranks the top of leaf disease especially in mature plantation. The disease was first reported in Malaysia in 1960 (Newsam, 1960), India in 1961 (Ramakrishnan and Pillai, 1961), Nigeria in 1966 (Jayasinghe and Fernando, 2009) and afterwards in Sri Lanka in 1985 (Liyanage et al., 1986). The disease is generally severe in areas with high rainfall without any prolong dry period (MCR, 2000).

Cassiicolin produced by *C. cassiicola* causes many types of symptoms in over 80 host plants under diverse environmental conditions (Jayasinghe, 2000a). The host plants are tomato, cowpea, cucumber, tobacco, ground nut among others. The toxin for the pathogenicity results in the symptoms of the CLFD in rubber trees (Manju et

Table 1. Scientific Classification of *Corynespora cassiicola*.

Kingdom	Fungi
Phylum	Ascomycota
Class	Dothideomycetes
Sub class	Pleosporomycetidae
Order	Pleosporales
Family	Corynesporascaceae
Genus	*Corynespora*
Species	*cassiicola*

Table 2. Optimum environment.

Host	Temperature (°C)	leaf wetness
Tomato	20-28	>16 h necessary
Cucumber	25-30	-
Tobacco	27.5-30	-
Rubber	25-30	Greatest at 90%

Source: Fulmer (2011).

al., 2002). The pathogen causes the fall of both young and old leaves all year round. This may lead to dieback (Figure 2), delay in maturation of young rubber trees, yield reduction of about 45% of mature rubber trees (Ogbebor, 2010) and even plant death on susceptible clones (Jinji et al., 2007). According to Malaysian observations, spore dispersal is at the peak during dry season, but infections occur when the leaf surface is wet (Table 2) (Jayasinghe, 2000a).

Corynespora disease (caused by the fungus *C. cassiicola*) is more severe during refoliation, between December and April (Reshma et al., 2016). Though it affects leaves of all stages, young leaves in the light green stage appear to be the most susceptible. One of the unique features of this pathogen is the production of different types of symptoms depending on the type of the clone and maturity state of the plant. The symptoms diversity is a serious limiting factor to its early diagnosis and management.

However, circular lesions of varying sizes with papery centre, brown margin and a yellow halo is the most common symptom (Manju, 2011). The central region of the lesions may disintegrate, leaving holes. Sometimes, the shot hole effect is also noticed on leaves due to the disintegration of the centre of the spots (Figure 1) (Jinji et al., 2007). High temperature and humidity during refoliation period favours the disease incidence (Manju et al., 2016).

Its survival and spread is also a contributory factor. Pernezny and Simone (1993) reported several means of survival and spread of *C. cassiicola* in the field. They noted its survival in crop debris for about 2 years. Boosalis and Hamilton (1957) and Seaman et al. (1965) also reported that it can survive during the wet period in the root debris and stem in the field. Manju et al. (2016) reported that it could survive for 11days in infected leaf litter and also on infected intact leaves.

Figure 1. Fish-bone like, shoot pole effect on rubber leaf.

MANAGEMENT OF *C. CASSIICOLLA*

A number of management approaches (use of

Figure 2. Die back caused by *C. cassicolla*.

fungicides, cultural practices and integrated management of disease) have been evaluated and recommended as the control of CLFD in nursery and field (Manju, 2011). Chemical control of CLF is practiced in polybag and budwood nursery. Many fungicide combinations have been recommended by different researchers as an effective control. Jayasinghe (2000b) have recommended frequent spraying of fungicides on polybag nurseries during the rainy season, due to the fact that all rubber clones including highly resistant ones in the field are extremely susceptible to CLF during juvenile stage. Joseph and Manju (2002) also recommended different water based fungicides for the control of CLFD of rubber, stating that a mixture of mancozeb (0.2%), carbendazim (0.5%) and a combination of metalaxyl + mancozeb (0.2%) were consistently found more effective in nurseries. They also noted that spraying of mancozeb at weekly intervals was recommended, as it was the cheapest and most effective fungicide available. Fernando et al. (2010) concluded from their investigations that, to manage CLFD in the nursery, a combination of overhead shading and the application of fungicide mancozeb was the most effective method.

The timing of the spraying, however, is very important. When the leaves are light green during refoliation, it should be sprayed. The leaves may be affected if the spraying is delayed till the leaves are fully mature (Manju et al., 2016).

Critically speaking, many manual hours of labour and enormous quantities of fungicides are required every year for the management of CLF in many rubber plantations all over the world. The cost of fungicides and their long-term effect on the environment justify the need for breeding disease resistant trees. A multidisciplinary breeding program for development of disease resistant clones would have to continuously utilize Wickham resource as well as wild germplasm in addition to other *Hevea* species, in order to have sustainable rubber production (Narayanan and Mydin, 2012).

However, the hygiene of the plantation is of great importance as un-kept plantations give room for the causal organism to thrive. This is supported by the findings of Ogbebor (2010) which revealed that low management practice in both nursery and plantation supported the increasing rate of diseases.

FUTURE OF THE PARA RUBBER TREE WITH *C. CASSIICOLA* INFECTION

CLFD has become a threat to the natural rubber plantation industry by limiting its productivity level. There have been 72 documented report of *C. cassicolla* infection, from 1957 to 2013 (Fulmer, 2011). The increase and severity of the disease may be connected to its wide host range, variability of the pathogen (Dede et al., 2012) and ability to cause different kinds of disease in the host plant (Dixon et al., 2009). Ogbebor (2010) reported that *Corynespora* had the highest incidence of leaf diseases with an index range of 26.19 to 40.19; while the least, 7.61 to 17.91, was recorded for *Colletotrichum* leaf fall.

The major objective of *H. brasilensis* breeding is to develop high yielding clones with secondary characters, like resistance or tolerance to leaf disease. This will be effective with the understanding of the function of Para rubber tree (Venkatachalam et al., 2013). The resistance of some rubber clones to *C. cassiicolla* infections may be as a result of their ability to neutralize toxin or due to the fact that the toxin is poorly or not recognised by its specific receptors (Breton and D'Auzac, 1999). The identification of disease resistance genes is one of the major focuses of the Para tree research. Hypersensitive response (HR) is the early defense response that causes necrosis and cell death to restrict the growth of the pathogen (Yu et al., 1998). Plant signalling molecules, salicylic, and jasmonic acids play a critical role in activating systemic acquired resistance (SAR) and induce certain pathogenesis-related (PR) proteins (Durrant and Dong, 2004). The nucleotide-binding site (NBS)-coding R gene family is the largest group of disease resistance genes in plants (Mun et al., 2009).

It had been identified in *H. brasiliensis* similar to that of *Oryz asativa* (Ahmad et al., 2013). Some *Hevea* clones have been tested for their capacity to produce phytoalexins and a strong correlation between phytoalexin accumulation and clone resistance. More lignin accumulation was often associated with clone resistance (Narayanan et al., 2012).

However, genetic improvement through conventional breeding has been hampered by long experimental period, insufficient fruit production, and a high level of heterozygosity (Masson et al., 2013).

In conclusion, the fungus (C. *cassiicolla*) could be used as a bio-herbicide and biological pest control; since it infect many plants considered as weeds (Dixon et al., 2009).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Ahmad YAR, Abhilash OU, Biswapriya BM, Gincy PT, Kandakumar J, Yun F, Shaobin H, Su YO, Fui LN, Ling SL, Hock ST, Muhd KLMS, Beng S T, Bee FK, Siti SB, Nurohaida AA, Anton Y, Bjarne K, Alexandre D, Nokuthula PM, Qingyi Y, Brennick JL, Tracey AKF, Aaron GY, Rui C, Lei W, Nazalan N, Jennifer AS, Maqsudul A (2013). Draft genome sequence of the rubber tree *Hevea brasiliensis*; BMC Genomic 14:75.

Asawatreratanakul K, Zhang YW, Wititsuwannakul D, Wititsuwannakul R, Takahashi S, Rattanapittayaporn A, Koyama T (2003). Molecular cloning, expression and characterization of cDNA encoding cis-prenyltransferases from Hevea brasiliensis: a key factor participating in natural rubber biosynthesis. European Journal Biochemistry 270:4671-4680.

Baulkwill WJ (1989). The history of natural rubber production. In: Webster C. C. and Baulkwill W. J. (eds.), Rubber. Longman Scientific and Technical, Essex, England pp. 1-56.

Begho ER (1995). Hevea plantation establishment. Proceeding of training workshop on the *Hevea* Plantation establishment held at RRIN Iyanomo 2nd – 4th August, 55 p.

Bello EI, Otu F (2015). Physicochemical Properties of Rubber (Hevea brasiliensis) Seed Oil, Its Biodiesel and Blends with Diesel, British Journal of Applied Science and Technology 6(3):261-275.

Blackley DC (1997), Polymer Latices: Science and technology: Types of latices 2nd edition, Springer Science & Business Media 2:2-7.

Boosalis M G, Hamilton RI (1957). Root and stem rot of Soybean caused by *Corynespora cassiicola* (Berk & Curt) Wei. Plant Disease Reporter 41(8):696-698.

Breton F, D'Auzac J (l999). Cassiicoline, a host selective toxin produced by *Corynespora cassiicola* causative agent of *Hevea* leaf fall disease. IRRDB Annual Meeting and Symposium 1999. Haicau, China. http://dl.nsf.ac.lk/bitstream/handle/1/9078/BRRISL-42-56.pdf?sequence=2

Cornish K, Siler DJ, Grosjean OK, Godman N (1993). Fundamental similarities in rubber particle architecture and function in three evolutionarily divergent plant species; Journal of Natural Rubber Research 8:275-285.

Davis W (1997). The rubber industry's biological nightmare. Fortune 136(3):86

Dede A, Akpaja EO, Akendolor A (2012). Susceptibility of *Hevea brasiliensis (Willd Ex Adr. De Juss)* Muell Arg) and *Lycopersicon esculentum L.* Leaves to selected isolates of *Corynespora cassiicola* (Berk. and Curt.) boson.org.ng/uploads/SUSCEPTIBILITY%20OF%20HEVEA%20BRASILIENSIS

Dijkman MJ (1951). *Hevea:* Thirty years of research in the Far East. University of Miami press, Florida pp. 5-7.

Dillon SK, Nolan M, Li W, Bell C, Wu HX, Southerton SG (2010). Allelic variation in cell wall candidate genes affecting solid wood properties in natural populations and land races of Pinus radiata. Genetics 185:1477-1487.

Dixon L, Schlub R, Pernezny K, Datnoff L (2009). Host specialization and phylogenetic diversity of Corynespora cassiicola. Phytopathology 99(9):1015-1027.

Döring M (2018). *Hevea brasiliensis* Müll. Arg. in English Wikipedia - Species Pages. Wikimedia Foundation. Checklist Dataset https://doi.org/10.15468/c3kkgh

Durrant WE, Dong X (2004). Systemic acquired resistance. Annual Review of Phytopathology 42(1):185-209

Food and Agricultural Organization (FAO) (2001), Non-forest tree plantations. Report based on the work of W. Killmann. Forest Plantation Thematic Papers, Working Paper 6. Forest Resources Development Service, Forest Resources Division. FAO, Rome (unpublished).

Fernando TH, Jayasinghe CK, Wijesundera RL, Siriwardana D (2010). Screening of fungicides against Corynespora leaf fall disease of rubber under nursery conditions Journal of Plant Diseases and Protection 117(3):117-121.

Flaherty DK (2012). Immediate Allergic Reactions in Immunology for pharmacy, St. Louis, Mo Elsevier pp. 118-126 ISBN 9780323069472.

Fulmer A (2011). The (Emerging) Reality of *Corynespora* cassiicola: Insights from a literature review. Unpublished thesis

Hevea Africa Limited (HAL) (2014), factsheet. http://www.heveaafricaltd.com/rubber-tree/factsheet/

Heuzé V, Tran G (2017). Rubber *(Hevea brasiliensis)* Feedipedia, a programme by INRA, CIRAD, AFZ and FAO, https//www.Feddipedia.org/node/39

Ikwuagwu OE, Ononogbu IC, Njoku OU (2000). Production of biodiesel using rubber (Hevea brasiliensis (Kunth. Muell.)) seed oil. Industrial Crops and Products 12:57-62.

Jayasinghe CK (2000a). *Corynespora* Leaf Fall: The Most Challenging Rubber Disease in Asian and African Continents. Bulletin of the Rubber Research Institute of Sri Lanka 42:56-64.

Jayasinghe CK, Fernando THPS (2009). *Corynespora* leaf fall of Hevea Rubber: The most threatening leaf disease leaf disease in Asia and African continents ISBN: 978-955-50917-1-8.

Jayasinghe CK (2000b). *Corynespora* Leaf Fall of Rubber in Sri Lanka. Diversity of the Pathogen and Pathogenesis. International Rubber Research and Development Board Corynespora leaf fall disease workshop in Kuala Lumpur and Medan from 6th to 14th June, 2000.

Jinji P, Zhang X, Qi Y, Xie Y, Zhang H, Zhang H (2007). First record of *Corynespora* leaf fall disease of *Hevea* rubber tree in China, Australasian Plant Disease Notes 235-236. DOI:10.1071/DN07017

Joseph A, Manju MJ (2002). Control of *Corynespora* leaf disease in rubber nurseries. Nation. Symp. on Crop Protection and WTO – An Indian Perspective, CPCRI, Kasaragod, Kerala, Jan. 22 – 25, 2002.

Jules J (2007). *Hevea* rubber breeding and genetics, Horticultural reviews, 33: 176- 203 Kew Science (2017); http://www.ipni.org and http://apps.kew.org/wcsp

Liyanage AS, Jayasinghe CK, Liyanage NIS, Jayaratne R (1986). Corynespora leaf spot disease of rubber (*Heveabrasiliensis*) a new record. Journal of the Rubber Research Institute of Sri Lanka 65:47-50.

Malaysian Country Report (MCR) (2000). International Rubber Research and Development Board (IRRDB) Workshop on *Corynespora* leaf fall of Rubber; 6-9 June 2000. P 2.

Manju MJ, Mushrif SK, Parasappa HH, Shankarappa TH, Benagi VI, Idicula SP, Hegde LN (2016). Survival ability of *Corynespora cassiicola* in rubber (*Hevea brasiliensis* Muell. Arg.) plantations. International Journal of Life Sciences Scientific Research 2(2):43-45.

Manju MJ (2011). Epidemiology and Management of *Corynespora* Leaf Fall Disease of Rubber caused by *Corynespora cassiicola* (Berk & Curt.) Wei., PHD thesis (unpublished)

Manju MJ, Idicula SP, Jacob CK, Vinod KK, Prem E (2002). Management of Corynespora leaf fall (CLF) disease of rubber with water based fungicide formulations. Plantation Crop Research and Development in the New Millennium pp. 527-530.

Masson AJ, Julien M, Boedt L (2013). Industrial propagation by rooted cuttings of mature selected clones of *Hevea brasiliensis*; Boisetforêts Destropiques 317(3):51-58

Mekonnen A (2015). The West and China in Africa: Civilization without Justice, Wipf and Stock Publishers P 177, ISBN 13: 978-1-4982-2018-7

Milliken W, Klitgard B, Baracat A (2009). Neotropikey - Interactive key and information resources for flowering plants of the Neotropics. http://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:349913-1

Mooibroek H, Cornish K (2000). Alternative sources of natural rubber.

Applied Microbiology and Biotechnology 53:355-365.
Mun JH, Yu HJ, Park S, Park BS (2009). Genome-wide identification of NBS-encoding resistance genes in Brassica rapa. Molecular Genetics and Genomics 282:617-631.
Narayanan C, Mydin KK (2012). Breeding for disease resistance in *Hevea* spp. - status, potential threats, and possible strategies. In: Sniezko, Richard A.; Yanchuk, Alvin D.; Kliejunas, John T.; Palmieri, Katharine M.; Alexander, Janice M.; Frankel, Susan J., tech. coords. Proceedings of the fourth international workshop on the genetics of host-parasite interactions in forestry: Disease and insect resistance in forest trees. Gen. Tech. Rep. PSW-GTR-240. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture pp. 240-251.
Newsam A (1960). Plant Pathology Division Report. Rubber Research Institute of Malaysia, Kuala Lumpur, Malaysia.
Ogbebor ON (2010). The status of three common leaf disease of Para rubber in Nigeria. Journal of Animal and Plant Sciences 6(1):567-570.
Ohikhena SO (2006). Small scale industrial application of rubber seed oil in soap manufacture. Ife Journal of Science 8(2):207-210.
Omorusi VI, Ikerodah-Omo EE, Mokwunye MUB (2011). Evaluation of effect of antagonistic fungi and arbuscular mycorrhizal fungi (AMF) on incidences of some disease *Hevea brasiliensis* (Muell. Arg). Nature and Science 9(12):151-154.
Pernezny K, Simone GW (1993). Target spot of several vegetable crops. Florida Cooperative Extension Services. Institute of Food and Agricultural Sciences, University of Florida 39 p.
Priyadarsha PM (2017). Biology of *Hevea* Rubber, pp 10-25, Springer Nature. ISBN 978-3- 319-34304-2
Rahman AYA, Usharraj AO, Misra BB, Thottathil GP, Jayasekaran K, Yun F Hou S, Ong SY, Ng FL, Lee LS, Tan HS, Sakaff MK, Muhd L, The BS, Khoo BF, Badai SS, Aziz NA, Yuryev A, Knudsen B, e Dionne-Laporte A, Mchunu NP, Yu Q, Langston BJ, Freitas TAK, Young AG, Chen R, Wang L, Najimudin N, Saito JA, Alam M (2013). Draft genome sequence of the rubber tree *Hevea brasiliensis*; BMC Genomics 14:75.
Ramadhas AS, Jayaraj S, Muraleedharan C (2005). Characterization and effect of using rubber seed oil as fuel in the compression ignition engines. Renewable Energy 30(5):795-803.
Ramakrishnan TS, Pillay PNR (1961). Abnornal leaf fall disease of rubber caused by *Phytopthora palmivora* (Butler) Butler 2. Rubber Board Bulletin 5(2):76-84.
Reshma M, Philip S, Rose D, Joseph A, Prem E, Joseph J (2016). Pathogenicity and toxin production of *Corynespora cassiicola* isolates causing *Corynespora* Leaf Fall Disease In *Hevea brasiliensis* Rubber Science 29(3):277-285
Saha T, Priyadarshan PM (2012). Genomics of tree crops. Springer Science and Business Media pp. 261-300.
Sakdapipanich JT (2007). Structural characterization of natural rubber based on recent evidence from selective enzymatic treatments. Journal of Bioscience Bioengineering 103:287-292.
Sando T, Takeno S, Watanabe N, Okumoto H, Kuzuyama T, Yamashita A, Hattori M, Ogasawara N, Fukusaki E, Kobayashi A (2008). Cloning and characterization of the 2-C-methyl-D-erythritol 4-phosphate (MEP) pathway genes of a natural-rubber producing plant *Hevea brasiliensis*. Bioscience, Biotechnology and Biochemistry 72:2903-2917
Seaman WL, Shoemaker RA (1965). *Coryncspora cassiicola* on Soybean in Ont. Plant Disease Reporter 48(1):69.
Sharpe K (2017). Genus & Species of Rubber wood, KEW: Hevea brasiliensis (rubber tree). https://www.gardenguides.com/131330-genus-species-rubberwood.html
Venkatachalam P, Geetha N, Sangeetha P, Thulaseedharan A (2013). Natural rubber producing plants: An overview; African Journal of Biotechnology 12(12):1297-1310
Yeang HY, Arif SAM, Yusuf F, Sunderasan E (2002). Allergenic protein of natural rubber latex, Methods 27:32-45.
Yu I, Parker J, Bent AF (1998). Gene-for-gene disease resistance without the hypersensitive response in *Arabidopsis dnd1* mutant. Proceedings of the National Academy of Sciences 95(13):7819-7824.

Vol. 13(40), pp. 2104-2117, 4 October, 2018
DOI: 10.5897/AJAR2018.13301
Article Number: 547761558717
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Occurrence of plant bacterial diseases in Jordan

Hamed Khlaif[1], Ibtihal Abu-Obeid[2*] and Bilal Werikat[3]

[1]Plant Protection Department, Faculty of Agriculture, The University of Jordan, Jordan.
[2]Plant Protection Directorate, National Agricultural Research Center (NARC), Jordan.
[3]Plant Production and Protection, Faculty of Agricultural Technology, Al-Balqa Applied University, Jordan.

Received 4 June, 2018; Accepted 30 July, 2018

Different studies were done in order to investigate the occurrence of bacterial diseases on different crops grown in Jordan during different growing seasons. Surveys were made and different bacterial diseases have been recorded based on symptoms and pathogenic nature. Morphological characters, biochemical tests and PCR detections were employed in order to detect and identify the causal agents of different inspected plant bacterial diseases. In addition, the distribution of the identified bacterial diseases, throughout the country was recorded. The results of our study revealed the occurrence of different bacterial diseases attacking different crops; grown in many growing regions throughout the country. Some of them were found to have a wide host range such as crown gall and soft rot, while others had a restricted host range as in the case of bacterial speck of tomato which was found to be restricted to tomato and black leg of potato. As a result of this study, the following diseases; angular leaf spot of cucumber, tomato speck, common blight, crown gall, soft rot, black rot, black leg and bacterial cankers resulted in high economic losses in yield. The spread of these diseases in the different areas in Jordan with different environmental conditions may result in the development of new races of the causal agents without developing typical symptoms making their diagnoses under field conditions difficult. Whereas the bacterial diseases needs deep and ideal studies in order to diagnose diseases, the diagnoses of these diseases act as the base for researchers to challenge and withdraw researches into the improvement of novel, more effective and sustainable bacterial disease control strategies.

Key words: Bacterial diseases, survey, Jordan.

INTRODUCTION

The world's population is increasing every year and in order to meet their demands, global crop production needs to be increased. Plant diseases attack all agricultural crops which are considered as the main source for human food and clothing all over the world and considered among the main factors that drastically affect its production, resulting in economic losses either in the field or in storage by decreasing crop production in quality and quantity. Thus, one of the methods to increase food production is to control plant diseases. Plant disease causal agents could be; fungi, bacteria, viruses and nematodes. Different bacterial diseases have been reported to attack many agricultural crops around the world, leading to high economic losses in yield under

*Corresponding author. E-mail: ibtihal@narc.gov.jo.

favorable environmental conditions and could eliminate plantation of certain crops in certain areas as in the case of fire blight (*Erwinia amylovora*) attacking pome fruits in northern states of United States of America (Kennedy and Alcorn, 1980; Agrios, 2005).

Moreover, plant bacterial disease diagnoses are very difficult under unfavorable conditions were typical symptoms do not develop and could be masked with other disease symptoms as in the case of black rot of crucifers caused by *Xanthomonas campestris* pv. *campestris*; a humid, warm season pathogen while crucifers hosts are winter season crops, typical symptoms will not develop under cold conditions (Mahiar and Khlaif, 2000).

Plant bacterial diseases spread in tropical and subtropical regions, and host range of bacterial diseases varies according to the disease, however some of them are with a wide host rang such as soft rot *Pectobacterium carotovorum* subsp*. carotovorum* (Omar and Khlaif, 2000 and Abu-Obeid et al., 2017), and crown gall; *Agrobacterium tumefaciens* (Al-Karablieh and Khlaif, 2002; Al-Karablieh et al., 2006). On the other hand, some bacterial diseases had a narrow and restricted host ranges as in the case of black leg of potato *P. carotovorum* subsp*. atroseptica* (Al Masa'adeh and Khlaif, 2003; Masa'adeh and Khlaif, 2004; Abu-Obeid et al., 2017) and bacterial speck of tomato *Pseudomonas syringae* pv. *tomato* (Abu-El Samen and Khlaif, 1999).

Recently the interests in bacterial diseases have been increased due to its importance and its serious damage on different crops resulting in great losses in quality and quantity.

Economic importance

Losses due to bacterial diseases are difficult to estimate, especially in fruit trees where losses are not confined to the year of disease development.

The prevalence of favorable environmental conditions leads to high economic losses to the crop as in the case of angular leaf spot of cucumber under plastic houses (Khlaif, 1991a and b).

Ralstonia solanacearum (*Pseudomonas solanacearum*); the causal agent of vascular wilt disease of solanaceae, ranked the second most important bacterial pathogen (Mansfield et al. 2012). The pathogen is distributed worldwide and induces a destructive economic impact. Direct yield losses by *R. solanacearum* vary widely according to the host, cultivar, climate, soil type, cropping pattern, and pathogen strain. Due to *R. solanacearum,* yield losses were estimated from 0 to 91% in tomato, 33 to 90% in potato, 10 to 30% in tobacco, and up to 80 to 100% in banana in Africa, India and Indonesia (Kelman, 1998).

Xanthomonas oryzae pv. *oryzae* causing leaf blight of rice is a major disease of rice and is a serious threat to rice production in both temperate and tropical rice-growing regions, due to its high epidemic potential causing up to 60% loss in India and Indonesia (Ou, 1985; Raina et al., 1982).

Canker and gummosis of stone fruit trees caused by *Pseudomonas syringae* pv*. syringae*, are of major concern in fruit producing areas worldwide, and are exceedingly and difficult to control, and resulted in significant economic losses. In 1967 about 750000 peach trees were killed in France and resulted in 10-75% losses of trees and reduction in yield reached 10-20 % (Luisetti et al., 1976).

In Florida citrus canker, caused by *Xanthomonas citri* subsp. *citri*, led to the destruction of half million citrus seedlings and bearing trees and to millions of dollar losses (Kennedy and Alcorn, 1980 and Kelman, 1998).

Bacterial blight of beans causes reduction in yield and decreases the marketable value of the crop, including seed size, quality and may range from a trace to 100%, especially when favorable environmental conditions persist during the early growth and flowering stages. Kennedy and Alcorn (1980), estimated losses in dry edible beans due to bacterial blights which ranged from 75 to 90% in North Dakota, while in Jordan Valley losses of bean yield due to common blight estimated ranged from 73 to 85% of the total production (Khlaif and Qadous, 1995).

Production of tomato seedlings free from bacterial speck is impossible, especially under plastic houses conditions in the Jordan Valley; 75% of tomato fruits showed specks which resulted in a 22% yield reduction (Abu-El Samen and Khlaif, 1999).

Angular leaf spot disease of cucumber, caused by *Pseudomonas syringae* pv. *lachrymans* was found to reduce the yield of cucumber at a rate of 30.6 to 64.4% in the Jordan valley and about 50-93% in the Uplands of Jordan (Khlaif, 1991a,b,c; Khlaif and Abu-Blan, 1994).

Due to lack of information about the situation of bacterial diseases in Jordan, this study was undertaken in order to inspect, diagnose, isolate, and identify the causal agents of bacterial plant diseases and their occurrence in Jordan over a period of more than 15 years.

MATERIALS AND METHODS

Extensive field surveys were undertaken to inspect, detect the occurrence, prevalence and the incidence of different bacterial diseases affecting economic crops, including; vegetables, fruit trees and ornamentals planted in different agricultural areas in Jordan. Through field trips to different agricultural areas during the different growing seasons in Jordan, samples of different crops suspected to be infected with different bacterial diseases throughout different growing seasons in Jordan, were collected, and placed in ice box and brought to the laboratory for further identification.

Isolation and identification of the pathogenic bacteria

Initial identification was performed according to Schaad et al. (2005), through isolation by using differential, common and semi selective media as recommended for the suspected bacterial pathogen. A small amount of suspected tissue was removed from plant parts suspected to be infected with a certain bacterial disease, with sterile scalpel, washed and rinsed with sterile distilled water (SDW) and disinfected with diluted bleach solution (0.5% sodium hypochlorite), after rinsing in sterile water, tissue was chopped up with a sterile scalpel in a droplet of SDW and left to stand for 15 min. The bits of surface sterilized tissues were transferred onto the surface of loop and the resulted suspension was streaked on the surface of dried media plates. The media used for isolation were selective media according to the suspected pathogen as for example; D1 media was used in the case of crown gall (Fakhouri and Khlaif, 1996; Al-Karablieh and Khlaif, 2002; Al-karabliah et al., 2006), BCBRVB in the case of fluorescent *Pseudomonas* (Abu-El Samen and Khlaif, 1999; Hijazin and Khlaif, 2005), Logan media in the case of *Pectobacterium* (Masa'adeh and Khlaif, 2004; Abu-Obeid et al., 2017), TZC in the case of *Ralstonia solanacearum*, NA and SX Agar in the case of the *Xanthomonas campestris pv*. *campestris* (Mahiar and Khlaif, 2000), on the other hand, Nutrient Agar and KB media were used as common media for other pathogens. Inoculated media plats were incubated at 25 ± 1°C, checked periodically for development of suspected phytopathogenic bacterial colonies, and then subculturing was made by transferring a suspected colony to a new media plate through streaking for purification. Then, the obtained purified suspected colonies were transferred into agar slants and allowed to grow, kept in refrigerator for further identification.

Then the colonies of the suspected bacterial pathogen causal agents were subjected to identification procedures through biochemical and physiological tests as recommended by Schaad et al. (2005). The same tests were run against a reference culture of the most different identified pathogens.

Beside these biochemical and physiological tests, detection and identification of some bacterial pathogens was done using biotechnological molecular techniques such as polymerase chain reaction, (PCR), cloning and sequencing were employed in the identification of different bacterial pathogens of these; *Agrobacterium tumifaciens* (Al-karabliah et al., 2006), *P. carotovorum* subsp. *carotovorum* (Abu-Obeid et al., 2017) *P. carotovorum* sub sp. *atroseptica* (Al-zomor et al., 2013), *P. savastaoni* pv. s*avastaoni* (Hijazin, and Khlaif, 2005), *Pseudomonas syringae* pv. *tomato* (Werikat et al., 2005), etc.

RESULTS AND DISCUSSION

Approximately, all growing regions planted with different crops have been inspected and different bacterial diseases have been recorded in cultivated and non-cultivated crop plants of Jordan. The results of this study indicated the occurrence of different bacterial diseases in the different inspected agricultural areas throughout the country. The different diagnosed and identified bacterial diseases and their causal agents are listed in Table 1.

However, the symptoms of the diagnosed and identified bacterial diseases vary from leaf spots, tumors, rots, wilts, scab, cankers, and gummosis etc., indicated by different causal agents.

The occurrence of these diseases depends on the geographical areas since Jordan is divided into different geographical areas of Jordan Valley, Jordan Valley rift, mountains or uplands and deserts (Figure 1) where the environmental conditions of these areas varies according to the season and location. In summer, it is very hot and dry in the desert, hot and dry in Jordan Valley, while it is warm and relatively humid in the uplands and mountains. In winter, it is warm and humid in Jordan Valley, cold and dry in the desert, at the same time cool and humid in the uplands. These wide climatic variations in Jordan could illustrate the importance of different plant bacterial diseases in relation to occurrence, development and spreading, as well as, under certain conditions could lead to an epidemic bacterial disease.

However, eight phytopathogenic bacterial genera were identified; *Agrobacterium* with two species were recorded. However, *A. tumefaciens* was found to be the most common, causing crown gall attacking 21 different hosts, including; stone fruits followed by grapes, roses, olives, quince, pomegranate and nemaguard. The disease was found to spread throughout the country in different climatic regions. Also, *A. rhizogenes* was with two hosts causing hairy root disease on apples and roses.

Erwinia with seven species, causing rots and blights were identified and recorded, from which the species *Carotovorum* with had two subspecies; *Carotovorum* and *Atroseptica*; *Erwinia carotovra* subsp. *cartovra* was found with a wide host range of about 30 different host plant including; vegetables and ornamentals and was found to spread all over agricultural regions either in field and storage (Khlaif, 1993). On the other hand, the subspecies *Atroseptica* has been found to be restricted to potato, causing black leg disease in winter in the Jordan Valley region and early spring in the uplands.

Erwinia amylovora the causal agent of fire blight disease on pome fruits attack four hosts; apple, pear, quince and firethorn in spring where it was severe on the flowering stage and was more serious on pears and apple (Al-Dahmashi and Khlaif, 2004). Other species of *Erwinia* such as *E. chrysanthmi* (*Dickey dadantii*), *E. trachephila* and *E. stewartii* were identified causing wilt, rot and leaf blight diseases on different hosts in many agricultural regions of Jordan (Table 1).

Seventeen species of *Xanthomonas* (Table 1) were identified and detected on different types of hosts, where *X*. *campestris* pv. *campestris* was the most common and reported on 10 different hosts causing symptoms ranging from black rot on crucifers to leaf spots and blights on legumes. Also, it was isolated from a wide range of weeds spreading in the same regions or fields of infected crop.

However, different phytopathogenic bacteria genera such as *X. campestris* pv. *phaseoli* and *Xanthomonas campestris* pv. *campestris* were isolated from different weeds and volunteer plants grown in the host fields (Table 1). These finding could bring a new dimensions in the epidemiology of these diseases and play an important role as a source of inoculums for these diseases.

X. arboricola pv. *pruni* attacked 6 different hosts of stone fruits causing leaf spots where it infects more seriously peaches, apricots and plums, especially in the

Table 1. List of diagnosed and identified plant bacterial diseases and their causal agents in Jordan.

S/ No	Bacterial Genus	Pathogen	Host Common name	Scientific name	Disease	Region
			1. Almond	1. *Prunus dulcis* (Miller)		
			2. Apple	2. *Malus domestica* Brokh		
			3. Apricot	3. *Prunus armeniaca* L.		
			4. Bitter Almond	*4. Prunus amygdalus* var. *amara*		
			5. Carob tree	*5. Ceratonia siliqua*		
			6. Cherry	6. *Prunus avium* L.		
			7. Fig	7. *Ficus carcia* L.		
1		(a) *Agrobacterium tumefaciens*	8. Grape	8. *Vitis vinifera* L.		
			9. Mahaleb	*9. Prunus mahaleb*		
		(Smith and Townsend) conn.	10. Mulberry	10. *Morus nigra* L.		
			11. Myrobalan	11.*Terminalia chebula*		
	Agrobacterium		12. Nectarine	12. *Prunu spersica* var *nectarine* (Aitf) Maxim		
			13. Olive	13.*Olea europea* L.	Crown Gall	Wide spread Jordan Valley and Uplands
			14. Peach	14. *Prunus persica* L.		
			15. Pear	15. *Pyrus communis* L.		
			16. Plum	16. *Prunus domestica* L.		
			17. Pomegranate	17. *Punica granatum*		
			18. Quince	18. *Cydonia oblonga*		
			19. Rose	19. *Rosa* sp.		
			20. Walnut	20. *Juglan sregia* L.		
			21. Nemaguard (Peach root stock)	21. *Prunus persica*		
		(b) *A. rhizogenes*	1. Apple	*1. Malus domestica Brokh*	Hairy root	Widespread
		(Riker et al.1939) Conn	2. Rose	*2. Rosa sp.*	Hairy root	

Table 1. Contd.

			1. Artichoke	*1. Helianthus tuberosus L.*		
			2. Banana	*2. Musa acuminata*		
			3. Bean	*3. Phaseolus vulgaris L.*		
			4. Beet	*4. Beta vulgaris L.*		
			5. Cabbage	*5. Brassica olearaceae var. capitata L.*	Soft rot	
			6. Cauliflower	*6. Brassica olearaceae var. botrytis L.*		
			7. Carrot	*7. Dacus carota L.*		
			8. Celery	*8. Apium graveolens L.*		
			9. Chard	*9. Beta vulgaris var. cicla*		
			10. Chinese cabbage	*10. Brassica chinensis L.*		
2	*Erwinia*	a- *Pectobacterium carotovorum* pv. *carotovorum* (Jones) Bergey	11. Dieffenbachia	*11. Dieffenbachia maculate*		Wide spread In Jordan Valley and uplands In storage, field and glass houses
			12. Eggplant	*12. Solanum melongena L.*		
			13. Garlic	*13. Allium sativum L.*		
			14. Lettuce	*14. Lactuca sativa L.*		
			15. Marrow	*15. Cucurbita pepo L.S. fal*		
			16. Onion	*16. Allium cepa*		
			17. Parsley	*17. Petroselnium crispum (Mill)*	Stem rot	
			18. Pea	*18. Pisum sativum L.*		
			19. Pepper	*19. Capsicum frutescens L.*		
			20. Pomegranate	*20. Punica granatum L.*		
			21. Potato	*21. Solanum tuberosum L.*		
			22. Pumpkin	*22. Cucurbita maxima L.*		
			23. Radish	*23. Raphanus sativus L.*		
			24. Spinach	*24. Spinacia olearaceae L.*		
			25. Sweet melon	*25. Cucumis melo L.*	Stem rot	
			26. Tomato	*26. Lycopersicon esculentum Miller*	Soft rot	
			27. Watermelon	*27. Citrullus fanatus var. caffr*	Soft rot	
			28. Gladiolus	*28. Gladiolus communis*	Soft rot	
			29. Cucumber	*29. Cucumis sativus L.*		Widespread
			30. Common mallow	*30. Malva sylvestris*		

Table 1. Contd.

		b. *Pectobacterium carotovorum* pv. *atroseptica* (Vanitall) Dye	potato	*Solanum tuberosum L.*	Black leg	Upland in spring JV in winter
		c. *Erwinia amylovora* (Burill) Winslow *et al*.	1. Apple 2. Pear 3. Quince 4. Firethorn	*1. Malus domestica* *2. Pyrus communis* *3. Cydonia oblonga Mill* *4. Pyracantha anyastifolia*	Fire blight	Widespread in the Up lands in Al Mafraq / Al Halabat
		d. *Erwinia chrysanthemi* Burkholder *et al*. *(Dickey dadantii*)	1- Banana 2- Begonia 3- Chrysanthemum 4- Potato 5- Onion	*1. Musa acuminate* *2. Begonia sp.* *3. Chrysanthemum sp.* *4. Solanum tuberosum* *5. Allium cepa*	RRhizome rot Wilt Associated with soft rot	JV in glass houses Widespread
		e. *Erwinia tracheiphila* (Smith) Bergley *et al*.	Cucumber	*Cucumis sativus L.*	Wilt	JV in winter under plastic house Up lands in Fall
		f- *Pantoea* (*Erwinia*) *stewartii*	Corn	*Zea mays*	Seedling leaf blight	JV and Uplands
		g- *Erwinia anunas*	Cucurbits	*Cucurbits*	Brown spots	JV in storage
3-	*Xanthomonas*	a. *Xanthomonas campestris* pv. *campestris*	1. Avocado	*1. Persea ammericana*	Leaf spot	
			2. Broccoli	*2. Brassica oleraceae* var. *italica* Plenk		JV in spring Uplands in fall
			3. Cabbage	*3. Brassica oleraceae* var. *capitata*	Black rot	
			4. Carrot	*4. Daucus carota* var. *sativus*		JV in Spring Uplands in Fall
			5. Cauliflower	5. *Brassica oleraceae* var. *botrytis*	Black rot	

Table 1. Contd.

		6. Chinese cabbage	6. *Brassica chinensis* L.	Leaf blight	
		7. Kohlrabi	7. *Brassica oleraceae* var. *gongylodes*	Black rot	
		8. Radish	8. *Raphanus sativus* L.	Black rot	
		9. Turnip	9. *Brassica rapa* L.	Black rot	
		10. Walnut	*10. Juglans regia*	Black rot	
		11. Pigweed	11. *Amaranthus blitoides* S. Watson	Leaf blight	JV in Spring Uplands in Fall
		12. Red-root Pig weed	12. *Amaranthus retroflexus*L		
		13. Goosefoot	*13. Chenopodium album* L.	Leaf spot	
		14. Dyer's croton	14. *Chrozophora oblique* (Vahi) sprenge		Widespread in crucifers fields in the uplands
		15. White rocket	15. *Diplotaxis ericoides* L.		
		16. European heliotrope	16. *Heliotropium europaeum*L.		
		17. Red cabbage	17. Brassica oleracea		Widespread in crucifers fields in the uplands
		18. Hairy nightshade	18. *Solanum luteum* Miller		
		19. Sow thistle	19. *Sonchus oleanaceus* L.		
	b. Xanthomonas campestris pv. *phaseoli* (Smith) Dye	1. Pea	1. *Pisum sativm* L.	Blight	Wide
		2. Bean	2. *Phaseolus vulgaris* L.	Common blight	spread

Table 1. Contd.

		3. Morning glory	3. *Ipomaea purpurea* L.		JV in Fall and spring
		4. Malva	*4. Malva syriaca L.*	Leaf spot	
		5. Hairy cowpea	*5. Vigna luteola*(Jaca) Benth	Leaf spot	In fields of JV and uplandsi n fall
		6. Cowpea	6. *Vigna unguiculata L. Walp*	Leaf spot	
	c. Xanthomonas campestris pv. *vesicatoria* (Poidge)1978	1. Pepper 2. Tomato	1. *Capsicum annum* L. *2. Lycopersicon esculentum* Miller	Bacterial spot	Winter in the J.V
	d.Xanthomonas campestris pv. *cucurbitae*	Cucumber	*Cucumis sativus* L.	Leaf spots	Plastic houses
	e. Xanthomonas campestris	1. Barley	*1. Hordeum vulgaris*	Black chaff	Winter J.V
	pv. *translucens* (Jones) Dye 1978	2. Oat	*2. Avena sativum*	(streaks/strips)	Spring uplands
		3. Wheat	*3. Triticum aestivum* L.		
	f. Xanthomonas ampelina	Grape vine	*Vitis vinifera*	Leaf spots	Upland J.V winter
	g. Xanthomonas fragariae	Strawberry	*Fragaria chiloensis* var. *ananassa*	ALS	Up lands in spring
		1. Almond	1. *Prunus dulcis* L. (Miller)		
		2. Apricot	2. *Prunus armenica* L.		
	h.Xanthomonas arboricola pv. *pruni*	3. Nectarine	3. *Prunus persica* var. *nectarine*	Leaf Spot	Fall , uplands Spring, J.V
		4. Peach	4. *Prunus persica* L.		
		5. Plum	5. *Prunus domestica* L.		
		6. Sweet cherry	6. *Prunus avium* L.		
	i. Xanthomonas arboricola (campestris) pv. *juglands* Dye 1978	Walnut	*Juglans regia* L.	Blight	Widespread Fall uplands

Table 1. Contd.

		j. Xanthomonas campestris pv. *pelargoni* Dye 1978	Geranium	*Pelargonium* sp.	Leaf spot stem rot	Winter uplands
		k. Xanthomonas campestris pv. dieffenbachiae (Mcculloch) Dye 1978	1. Dieffenbachiae	*1. Dieffenbachiae maculate*.	Leaf spots	Glass houses
			2. Flaming lily	2.*Anthurium andraenum*		
			3. Philodendron	*3. Philodendron* sp		
		l. Xanthomonas campestris pv. *begonia*	Begonia	*Syngonium podophyllum*	Leaf marginal lesions and wilt	Under glass houses
		m. Xanthomonas campestris pv. *schefflera*	Schefflera	*Schefflera* sp.	Leaf spots	Indoor glass houses
		n. Xanthomonas campestris pv. *raphani*	Crucifers	Crucifers	Leaf spots	JV
		o. Xanthomonas campestris pv. *musaceavum*	Banana	*Musa acuminata*	Wilt	JV
		p. Xanthomonas campestris pv. *citrumelo*	Citrus	Citrus	Bacterial spots	JV
		q. Xanthomonas axonopodis pv. *citri*	Citrus	Citrus	Bacterial canker	Imported Seedlings
4	*Pseudomonas*	*a. Pseudomonas syringae* pv. *lachrymans* (smith and Bryan) Young 1978	Cucumber	*Cucumis sativus* L.	ALS	Wide spread JV and Uplands

Table 1. Contd.

b. Pseudomonas syringae pv. *phaseoli* (Barkholder) Young	Bean	*Phaseolus vulgaris* L.	Halo blight	Wide spread
c. Pseudomonas syringae pv. *pisi*	Peas	*Pisum sativum*	Blight	Wide spread
	1. Bean	1. *Phaseolus vulgaris* L.		
	2. Pea	*2. Pisum sativum*		
	3. Cherry	3. *Prunus avium* L.		
	4. Citrus	4. Citrus lemon		
	5. Lemon	5. *Pisum sativum* L.		
	6. Pear	6. *Pyrus communis* L.		
	7. Plum	7. *Prunus domestica* L.		
d.Pseudomonas syringae pv. *syringae* Vanhall	8. Sunflower	8. *Hellathus annus* L.	Brown spot Bud blast	Wide spread
	9. Tomato	*9. Lycopersicon esculentum*		
	10. Valencia	*10. Citrus sinensis* var. *valencia*		
	11. Vetch	11. *Vicia sativa* L.		
	12. Wheat	12. *Triticum astivum* L		
	13. Barley	*13. Horeum vulgare*		
	14. Oat	*14. Avena sativa*		

Table 1. Contd.

	e. Pseudomonas syringae pv. *tomato*	Tomato	*Lycopersicon esculentum* Miller	Bacterial speck	Under plastic house in nurseries and open field
	f. Pseudomonas syringae pv. *morsprunorum*	1. Cherry 2. Plum 3. Apricot 4. Peach	1. *Prunus alium* L. 2. *Prunus domestica* L. *3. Prunus armeniaca* *4. Prunus persica*	Gummosis	Wide spread
	g.Pseudomonas savastanoi pv. *savastanoi*	1. Oleander 2. Olive 3. Jasmine 4. Ziziphus	*1. Nerium oleander* *2. Oleae uropea* *3. Jasminum graniflorum* *4. Ziziphus spina-christi*	Olive knots	Wide spread
	h. Pseudomonas syringae pv. *tabaci*	Tobacco	*Nicotiana tabacum* L.	Bacterial leaf blight	Widespread in JV in spring In Uplands in fall
	i. Pseudomonas virdiflava (Barkholder) Dowson	1. Bean 2. Cucumber 3. Tomato	*1. Phaseolus vulgaris* *2. Cucumis sativus* *3. Lycopersicon esculentum*	Stem galling Watery rot Leaf spot	Under plastic houses in JV
	j. Pseudomonas corrugata	Tomato	*Lycopersicon esculentum*	Pith necrosis Leaf spot	After cold, frost damage Under plastic house in JV
	k. Pseudomonas cichorii (swingle) stape	Lettuce	*Lactuca sativa*	Leaf spot	JV and uplands
	l. Pseudomonas gladiola pv. *gladiola*	Gladiolus	*Gladiolus* sp.	Soft rot	Glass houses
	m. Ralstonia(Pseudomonas) solanacearum	1. Banana 2. Tomato	*1. Musa acuminata* *2. Lycopersicon esculentum*	Moko disease Wilt	JV in spring and winter

Table 1. Contd.

		n.Pseudomonas syringae pv. *maculicola*	Crucifers	Crucifers	Bacterial leaf spot	Plastic houses
		o.Pseudomonas marginalis pv. *marginalis*	1. Crucifers 2. Gladiolus	1. Crucifers 2. *Gladiolus* sp.	Soft rot scab	JV Plastic houses
		p. Pseudomonas flourescense	Potato	*Solanum tuberosum* L.	Pink eye	JV
		q.Pseudomonas syringae pv*. dapulans*	Apple	*Malus domestica*	blister spot	Uplands
5	*Streptomyces*	*Streptomyces scabies*	1. Carrot 2. Potato 3. Raddish	1. *Daucus carota* subsp. *sativus* 2. *Solanum tuberosum* L *3. Raphanus sativus*	Common scab	Widespread in southern parts of Jordan
6	*Burkholdoria*	*a .Burkholdoria gladioli* pv. *allicola* (*Pseudomoma sgladioli* pv. *allicola*)	Onion	*Allium cepa*	Slippery skin	Common in storage JV in winter
		b. Burkholdoria cepacia	Onion	*Allium cepa*	Sour skin	Common in storage JV in winter
7	Clavibacter (*Corynebacterium*)	*a. Clavibacter michiganensis subsp. michiganensis*	Tomato	*Lycopersicon esculentum*	Bird's eye spot	JV winter and spring

fall season in the uplands, followed by *X. campestris* pv. *phaseoli* causing common blights and leaf spots of bean and peas. On the other hand, *X*. *campestris* pv. *translucence* was isolated and identified from 3 field crops showing strips or streaks symptoms; the disease was found to be common during winter and spring in the Jordan Valley and in the uplands, where barley was found to be the most susceptible crop. Other 13 *Xanthomonas* species with narrow host range, attacking different plant types ranging from ornamentals, fruit trees and vegetables were diagnosed and recorded (Table 1).

Different species of *Pseudomonas* were isolated and identified, of these *P. syringae* pv. *syringae* was the most common species causing many diseases on 14 different hosts; brown spot, scab, wilt, cankers, citrus blast and bud blast. Other

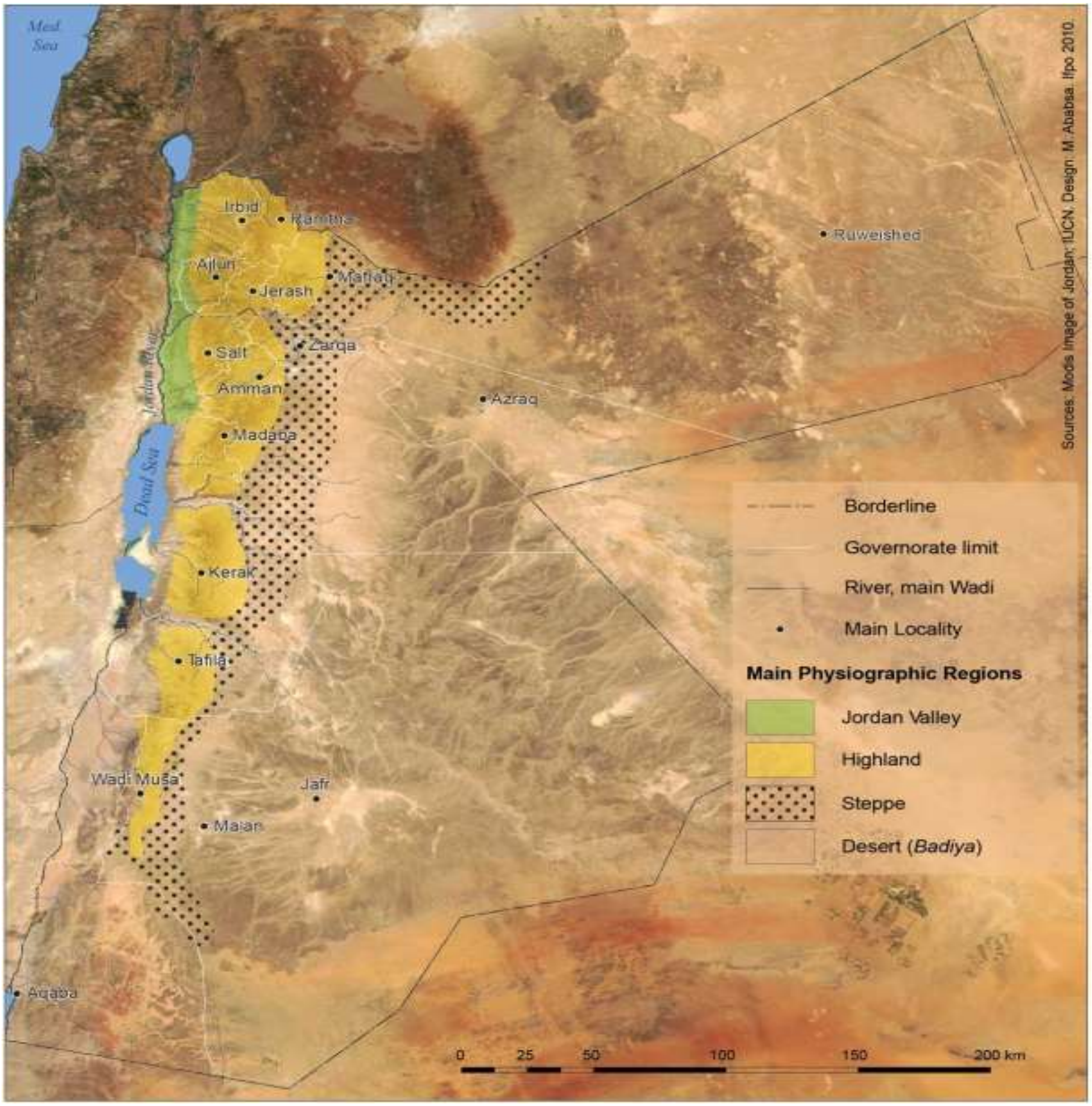

Figure 1. Map of Jordan showing the main physiographic regions.
Source: Atlas of Jordan, 2014.

Pseudomonas species attacked 24 different hosts causing different disease symptoms ranging from angular leaf spot such as ALS (*P. syringae* pv. *lachrymans*) on cucurbits especially under plastic houses, gummosis (*P. syringae* pv. *morsprunorum*) on stone fruits, knots (*P. savastanoi* pv. *savastanoi*) on olives, oleanders, jasmine and *Ziziphus* sp. and spread all over the country, causing a serious damage to all olive cultivars; Nabali baladi was found to be the less olive cultivar susceptible to olive knot disease (Khlaif, 2006).

Streptomyces scabies was found to cause common scab disease on potatoes, carrot and radish and was most common on potatoes in the southern parts of Jordan where the soil is sandy.

Burkholdoria gladioli pv. *allicola* (*Pseudomonas gladioli* pv. *allicola*) was found to cause slippery skin disease on onion.

Ralstonia solanacearum was isolated and identified from wilted plants of tomato under plastic houses and banana in the Jordan Valley during spring.

One species of *Clavibacter* (*Corynebacterium*) was detected and identified, *Clavibacter michiganensis* pv. *michiganensis* causing Bird's eye spot disease on tomato was recorded during winter in the Jordan Valley.

Conclusion

Many plant bacterial diseases were detected, identified and recorded that cause diseases of many crops grown in Jordan which resulted in high economic loss. Accordingly, the identification of these diseases using efficient methods is essential in order to investigate the ecology of these diseases and therefore help in employing the efficient control method. The occurrence of these bacterial diseases in the different growing areas in Jordan with different environmental conditions could develop new phytopathogenic bacterial strains, where atypical symptoms could be very difficult to diagnose and control.

This work acts as the base for researchers in this field to take advantage and implement further studies in controlling these diseases and decrease losses.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

REFERENCES

Abu-El Samen F, Khlaif H (1999). Epidemiology and control of bacterial speck of tomato in the Jordan Valley. Jordan Journal of Agricultural Science, Dirasat 26(2):205-215.

Abu-Obeid I, Khlaif H, Salem N (2017). Detection of bacterial soft rot of potato caused y *Pectobacterium carotovorum* subsp. *carotovorum* using specific PCR primers. African Journal of Agricultural Research 12(39):2910-2928.

Agrios G (2005). Plant Pathology (5th ed.). London: Elsevier Academic Press.

Al- Karablieh N, Khlaif H (2002). Occurrence and distribution of crown gall disease in Jordan. Phytopathologia Mediterranea 41(3):226-234.

Al Masa'adeh M, Khlaif H (2003). Potato blackleg in Jordan: Reaction of some potato cultivars to the infection and effect of planting date. Jordan Journal of Agricultural Science 30(2):15-20.

Al-Dahmashi MS, Khlaif H (2004). Fire blight of pome fruits in Jordan: disease development and response of different fruit cultivars to the disease. Scientia Horticulturae 101:81-93.

Al-karabliah N, Khlaif H, Al Banna L (2006). Identification of *Agrobacterium tumefaciens* strains by PCR- RFLP analysis of the 16S- rDNA. Jordan Journal of Agricultural Sciences 2(3):209-221.

Al-Karablieh N, Khalif H, Al-Banna L (2006). Identifcation of Agrobacterium tumefaciens strains by PCR-RFLP analysis of the 16S-rDNA. Jordan Journal of Agricultural Science 2:209-220

Al-zomor R, khlaif H, Akash M (2013). Detection and Identification of Erwinia carotovora subsp. atroseptica (Van Hall, 1992) the causal agent of Potato Black leg by RFLP-PCR. Jordan Journal of Agricultural Sciences 9(2):170-183.

Atlas of Jordan (2014). Beyrouth: Presses de l'Ifpo, Institut français du Proche-Orient Serie: Contemporain publications ISBN (Print version): 9782351593783 Electronic ISBN: 9782351594384 DOI: 10.4000/books.ifpo.4560, 485 pp.

Fakhouri W, Khlaif H (1996). Bio control of crown gall disease in Jordan. Jordan Journal of Agricultural Science 23(1):17-22.

Hijazin R, Khlaif H (2005). Detection of *Pseudomonas savastanoi* pv. *savastanoi* from olive and other hosts by polymerase chain reaction (PCR). Jordan Journal of Agricultural Science 32(1):71-77.

Kelman A (1998). One hundred and one years of research on bacterial wilt, In: P.H. Prior, C. Allen and J. Elphinstone (ed.), Bacterial Wilt Disease: Molecular and Ecological Aspects. Springer, Heidelberg pp. 1-5.

Kennedy BW, Alcorn SM (1980). Estimates of US crop losses due to Prokaryotes plant pathogen. Plant Disease 64 p.

Khlaif H (1991). Bacterial Spot of Tomato in Jordan: Identification and Response of some Tomato Cultivars to the causal agent. Mu'tah Journal for Research and Studies 6(2):192-209.

Khlaif H (1991a). Properties of *Pseudomonas syringae* pv. *lachrymans* (Smith and Brayan) Carsner, the causal agent of angular leaf spot of cucumber (*Cucumis stativus* L.) in Jordan. Jordan Journal of Agricultural Science 18(1):68-78.

Khlaif H (1991b). Angular leaf spot of cucumber (*Cucumis stativus* L.) in Jordan: Disease development and effect on yield. Jordan Journal of Agricultural Science 18B(3):110-116.

Khlaif H (1991c). Role of infested soil and contaminated seeds in the transmission of angular leaf spot of cucumber in Jordan. Jordan Journal of Agricultural Science 18B(4):143-154.

Khlaif H (1993). Bacterial stem rot of plastic-house grown tomato in the Jordan valley. Phytopathologica Meditteranea 32:58-61.

Khlaif H (2006). Olive knot disease in Jordan. Jordan Journal of Agriculture 2(4):387-400.

Khlaif H, Abu-Blan H (1994). Effectiveness of selected fungicides and bacteriosides in inhibiting *Pseudomonas syringae* pv. *lachrymans* in vitro and in controlling the pathogen in green houses. Jordan Journal of Agriculture 21B(4):115-125.

Khlaif, H. Qadous, N (1995). Common blight of bean in the Jordan Valley source of inoculum. Jordan Journal of Agriculture 22(3):717-725.

Luisetti J, Prunier JP, Gardan L, Gaignard JL, Vigouroux A (1976). Le dépérissement bactérien du pêcher. Invuflec, Paris, France.

Mahiar M, Khlaif H (2000). Black rot disease of crucifers in Jordan: Host range, and response of some crucifers' cultivars to the disease. Jordan Journal of Agriculture 27(1):26-33.

Mansfield J, Genin S, Magori S, Citovskyi V, Sriariyanumr M, Ronald P, Dow M, Verdier V, Beer S, Machado M, Toth I, Salmond G, Foster J (2012). Top 10 plant pathogenic bacteria in molecular plant pathology. Molecular Plant Pathology 13:614-629.

Masa'adeh M, Khlaif H (2004). Blackleg of potatoes in Jordan: source of inoculum. Jordan Journal of Agriculture 31:31-36.

Omar R, Khlaif H (2000). Soft rot disease of vegetables in Jordan: Host range, Reaction of some potato cultivars to the infection and effect of planting date. Jordan Journal of Agriculture 27(1):149-157.

Ou SH (1985). Rice diseases. Common wealth Myc. Inst., Kew, Surry, England 380 p.

Qadous N, Khlaif H (1997). Common blight of beans in the Jordan Valley: Disease development and response of different host cultivars to the disease. Jordan Journal of Agriculture 24(2):260-266.

Raina GL, Sidhu GS, Saini P. K (1982). Rice bacterial blight status in Punjab, India. Review of Plant Pathology 61:49-62.

Riker AJ, Banfield WM, Wright WH, Keitt GW, Sagen HE (1939). Studies on infectious hairy root of nursery trees of apples. African Journal of Agricultural Research 41:507-540.

Schaad N, Jones J, Chun W (2005). Laboratory Guide for Identification of Plant Pathogenic Bacteria (3rd ed.). Minnesota: APS, St. Paul.

Werikat B, Al Banna L, Khlaif H (2005). Detection and identification of bacterial speck of tomato *Pseudomonas syringae* pv. *tomato* by PCR. Jordan Journal of Agricultural Sciences 2(1):45-56.

Vol. 13(40), pp. 2118-2133, 4 October, 2018
DOI: 10.5897/AJAR2018.13418
Article Number: 485AA5258719
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Management of *Dinoderus porcellus* L. (Coleoptera: Bostrichidae) infesting yam chips using varietal resistance and botanical powders of three medicinal plants

Loko Yêyinou Laura Estelle[1*], Gnaho Annick Christelle[1], Toffa Joelle[1], Orobiyi Azize[1], Dansi Alexandre[2] and Tamò Manuele[3]

[1]Laboratory of Applied Entomology, Faculty of Sciences and Technology of Dassa (FAST-Dassa), National University of Sciences Technologies Engineering and Mathematics of Abomey (UNSTIM), BP 14 Dassa, Benin.
[2]Laboratory of Biotechnology, Genetic Resources and Plant and Animal Breeding (BIORAVE), FAST-Dassa, UNSTIM, BP 14 Dassa, Benin.
[3]International Institute of Tropical Agriculture, 08 BP 0932, Cotonou, Benin.

Received 26 July, 2018; Accepted 13 September, 2018

In Benin, stored yam chips are severely attacked by *Dinoderus porcellus* Lesne which causes important losses. The use of medicinal plants combined with the insect-resistant yam chips can be an efficient alternative of chemical insecticides for yam chips protection. This study aims to evaluate an integrated pest management of *D. porcellus* using combined effects of resistant yam chips (Boniwouré, Gaboubaba, Wonmangou, and Yakanougo landraces) and leaves powder of *Bridelia ferruginea* Benth, *Blighia sapida* Juss and *Khaya senegalensis* Cronquist. For that, repellence, weight loss, mortality and progeny production were evaluated with Antouka commercial insecticide as positive control and untreated yam chips as negative control. The results revealed that all treatments are strongly repellent and showed important reproductive inhibition rate and remarkable inhibition of emergency of *D. porcellus* progeny. The weight loss due of yam chips treated with the three medicinal plants was not significantly different from those treated with Antouka, but significantly different from untreated yam chips. Only *K. senegalensis* at 2% (w/w) combined with Wonmangou landrace was able to achieve 66.2% of mortality after 21 days of experimentation. Hence, combination of resistant yam chips with leaves powder of these three medicinal plants could be promoted for integrated management of *D. porcellus*.

Key words: *Dinoderus porcellus*, integrated pest management, medicinal plants, resistance varietal, storage, yam chips.

INTRODUCTION

Yam (*Dioscorea* spp.) is an important crop that contributes to food security and poverty reduction in sub-

*Corresponding author. E-mail: lokoestelle@yahoo.fr.

Saharan Africa. Generally, it is cultivated for underground starchy tubers consumption and are mainly produced in West Africa. That production represents 96.3% of the world production (FAO, 2016). Yam tubers are good sources of carbohydrates, dietetary fibers, proteins, vitamin C, and minerals (Opara, 1999; Tortoe et al., 2017) and are eaten on diverse forms: boiled, roasted, fried, pounded, and dough of yam flour (Ayodeji et al., 2012). With an estimated annual production of 3,041,245 tonnes in 2016, Benin ranks fourth behind Nigeria, Ghana and Côte d'Ivoire in yam consumption, with 425 kcal per capital per day (FAO, 2016). Yam production is now entirely part of customs and traditions of populations to the point that we can speak of yam civilization (Baco et al., 2004).

Despite its economic, food and socio-cultural functions, yam production remains hampered by numerous biotic (pests and diseases, etc.) and abiotic (poor soils, climate change, etc.) factors. Also, the difficulty of fresh tubers conservation causes important post-harvest losses (65-85% of the weight of tubers) and an irregularity of its availability throughout the year (Babajide et al., 2008). To overcome the highly perishable nature of tubers, yams are transformed into chips which are traditionally dried under the sun (Hounhouigan et al., 2003), thus enhancing food security (Babajide et al. 2008). Unfortunately, dried yam chips in traditional storage systems are severely attacked by *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae), which easily destroys stocks in few days (Ategbo et al., 1998, Vernier et al., 2005) and can cause losses of up to 50% of stocks (Loko et al., 2013). This pest, also found in dried cassava chips (Schäfer et al., 2000) causes' visual damage by penetrating the chips thus depreciating their market value and negatively influence the quality of reconstituted yam paste (Babarinde et al., 2013). To protect yam chips against insects attack, farmers use chemical insecticides of cotton (Loko et al., 2013), but that leads to several cases of food poisoning and deaths of entire families (Adedoyin et al., 2008; Adeleke, 2009). Due to this deplorable situation, it urges to find out alternative methods that will take into account populations' environment and health protection, and which will be less expensive and available for all. Botanical control meet these criteria and can act as repellents, feeding deterrents, toxicants, growth retardants, and chemosterilants (Hikal et al., 2017). Similarly, genetical control by the use of resistant varieties have enormous potential to reduce storage insect pest populations, and it is an environment-friendly management option (Keneni et al., 2011). Therefore, the use of botanical pesticides and insect-resistant yam chips to control *D. porcellus* appear as a promising alternative.

In the main yam chips production areas of Benin, three medicinal plants (*Bridelia ferruginea* Benth, *Blighia sapida* Juss and *Khaya senegalensis* Cronquist) were recorded as used by farmers to protect their stocks against storage insect pests (Loko et al., 2013). Studies carried out by Loko et al. (2017a) revealed the insect repellency and insecticidal properties of the leaves of these three medicinal plants. Moreover, a study led by Loko et al. (2017b) has allowed to identify four yam landraces (*Gaboubaba*, *Boniwouré*, *Yakanougo* and *Wonmangou*) which chips are resistant to *D. porcellus* attacks. Therefore, to contribute to the strengthening of food security in Benin through the identification of an integrated pest management strategy of *D. porcellus* this study aims evaluate the interactions of resistant yam chips from the four landraces with leaves powder of *B. sapida*, *K. senegalensis* and *B. ferruginea*.

MATERIALS AND METHODS

Yam landraces source

Tubers of four yam landraces of *Dioscorea cayenensis Lam.* – *Dioscorea rotundata* Poir. complex, belonging to varietal group of "*Kokoro*" were collected from farmers across the Northen and the Central region of the republic of Benin. *Gaboubaba* and *Yakanougo* were collected from Koko village, *Boniwouré* from Kataban village, and *Wonmangou* from Fôbouko village. These 4 landraces were selected according to their resistance to *D. porcellus* (Loko et al., 2017b) and their good agronomic (productivity, number of tubers), culinary (quality of pounded and boiled yam) and technological (quality of yam chips, ease of pounding) characteristics (Loko et al., 2015).

Collection and preparation of medicinal plant powders

Leaves of *B. sapida*, *K. senegalensis* and *B. ferruginea* were collected from the town of Dassa-Zoumé (latitude: 7° 41′ 33″ North, and longitude: 2° 13′ 25″ East). Their identity was confirmed by the National Herbarium of the University of Abomey-Calavi. The collected leaves were washed and dried at ambient temperature for 20 days in the shade in order to prevent the degradation of bioactive compounds by sunlight. After drying, the leaves were transformed into powder using an electrical blender and sieved to obtain the finest particles using a 300 µm sieve (Loko et al., 2017a). The fine powder obtained from each plant species put in black polyethylene bags in dark cool and dry place until use. The compilation of physico-chemical composition of leaves powder of these three medicinal plants on the basis of literature was presented in Table 1.

Processing of yam chips

Yam chips were obtained from processing of tubers of the 4 yam landraces following the method described by Babajide et al. (2006). For that, yam tubers were washed with water to remove sand and other unwanted elements, and peeled with a knife. The tubers were cut into slices of 2 to 3 cm. The yam slices obtained were pre-cooked in water at 50°C for 2 h. They were also macerated in this pre-cooking water for 24 h in order to soften them. The slices were strained and dried in the autoclave at 60°C for at least 3 days in order to have 12 to 14% of final moisture. The dried chips obtained were put in polythene bags and stored in the laboratory at ambient temperature. The chips samples were sterilized at 105°C for 2 h in order to kill the hidden insects and their eggs. The samples were then exposed to ambient temperature for 1 h.

Table 1. Phytochemical composition of the crude water extract of *K. senegalensis*, *B. sapida* and *B. ferruginea* leaves based on literature review.

Phytochemical parameter	Medicinal plants					
	K. senegalensis	References	*B. sapida*	References	*B. ferruginea*	References
Alkaloids	+	Adeiza et al., 2010 Abalaka et al., 2011 Kawo et al., 2011	+	Oreagba et al., 2016	+	Aka and Obidike, 2010 Ameyaw et al., 2012 Abubakar et al., 2017 Houndjo et al., 2017
Tannins	+	Kubmarawa et al., 2008 Adeiza et al., 2010 Abalaka et al., 2011 Kawo et al., 2011	+	Kazeem, et al., 2013 Oreagba et al., 2016	+	Adebayo and Ishola, 2009 Aka and Obidike, 2010 Ameyaw et al., 2012 Abubakar et al., 2017 Houndjo et al., 2017
Saponins	+	Kubmarawa et al., 2008 Adeiza et al., 2010 Abalaka et al., 2011 Kawo et al., 2011	+	Kazeem, et al., 2013 Oreagba et al., 2016	+	Ameyaw et al., 2012 Abubakar et al., 2017
Flavanoids	+	Adeiza et al., 2010	+	Kazeem, et al., 2013 Oreagba et al., 2016	+	Adebayo and Ishola, 2009 Aka and Obidike, 2010 Abubakar et al., 2017 Houndjo et al., 2017
Triterpenoids	+	Adeiza et al., 2010	+	Kazeem, et al., 2013	+	Houndjo et al., 2017
Cardiac glycosides	+	Adeiza et al., 2010	+	Oreagba et al., 2016	+	Adebayo and Ishola, 2009 Aka and Obidike, 2010
Phenols	+	Kubmarawa et al., 2008	+	Oreagba et al., 2016		
Limonoids	+	Olmo et al., 1997	−		−	
Steroids	−		−		+	Ameyaw et al., 2012 Houndjo et al., 2017
Anthraquinones	−		−		+	Ameyaw et al., 2012 Houndjo et al., 2017
Coumarins	−		−		+	Ameyaw et al., 2012 Houndjo et al., 2017

+: Presence, −: Absence.

Rearing of *D. porcellus*

D. porcellus was collected from infested yam chips purchased from Dassa market and maintained on healthy yam chips in the laboratory using the method described by Onzo et al. (2015). The experimental plan was composed of cylindrical plastic boxes opened at one extremity. The opened extremity is covered by a muslin cloth allowing an adequate aeration and preventing insects from running out. Dried yam chips (500 g) were infested in the plastic boxes with 50 adults (3-5 days old) of *D. porcellus*. The plastic boxes were kept on shelves in the laboratory at ambient temperature (Oni and Omoniyi, 2012). After two weeks, adult beetles were removed from the breeding boxes in order to obtain a F1 generation that was used for all experiments (Isha et al., 2009).

Repellence test

The experimental device consisting of a flat circular plastic tray (36 cm in diameter by 2 cm in height) with a cardboard divided into twelve equal compartments and delimited in the centre by a circle having 5 cm of radius glued at the bottom (Babadjide et al., 2008; Loko et al. 2017b), which was used to assess repellency in *D. porcellus* due to yam chips combined with leaves powder of the three medicinal plants. Ten grams of healthy chips of each resistant landrace mixed with a concentration of leaves powder (1, 3, 5, 7 and 10% w/w) were placed in each compartment of tray equidistantly from the centre (Chebet et al., 2013). Similarly, the Antouka commercial insecticide (Permethrin 3 g/kg + pyrimiphos 16 g/kg; Dustable powder) recommended for the protection of stored food from insect pests was applied on 10 g of untreated yam chips of each landraces at 0.05% (w/w) as recommended by the manufacturer, and put in compartments as positive control (Loko et al. 2017b). While untreated yam chips of the four landraces were used as a negative control. For each treatment, 25 adults of *D. porcellus* (3-7 days old) starved for 24 h were released in the center of the tray, which was immediately covered with a transparent muslin cloth, to prevent the insects from escaping (Isah et al., 2009). The experiments were replicated at 3 different times (15, 30, and 45 days) with 4 replications (a total of 12 repetitions) for each leaves powder concentration. The total number of insects found in untreated yam chips (P) and treated yam chips (G) was recorded after 1, 12, and 24 h of infestation (Loko et al., 2017a). According to Dutra et al. (2016), repellent effect of plants was estimated by calculating the percent repellency (PR) and repellency index (IR). Repulsion percentage (PR) was calculated using the following formula of McDonald et al. (1970):

$$PR = [(Nc - Nt) / (Nc + Nt)] \times 100$$

Where Nc = number of insects present in untreated yam chips; Nt = number of insects present in treated yam chips. The mean repellency value of each treatment was calculated and assigned to the repellent classes from 0 to V: class 0 ($PR \leq 0.1\%$), class I (PR = 0.1 - 20%), class II (PR = 20.1 - 40%), Class III (40.1 - 60%), Class IV (60.1 - 80%) and Class V (80.1 - 100%).

The repellency index (IR) was calculated according to the following formula:

$$IR = 2G / G + P$$

Where G = percentage of insects attracted by treated yam chips, and P = percentage of insects attracted by untreated yam chips. The IR values are between 0 and 2 (Gusmão et al., 2013) with, IR = 1 indicates a similar repellency between treated and untreated yam chips (neutral treatment), IR> 1 indicates a lower repellency of treated yam chips compared to untreated yam chips (attractive treatment) and IR <1 correspond to a greater repulsion of treated yam chips compared to untreated yam chips (repellent treatment) (Padín et al., 2013).

Feeding deterrence test

Feeding deterrence test was based on the method used by Isah et al. (2012), and Onzo et al. (2015). For that, 50 g of disinfected yam chips from each resistant landraces mixed with different concentrations of leaves powder of each medicinal plants (1, 3, 5, 7, and 10 % w/w), and Antouka commercial insecticide (Permethrin 3 g/kg + pyrimiphos 16 g/kg, Dustable powder) at 0.05% (w/w) as a positive control were put in experimental boxes (6 cm in height and 8 cm in diameter). In the experiment, the untreated yam chips were used as negative control. In each box, yam chips of each landrace were infested with 20 adults of *D. porcellus* (3-7 days old) starved for 24 h. These boxes were covered by a muslin cloth to prevent the escape of insects and serves as aeration medium. Each treatment was repeated 4 times. The boxes were placed in the laboratory in a completely randomized block for 30, 60 and 90 days (Isah et al., 2012). At the end of each experimental period, the damage due to *D. porcellus* attacks was evaluated on the basis of proportion of yam chips consumed by the pests. This proportion was estimated according to the formula (Chijindu and Boateng, 2008):

$$\text{Percentage of weight loss} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100$$

Mortality test

Mortality test was conducted according to the methodology used by Chebet et al. (2013) with some modifications. Leaves powder of each of the three medicinal plants were mixed with 100 g of disinfected yam chips of each landrace in plastic boxes (10 cm of high and 13 cm in diameter) at different concentrations (0, 2, 4, 6, 8, 10% w/w). Yam chips impregnated with Antouka synthetic insecticide (Permethrin 3 g/kg + pyrimiphos 16 g/kg, DP) (0.05% weight/weight) were used as a positive control. Ten pairs of unsexed adult insects were introduced into treated and untreated yam chips. Each box was covered with a transparent muslin cloth, to prevent the insects from escaping. Treatments were arranged in a completely randomised design with 4 replicates. The dead adults were counted after 1, 3, 5, 7, 14 and 21 days of infestation (Othira et al., 2009). The adult mortality rate was calculated according to the formula of Asawalam et al. (2006) and corrected with Abbott's formula (Abbott, 1925) to eliminate the natural mortality of control:

$$\text{Percent mortality} = \frac{\text{number of } D. porcellus \text{ dead}}{\text{Number of } D. porcellus \text{ introduced}} \times 100$$

$$\text{Corrected mortality } (\%) = \frac{\%\text{ mortality in T} - \%\text{ mortality in C}}{100 - \%\text{ mortality in C}} \times 100$$

Where T = treated yam chips and C = untreated yam chips.

Reproductive inhibition test

Twenty grams of yam chips from the four resistant yam landraces were introduced into the experimental boxes (height: 6 cm and diameter: 8 cm) and mixed with different concentrations of powders of each medicinal plant (1, 3, 5, 7, and 10% w/w) (Chebet et al., 2003), and Antouka commercial insecticide (Permethrin 3 g/kg + pyrimiphos 16 g/kg; DP) at 0.05% (w/w) as a positive control. The untreated yam chips were used as negative control. Twenty newly emerged adults (3-7 days old) of *D. porcellus* (10 males and 10 females) were introduced into the centre of each experimental box. They were allowed to lay eggs for one week after which they were removed (Chijindu et al., 2008). The treatments were arranged in a completely randomised design with 4 replicates. The emerged adults of F1 progeny were counted 35 days after the begining of experiment. For that, experimental boxes were prospected and emerged adults were collected every 2 days until there is no emerged adult. The percent reduction in adult emergence or reproductive inhibition rate (IR %) was calculated according to Tapondjou et al. (2002) using the formula:

$$\textbf{Reproductive inhibition rate} = \frac{NU - \textbf{NT}}{\textbf{NU}} \times \textbf{100}$$

Where, NU = number of newly emerged adult insects in untreated yam chips, NT = number of newly emerged adult insects in treated yam chips.

Statistical analysis

Data on percentage mortality, repellency, weight loss, and reproductive inhibition were arcsine-transformed (arscine√x), while data on the number of emerged F1 progeny were log-transformed (log(x + 1)) in order to homogenize their variance. The transformed data were then subjected to general linear model (GLM) using IBM SPSS Statistics 25 software package. Significant differences among the means were separated using Student Newman keuls statistic at the 5% level of probability. The original data are presented in tables and figures. Principal component analysis (ACP) was also carried out with Minitab software version 18 in order to examine the contribution of each combination of resistant yam chips treated with leaves powder of medicinal plants on *D. porcellus* control. For that, the different combinations of resistant yam chips and leaves powder of medicinal plants were considered as individuals and corresponding mean values of repellency, mortality, reproductive inhibition, and weight loss were as variables.

RESULTS

Repellent effect of resistant yam chips combined with leaves powder on *D. porcellus*

The synthetic insecticide Antouka and resistant yam chips combined with leaves powder of *B. sapida*, *K. senegalensis* and *B. ferruginea* at all concentrations had a strong repellent effect on *D. porcellus* (Table 2). However, no significant interaction between resistant yam chips and leaves powder of the three medicinal plants on *D. porcellus* repellency were observed (p ≥ 0.05). Moreover, the interaction between resistant yam chips, medicinal plants and leaves powder concentration on repellence of *D. porcellus* was not significant (p ≥ 0.05) for all treatments. The results showed that percent repellency of *D. porcellus* adults by resistant yam chips treated with different concentration of leaves powder of the three medicinal plants had not varied significantly than commercial insecticide Antouka after 1 h of experiment (p ≥ 0.05). However, yam chips of Yakanougo landrace combined with leaves powder of *B. sapida* respectively at 7 and 3% were more repellent than Antouka insecticide after 12 h (p ≤ 0.05) and 24 h (p ≤ 0.05) of experiment. The results also showed that leaves powder of *B. sapida*, *K. senegalensis* and *B. ferruginea* had repellent classes ranging from II to IV with a repellency index varying from 0.33 to 0.65 (Table 2). Similarly to Antouka insecticide, leaves powder of *B. sapida* combined with yam chips of Wonmangou landrace at 5 and 7%, Yakanougo landrace at 3, 5 and 7%, and Bonioué landrace at 5 and 7% exhibited a class IV of repellence (Table 1). Similar trend was observed with yam chips of Boniwouré landrace combined with leaves powder of *K. senegalensis* at 5%.

Effect of resistant yam chips combined with leaves powder on *D. porcellus* damages

There was a statistically significant interaction of resistant yam chips combined with leaves powder of the three medicinal plants on reduction of *D. porcellus* damages after 30 (p ≤ 0.05), and 60 (p ≤ 0.05) days of experiments. After 90 days of experimentation this interaction was not significant (p ≥ 0.05). However, no concentration-dependent reduction of weight loss was observed with leaves powder of different medicinal plants (p ≥ 0.05). After 30 days of experiment, only leaves powder of *B. sapida* combined with yam chips of Gaboubaba at 3%, and Wonmangou at 1 and 5% exhibited a significant reduction of weight loss (p ≤ 0.01) than untreated yam chips. The combination of yam chips of resistant landraces with different concentrations of leaves powders of *B. sapida*, *K. senegalensis* and *B. ferruginea* caused a significant reduction of weight loss than untreated yam chips at 60 (p ≤ 0.001), and 90 days (p ≤ 0.001) of experiments. No significant difference was observed between weight loss of yam chips protected with synthethic insecticide Antouka and those protected with leaves powder of the three medicinal plants during all the experimental periods (Table 3).

Effect of resistant yam chips combined with leaves powder on *D. porcellus* mortality

The combination of resistant yam chips with different concentration of leaves powder of the three medicinal plants increased the mortality of *D. porcellus* during all experimental period than untreated yam chips (Figure 1). A significant interaction (p ≤ 0.05) of resistant yam chips treated with different leaves powder concentrations of *K. senegalensis* on *D. porcellus* mortality (Figure 1b) was observed after 1, and 3 days of experiment. However, after 5 days of experiment, no significant interaction (p ≥ 0.05) between resistant yam chips, medicinal plants and leaves powder concentration on *D. porcellus* mortality was recorded. The results showed that mortality was concentration-dependent increasing with increasing dosage of leaves powder of medicinal plants after 21 days of experiment (p ≤ 0.05). The highest mortality was recorded with the synthetic insecticide Antouka with a mean mortality rate of 84.8% (Figure 1). While, the lowest mortality rates were observed on untreated yam chips with a mean mortality rate of 10.5% after 21 days of experiment. The combination of leaves powder of *K. senegalensis* with yam chips of the four resistant landraces at 8%, of leaves powder of *B. sapida* with yam

Table 2. Percent repellence (mean ± SE) of adult *D. porcellus* and repellent class of *B. sapida*, *K. senegalensis*, and *B. ferruginea* leaves powder combined with resistant yam chips at different concentrations and exposure time.

Species name	Landraces	Powders concentration (%)	Percentage of repellency of treatments after			Mean repellency	Repellency class	Repellency index	Classification
			1 h	12	24 h				
B. sapida	Boniwouré	1	57.10 ± 12.0 [a]	49.9 ± 13.10 [a]	51.40 ± 13.5 [ab]	52.83 ± 6.52 [a]	III	0.47 ± 0.06	Repellent
		3	52.10 ± 3.37 [a]	58.00 ± 12.1 [a]	67.41 ± 7.07 [a]	59.20 ± 4.70 [a]	III	0.41 ± 0.05	Repellent
		5	70.79 ± 7.70 [a]	58.1 ± 16.60 [a]	68.33 ± 9.28 [a]	65.73 ± 6.24 [a]	IV	0.34 ± 0.06	Repellent
		7	69.36 ± 4.30 [a]	70.00 ± 5.00 [ab]	62.80 ± 14.8 [ab]	67.38 ± 4.82 [a]	IV	0.33 ± 0.05	Repellent
		10	41.67 ± 8.33 [a]	42.00 ± 8.99 [a]	39.90 ± 12.9 [ab]	41.21 ± 5.15 [a]	III	0.59 ± 0.05	Repellent
	Gaboubaba	1	29.80 ± 10.60 [a]	56.40 ± 15.8 [a]	53.30 ± 15.4 [ab]	46.49 ± 8.21 [a]	III	0.54 ± 0.08	Repellent
		3	47.00 ± 4.56 [a]	56.70 ± 12.0 [a]	56.77 ± 8.43 [ab]	53.48 ± 4.72 [a]	III	0.47 ± 0.05	Repellent
		5	37.00 ± 24.4 [a]	35.00 ± 12.6 [a]	45.66 ± 9.19 [ab]	39.23 ± 8.51[a]	II	0.61 ± 0.08	Repellent
		7	40.70 ± 11.7 [a]	42.42 ± 9.52 [a]	41.40 ± 11.2 [ab]	41.50 ± 5.45 [a]	III	0.59 ± 0.05	Repellent
		10	21.00 ± 12.4 [a]	42.77 ± 1.58 [a]	46.40 ± 17.6 [ab]	36.72 ± 7.39 [a]	II	0.63 ± 0.07	Repellent
	Wanmangou	1	32.06 ± 6.63 [a]	46.67 ± 5.30 [a]	57.20 ± 13.1 [ab]	45.32 ± 5.79 [a]	III	0.55 ± 0.06	Repellent
		3	70.00 ± 5.00 [a]	56.40 ± 3.96 [a]	63.89 ± 7.35 [ab]	58.13 ± 4.95 [a]	III	0.42 ± 0.05	Repellent
		5	63.06 ± 1.94 [a]	66.03 ± 3.31 [a]	61.85 ± 9.21 [ab]	63.65 ± 2.95 [a]	IV	0.36 ± 0.03	Repellent
		7	56.10 ± 12.0 [a]	63.52 ± 5.88 [a]	63.54 ± 4.58 [ab]	61.05 ± 4.26 [a]	IV	0.39 ± 0.04	Repellent
		10	41.67 ± 8. 33 [a]	53.30 ± 14.8 [a]	40.90 ± 17.9 [ab]	45.29 ± 7.41 [a]	III	0.55 ± 0.07	Repellent
	Yakanougo	1	25.93 ± 7.41 [a]	54.60 ± 16.8 [a]	62.10 ± 11.7 [ab]	51.07 ± 7.10 [a]	III	0.49 ± 0.07	Repellent
		3	63.52 ± 5.88 [a]	72.88 ± 4.84 [ab]	73.48 ± 5.30 [a]	69.96 ± 3.13 [a]	IV	0.30 ± 0.03	Repellent
		5	57.8 ± 12.4 [a]	59.30 ± 13.4 [a]	63.80 ± 12.2 [ab]	60.28 ± 6.38 [a]	IV	0.40 ± 0.06	Repellent
		7	74.81 ± 4.12 [a]	75.93 ± 0.93 [b]	68.99 ± 7.16 [a]	73.25 ± 2.63 [a]	IV	0.27 ± 0.03	Repellent
		10	44.80 ± 14.9 [a]	54.40 ± 10.3 [a]	36.30 ± 10.4 [ab]	45.17 ± 6.57 [a]	III	0.55 ± 0.06	Repellent
K. senegalensis	Boniwouré	1	56.61 ± 8.26 [a]	58.10 ± 8.30 [a]	50.80 ± 18.3 [ab]	55.17 ± 6.37 [a]	III	0.45 ± 0.06	Repellent
		3	54.90 ± 11.3 [a]	47.78 ± 7.78 [a]	50.40 ± 12.6 [ab]	52.09 ± 5.14 [a]	III	0.48 ± 0.05	Repellent
		5	57.10 ± 12.0 [a]	64.00 ± 10.7 [ab]	68.33 ± 9.28 [a]	63.17 ± 5.60 [a]	IV	0.37 ± 0.06	Repellent
		7	42.40 ± 16.3 [a]	36.11 ± 7.35 [a]	41.70 ± 10.1 [ab]	40.99 ± 5.79 [a]	III	0.59 ± 0.06	Repellent
		10	51.30 ± 12.4 [a]	37.96 ± 9.12 [a]	41.14 ± 8.86 [ab]	43.45 ± 5.50 [a]	III	0.56 ± 0.05	Repellent
	Gaboubaba	1	59.37 ± 9.78 [a]	36.51 ± 3.17 [a]	25.71 ± 8.73 [b]	40.53 ± 6.31 [a]	III	0.59 ± 0.06	Repellent
		3	39.7 ± 16.8 [a]	41.40 ± 13.9 [a]	27.00 ± 14.3 [b]	36.77 ± 8.17 [a]	II	0.63 ± 0.08	Repellent
		5	25.1 ± 12.5[a]	46.10 ± 2.09 [a]	61.85 ± 9.21 [ab]	44.36 ± 6.98 [a]	III	0.56 ± 0.06	Repellent
		7	46.14 ± 4.78 [a]	36.90 ± 17.5 [a]	26.90 ± 16.1 [b]	37.56 ± 7.41 [a]	II	0.62 ± 0.07	Repellent
		10	44.44 ± 8.01 [a]	63.89 ± 7.35 [ab]	41.96 ± 0.95 [ab]	45.63 ± 7.28 [a]	III	0.50 ± 0.05	Repellent
	Wanmangou	1	63.1 ± 10.2 [a]	36.90 ± 17.5 [a]	58.10 ± 8.30 [ab]	52.70 ± 7.49 [a]	III	0.47 ± 0.07	Repellent
		3	48.6 ± 17.5 [a]	17.86 ± 3.57 [a]	26.43 ± 7.46 [b]	37.70 ± 7.73 [a]	II	0.62 ± 0.08	Repellent
		5	58.10 ± 8.30 [a]	59.30 ± 13.4 [a]	50.84 ± 9.06 [ab]	56.07 ± 5.40 [a]	III	0.44 ± 0.05	Repellent

Table 2. Contd.

		7	46.14 ± 4.78 [a]	32.30 ± 19.6 [a]	58.30 ± 12.7 [ab]	46.11 ± 8.04 [a]	III	0.54 ± 0.08	Repellent
		10	49.8 ± 18.3 [a]	38.90 ± 14.0 [a]	49.10 ± 12.5 [ab]	45.91 ± 7.75 [a]	III	0.54 ± 0.08	Repellent
	Yakanougo	1	45.4 ± 18.6 [a]	50.00 ± 9.62 [a]	44.40 ± 11.1 [ab]	46.60 ± 6.89 [a]	III	0.53 ± 0.07	Repellent
		3	42.22 ± 8.89 [a]	32.50 ± 10.3 [a]	42.40 ± 12.2 [ab]	40.25 ± 4.97 [a]	III	0.60 ± 0.05	Repellent
		5	29.8 ± 10.6 [a]	45.00 ± 10.4 [a]	45.66 ± 9.19 [ab]	48.47 ± 8.37 [a]	III	0.52 ± 0.08	Repellent
		7	64.3 ± 10.7[a]	44.40 ± 11.1 [a]	55.56 ± 8.01 [ab]	55.29 ± 5.94 [a]	III	0.45 ± 0.06	Repellent
		10	44. 24 ± 9.47 [a]	52. 22 ± 7.78 [a]	35.20 ± 10.2 [ab]	43.88 ± 5.22 [a]	III	0.56 ± 0.05	Repellent
	Boniwouré	1	50.8 ± 18.3[a]	59.50 ± 10.9 [a]	53.50 ± 12.1 [ab]	54.60 ± 7.19 [a]	III	0.45 ± 0.07	Repellent
		3	52.9 ± 13.2[a]	41.9 ± 11.0 [a]	64.00 ± 10.7 [a]	52.92 ± 6.68 [a]	III	0.47 ± 0.07	Repellent
		5	47.2 ± 12.1[a]	27.38 ± 8.33 [a]	52.90 ± 19.6 [ab]	42.50 ± 8.06 [a]	III	0.58 ± 0.08	Repellent
		7	47.1 ± 17.0[a]	62.70 ± 6.50 [ab]	37.96 ± 9.12 [ab]	49.25 ± 6.90 [a]	III	0.51 ± 0.07	Repellent
		10	52.38 ± 9.52[a]	48.3 ± 11.7 [a]	36.51 ± 3.17 [ab]	45.71 ± 5.05 [a]	III	0.54 ± 0.05	Repellent
	Gaboubaba	1	36.51 ± 3.17[a]	34.49 ± 4.76 [a]	42.00 ± 8.99 [ab]	37.67 ± 3.27 [a]	II	0.62 ± 0.03	Repellent
		3	36.4 ± 19.4[a]	41.11 ± 4.84 [a]	43.30 ± 14.3 [ab]	40.26 ± 7.16 [a]	III	0.60 ± 0.07	Repellent
		5	52.38 ± 9.52[a]	27.38 ± 8.33 [a]	26.74 ± 8.45 [b]	35.50 ± 6.09 [a]	II	0.65 ± 0.06	Repellent
		7	57.14 ± 9.18[a]	54.76 ± 8.58 [a]	55.95 ± 9.74 [ab]	55.95 ± 4.60 [a]	III	0.44 ± 0.05	Repellent
B. ferruginea		10	39.29 ± 7.43[a]	44.44 ± 8.01 [a]	44.00 ± 13.5 [ab]	42.59 ± 5.08 [a]	III	0.57 ± 0.05	Repellent
	Wanmangou	1	35.0 ± 12.6[a]	44.29 ± 2.97 [a]	36.40 ± 19.6 [ab]	38.56 ± 6.93 [a]	II	0.61 ± 0.07	Repellent
		3	40.9 ± 17.9[a]	42.80 ± 16.6 [a]	40.55 ± 3.68 [ab]	41.40 ± 7.13 [a]	III	0.59 ± 0.07	Repellent
		5	28.7 ± 11.4[a]	41.30 ± 15.1 [a]	62.22 ± 2.22 [ab]	44.07 ± 7.36 [a]	III	0.56 ± 0.07	Repellent
		7	36.3 ± 10.4[a]	46.20 ± 11.3 [a]	38.33 ± 7.26 [ab]	40.28 ± 5.13 [a]	III	0.60 ± 0.05	Repellent
		10	47.62 ± 9.91[a]	61.67 ± 7.26 [a]	56.90 ± 10.7 [ab]	55.39 ± 5.13 [a]	III	0.45 ± 0.05	Repellent
	Yakanougo	1	38.6 ± 17.6[a]	56.77 ± 8.43 [a]	47.62 ± 6.25 [ab]	47.67 ± 6.47 [a]	III	0.52 ± 0.06	Repellent
		3	53.6 ± 19.7[a]	46.30 ± 6.68 [a]	46.10 ± 2.09 [ab]	48.66 ± 6.15 [a]	III	0.51 ± 0.06	Repellent
		5	33.73 ± 5.16[a]	48.57 ± 5.71 [a]	34.40 ± 21.7 [ab]	38.90 ± 7.08 [a]	II	0.61 ± 0.07	Repellent
		7	41.9 ± 16.5[a]	54.76 ± 8.58 [a]	33.30 ± 12.8 [ab]	43.33 ± 7.23 [a]	III	0.57 ± 0.07	Repellent
		10	41.7 ± 12.7[a]	49.63 ± 8.25 [a]	45.40 ± 7.80 [ab]	45.56 ± 5.06 [a]	III	0.54 ± 0.05	Repellent
Control+	Antouka	0.05	56.64 ± 3.15[a]	60.79 ± 2.41 [a]	64.45 ± 2.21 [a]	60.85 ± 1.52 [a]	IV	0.39 ± 0.01	Repellent

Means within the same rows followed by the same letter are not significantly different using Student Newman Keuls test ($p < 0.05$).

chips of Yakanougo and Bonioure landraces at 6%, and of leaves powder of *B. ferruginea* with yam chips of Gabouba landrace at 6% caused a mortality of more than 50% of the *D. porcellus* population.

Effect of resistant yam chips combined with leaves powder on *D. porcellus* reproduction

A mean number of *D. porcellus* adults emerged from resistant yam chips treated with different concentrations of leaves powder of *B. sapida*, *K. senegalensis* and *B. ferruginea* was significantly different from those of untreated yam chips after 35 ($p \leq 0.001$) and 37 days ($p \leq 0.001$) of experimentation (Table 4). However, no significant

Table 3. Weight loss (mean ± SE) of resistant yam chips treated with varying concentrations of leaves powder of *B. sapida*, *K. senegalensis*, and B*. ferruginea* after 30, 60 and 90 days of *D. porcellus* feeding.

Species name	Landraces	Powders concentration (%)	Average weight losses (%) after		
			30 days	60 days	90 days
B. sapida	Boniwouré	1	1.80 ± 0.28 ab	3.40 ± 0.36 b	3.56 ± 0.81 b
		3	1.90 ± 0.57 ab	3.05 ± 0.67 b	4.25 ± 0.51 b
		5	1.66 ± 0.51 ab	3.31 ± 0.36 b	4.31 ± 0.65 ab
		7	1.33 ± 0.39 ab	3.31 ± 0.16 b	4.46 ± 0.25 ab
		10	1.61 ± 0.59 ab	2.91 ± 0.28 b	3.95 ±0.35 b
	Gaboubaba	1	0.45 ± 0.05 ab	2.70 ± 0.42 b	4.10 ± 0.15 ab
		3	0.23 ± 0.06 b	2.30 ± 0.46 b	3.25 ± 0.58 b
		5	0.76 ± 0.36 ab	2.45 ± 0.33 b	3.33 ± 0.47 b
		7	1.15 ± 0.26 ab	2.38 ± 0.23 b	3.31 ± 0.1 b
		10	0.80 ± 0.17 ab	2.23 ± 0.03 b	3.16 ± 0.11 b
	Wanmangou	1	0.33 ± 0.07 b	2.35 ± 0.14 b	3.70 ± 0.18 b
		3	0.88 ± 0.28 ab	2.61 ± 0.43 b	3.70 ± 0.34 b
		5	0.21 ± 0.09 b	2.21 ± 0.16 b	3.85 ± 0.25 b
		7	0.56 ± 0.32 ab	2.23 ± 0.33 b	3.68 ± 0.3 b
		10	0.88 ± 0.15 ab	2.83 ± 0.13 b	4.26 ± 0.18 b
	Yakanougo	1	1.26 ± 0.48 ab	3.41 ± 0.49 b	3.21 ± 1.53 b
		3	1.6 ± 0.44 ab	3.68 ± 0.33 b	5.45 ± 0.52 ab
		5	1.25 ± 0.57 ab	3.01 ± 0.44 b	4.68 ± 0.16 ab
		7	1.11 ± 0.15 ab	3.13 ± 0.12 b	4.30 ± 0.05 ab
		10	1.71 ± 0.14 ab	3.60 ± 0.21 b	3.33 ± 1.17 b
K. senegalensis	Boniwouré	1	1.46 ± 0.22 ab	3.30 ± 0.13 b	4.61 ± 0.27 b
		3	1.68 ± 0.45 ab	3.10 ± 0.52 b	3.96 ± 0.46 b
		5	1.21 ± 0.4 ab	2.86 ± 0.5 b	3.81 ± 0.62 b
		7	1.13 ± 0.28 ab	2.78 ± 0.06 b	3.53 ± 0.04 b
		10	0.71 ± 0.16 ab	2.58 ± 0.18 b	3.48 ± 0.44 b
	Gaboubaba	1	0.68 ± 0.18 ab	1.95 ± 0.24 b	3.35 ± 0.16 b
		3	1.21 ± 0.26 ab	2.20 ± 0.14 b	3.21 ± 0.26 b
		5	1.15 ± 0.28 ab	2.55 ± 0.1 b	3.63 ± 0.19 b
		7	1.15 ± 0.17 ab	2.68 ± 0.36 b	3.43 ± 0.24 b
		10	0.85 ± 0.2 ab	2.58 ± 0.18 b	3.45 ± 0.28 b
	Wanmangou	1	0.75 ± 0.27 ab	2.55 ± 0.32 b	3.78 ± 0.35 b
		3	0.80 ± 0.2 ab	2.78 ± 0.37 b	4.36 ± 0.24 ab
		5	0.55 ± 0.23 ab	2.28 ± 0.06 b	3.61 ± 0.26 b
		7	0.53 ± 0.19 ab	2.13 ± 0.25 b	3.31 ± 0.2 b

Table 3. Contd.

		10	0.71 ± 0.27 ab	2.73 ± 0.46 b	3.60 ± 0.5 b
	Yakanougo	1	0.86 ± 0.21 ab	3.15 ± 0.13 b	4.58 ± 0.23 b
		3	1.28 ± 0.3 ab	2.60 ± 0.25 b	3.48 ± 0.19 b
		5	0.83 ± 0.12 ab	2.66 ± 0.38 b	3.58 ± 0.23 b
		7	1.06 ± 0.09 ab	2.56 ± 0.5 b	3.31 ± 0.39 b
		10	0.93 ± 0.13 ab	2.98 ± 0.33 b	4.06 ± 0.28 ab
B. ferruginea	Boniwouré	1	0.88 ± 0.13 ab	2.73 ± 0.18 b	3.75 ± 0.3 b
		3	1.03 ± 0.27 ab	2.31 ± 0.21 b	2.96 ± 0.21 b
		5	0.76 ± 0.1 ab	3.00 ± 0.72 b	3.81 ± 0.44 b
		7	1.60 ± 0.6 ab	2.95 ± 0.57 b	3.86 ± 0.45 b
		10	1.33 ± 0.23 ab	3.18 ± 0.26 b	4.05 ± 0.24 b
	Gaboubaba	1	1.03 ± 0.13 ab	3.03 ± 0.1 b	3.56 ± 0.4 b
		3	0.78 ± 0.21 ab	2.96 ± 0.2 b	3.73 ± 0.24 b
		5	1.10 ± 0.36 ab	3.36 ± 0.16 b	3.95 ± 0 b
		7	1.15 ± 0.1 ab	2.86 ± 0.31 b	3.93 ± 0.17 b
		10	1.10 ± 0.27 ab	3.30 ± 0.25 b	4.03 ± 0.3 b
	Wanmangou	1	0.51 ± 0.03 ab	2.10 ± 0.17 b	3.40 ± 0.62 b
		3	1.31 ± 0.16 ab	3.63 ± 0.24 b	4.76 ± 0.24 ab
		5	0.70 ± 0.21 ab	2.98 ± 0.19 b	3.71 ± 0.06 b
		7	1.00 ± 0.23 ab	3.15 ± 0.2 b	3.95 ± 0.17 b
		10	1.01 ± 0.22 ab	3.53 ± 0.27 b	4.16 ± 0.22 b
	Yakanougo	1	0.83 ± 0.14 ab	2.80 ± 0.45 b	2.78 ± 0.91 b
		3	0.96 ± 0.26 ab	3.13 ± 0.14 b	3.81 ± 0.24 b
		5	1.66 ± 0.54 ab	2.90 ± 0.53 b	3.86 ± 0.54 b
		7	1.28 ± 0.2 ab	3.33 ± 0.13 b	4.18 ± 0.31 b
		10	1.20 ± 0.4 ab	3.60 ± 0.27 b	4.25 ± 0.24 b
Control +		0.05	1.49 ± 0.08 ab	3.31 ± 0.07 b	4.10 ± 0.10 b
Control -		Any treatment	1.91 ± 0.09 a	4.05 ± 0.17 a	7.54 ± 0.28 a

Means within the same rows followed by the same letter are not significantly different using Student Newman Keuls test ($p < 0.05$).

difference was noted between resistant yam chips treated with leaves powder of the three medicinal plants and insecticide Antouka during experimentations. Significant concentration-dependent reproductive inhibition was observed after 35 days of experimentation ($p \leq 0.05$). Signicant interaction between medicinal plants and concentrations of leaves powder on reproductive inhibition rate was observed ($p \leq 0.001$) after 35 days of experimentation. The resistant yam chips of the four landraces combined with leaves powder of *K. senegalensis* significantly inhibited *D. porcellus* reproduction ($p \leq 0.001$) after 35 days of experimentation. While, in 37 days of experimentation, reproductive

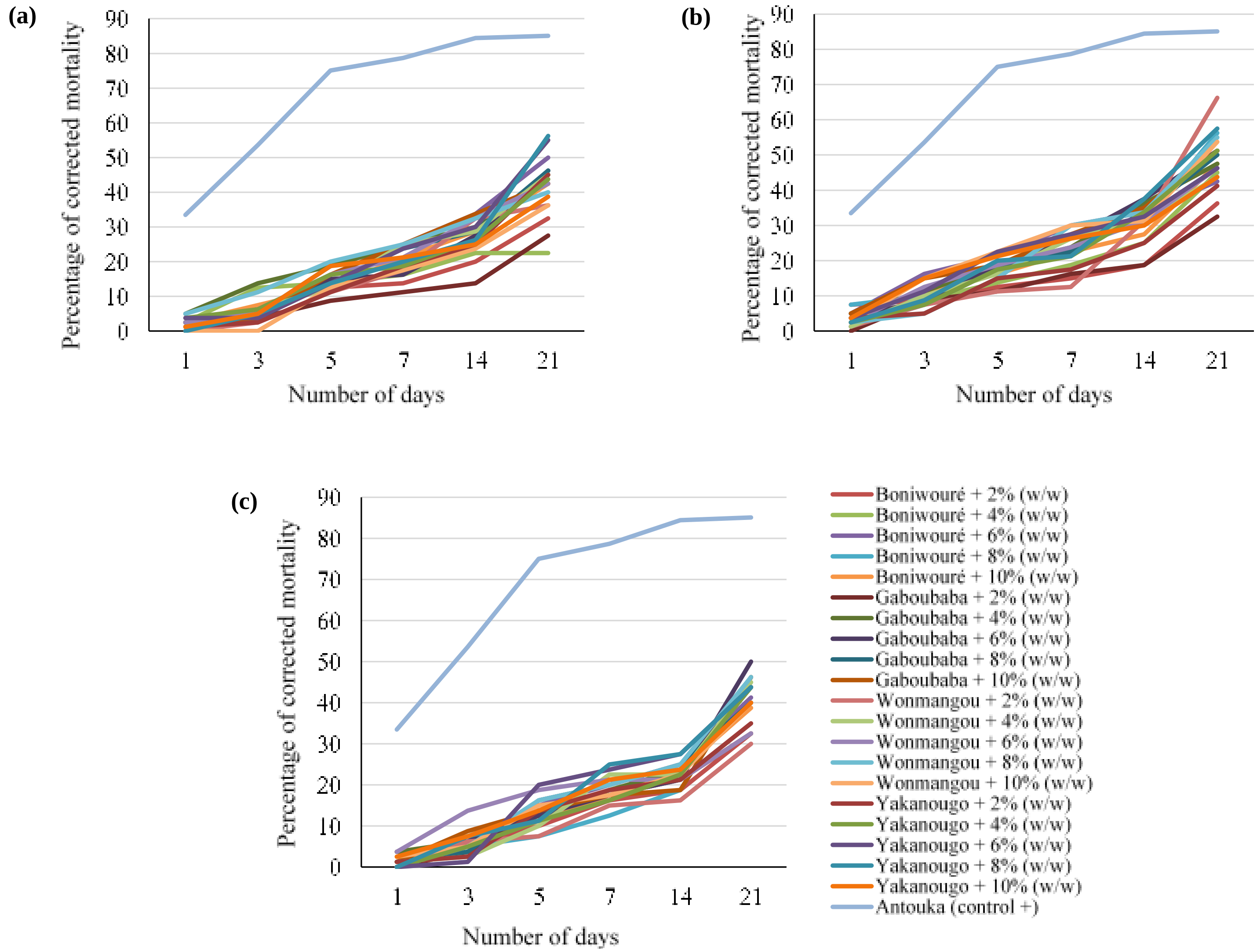

Figure 1. Mortality of *D. porcellus* feeding on resistant yam chips treated with leaves powder of (a) *B. sapida*, (b) *K. senegalensis*, and (c) *B. ferruginea*. Mortality rate was corrected using Abbott's formula.

inhibition rate of all treatments weren't significatively different from what we noticed with synthetic insecticide Antouka, except yakanougo and Bonioué landraces combined respectively with leaves powder of *B. sapida* at 10% and *B. ferruginae* at 5% (Table 4).

Contribution of each combination of resistant yam chips with leaves powder on *D. porcellus* control

Principal component analysis showed that the first three axes represent about 81.5% of total variability. The first axis was positively correlated with weight loss and repellency while the second axis was correlated with mortality and reproductive inhibition of *D. porcellus*. Furthermore, observing the loading plot and the score plot obtained from principal component analysis, the 12 combinations of resistant yam chips treated with leaves powder have been grouped in 4 groups (Figure 2). The first group composed of yam chips of Yakanougo, Wonmangou and Gaboubaba landraces combined with leaves powder of *K. senegalensis* are characterised by their high reproductive inhibition rate of *D. porcellus*. The second group characterised by a strong repellency effect on *D. porcellus* contains yam chips of Bonioué landrace treated with leaves powder of *B. sapida* and *K. senegalensis*, and yam chips of Gaboubaba landrace combined with leaves powder of *B. sapida*. The integration of Gaboubaba with leaves powder of *K. senegalensis* which composed the third group was characterised by a low weight loss. The fourth group was composed of the five remaining combinations which are

Table 4. Effect of yam chips from resistant landraces treated with different concentrations of *B. sapida*, *K. senegalensis* and *B. ferruginea* leaves powder on mean number of emerged adults (mean ± ES) and reproductive inhibition rate of *D. porcellus.*

Treatment	Landraces	Concentration (%w/w)	Mean number of F1 progenies		Reproduction inhibition rate (%)	
			35 days	37 days	35 days	37 days
B. sapida	Boniwouré	1	8.33 ± 2.40 b	1.33 ± 0.33 a	81.84 ± 3.59 abc	90.62 ± 0.87 ab
		3	4.00 ± 0.58 b	1.67 ± 0.33 a	81.95 ± 6.25 abc	84.71 ± 4.92 ab
		5	6.00 ± 1.53 b	1.00 ± 0.58 a	81.13 ± 5.90 abc	92.49 ± 4.44 ab
		7	3.33 ± 0.33 b	1.33 ± 0.33 a	83.57 ± 2.55 abc	84.26 ± 4.63 ab
		10	6.33 ± 0.33 b	1.33 ± 0.88 a	84.21 ± 4.45 abc	85.86 ± 9.95 ab
	Gaboubaba	1	4.33 ± 1.86 b	2.33 ± 0.33 a	89.50 ± 5.10 bcd	85.47 ± 4.08 ab
		3	4.00 ± 0.58 b	1.00 ± 0.00 a	81.95 ± 6.25 abc	90.84 ± 1.91 ab
		5	5.67 ± 2.03 b	1.67 ± 0.33 a	83.95 ± 5.57 abc	87.08 ± 1.94 ab
		7	3.67 ± 0.88 b	1.67 ± 0.33 a	83.27 ± 1.27 abc	81.02 ± 3.24 ab
		10	6.33 ± 1.45 b	0.67 ± 0.33 a	85.45 ± 3.27 abc	93.27 ± 3.42 ab
	Wonmangou	1	5.67 ± 0.88 b	0.67 ± 0.33 a	87.21 ± 1.72 abc	95.77 ± 2.41 ab
		3	6.00 ± 1.53 b	1.33 ± 0.33 a	77.88 ± 1.69 abc	87.81 ± 3.55 ab
		5	5.33 ± 1.45 b	2.00 ± 0.58 a	82.84 ± 6.61 abc	83.87 ± 4.71 ab
		7	3.33 ± 1.33 b	0.67 ± 0.33 a	80.30 ± 11.6 abc	92.13 ± 3.96 ab
		10	7.67 ± 2.96 b	2.00 ± 1.53 a	79.14 ± 8.97 abc	87.45 ± 8.43 ab
	Yakanougo	1	6.00 ± 2.08 b	2.33 ± 0.88 a	86.23 ± 5.29 abc	80.03 ± 8.44 ab
		3	7.00 ± 0.58 b	1.00 ± 0.58 a	69.45 ± 8.90 abc	89.77 ± 5.37 ab
		5	7.67 ± 1.76 b	1.67 ± 0.33 a	77.73 ± 3.78 abc	87.08 ± 1.94 ab
		7	5.00 ± 1.15 b	0.33 ± 0.33 a	76.54 ± 3.59 abc	96.30 ± 3.70 ab
		10	6.33 ± 1.76 b	2.33 ± 0.88 a	85.93 ± 3.68 abc	74.36 ± 9.47 a
K. senegalensis	Boniwouré	1	7.67 ± 2.19 b	1.33 ± 0.33 a	81.26 ± 5.84 abc	90.61 ± 2.58 ab
		3	5.33 ± 1.86 b	2.00 ± 0.58 a	90.46 ± 1.86 bcd	80.03 ± 6.54 ab
		5	6.33 ± 1.76 b	1.33 ± 0.33 a	83.51 ± 3.84 abc	90.56 ± 2.16 ab
		7	5.33 ± 1.20 b	1.67 ± 0.88 a	93.34 ± 1.73 cd	86.25 ± 7.02 ab
		10	5.00 ± 2.08 b	2.00 ± 0.58 a	89.76 ± 4.47 bcd	81.90 ± 4.01 ab
	Gaboubaba	1	6.67 ± 0.88 b	1.67 ± 0.88 a	82.64 ± 5.14 abc	87.96 ± 7.23 ab
		3	4.00 ± 1.53 b	1.67 ± 0.33 a	91.07 ± 4.26 bcd	84.13 ± 3.54 ab
		5	4.00 ± 0.58 b	1.67 ± 0.33 a	89.33 ± 1.26 bcd	87.80 ± 3.33 ab
		7	5.33 ± 0.88 b	1.67 ± 0.68 a	93.54 ± 0.93 cd	80.10 ± 11.5 ab
		10	5.00 ± 0.58 b	1.33 ± 0.33 a	89.19 ± 1.37 bcd	86.78 ± 4.51 ab
	Wonmangou	1	7.67 ± 0.67 b	1.33 ± 0.88 a	80.06 ± 6.38 abc	91.67 ± 4.81 ab
		3	5.67 ± 1.76 b	1.00 ± 0.58 a	89.39 ± 2.89 bcd	89.63 ± 5.79 ab
		5	3.67 ± 1.20 b	1.33 ± 0.33 a	90.47 ± 2.61 bcd	90.83 ± 1.47 ab
		7	3.67 ± 1.20 b	1.00 ± 0.00 a	95.54 ± 1.37 cd	89.64 ± 2.01 ab

Table 4. Contd.

		10	5.67 ± 1.33 ^{b}	1.67 ± 0.68 ^{a}	86.75 ± 4.25 ^{abc}	84.43 ± 5.90 ^{ab}
		1	5.67 ± 1.20 ^{b}	1.67 ± 0.33 ^{a}	84.39 ± 6.72 ^{abc}	88.36 ± 2.76 ^{ab}
		3	5.33 ± 1.33 ^{b}	1.33 ± 0.88 ^{a}	88.41 ± 5.03 ^{bcd}	88.60 ± 6.66 ^{ab}
	Yakanougo	5	6.33 ± 0.67 ^{b}	1.33 ± 0.67 ^{a}	83.12 ± 0.95 ^{abc}	91.63 ± 4.21 ^{ab}
		7	6.33 ± 0.67 ^{b}	2.00 ± 0.58 ^{a}	92.14 ± 1.38 ^{bcd}	79.75 ± 5.80 ^{ab}
		10	3.33 ± 0.88 ^{b}	1.33 ± 0.33 ^{a}	93.05 ± 1.20 ^{cd}	87.71 ± 2.26 ^{ab}
		1	7.67 ± 2.33 ^{b}	2.33 ± 0.68 ^{a}	76.51 ± 6.83 ^{abc}	80.99 ± 5.60 ^{ab}
		3	6.00 ± 2.08 ^{b}	1.33 ± 0.33 ^{a}	73.63 ± 5.67 ^{abc}	86.90 ± 2.56 ^{ab}
	Boniwouré	5	5.00 ± 0.58 ^{b}	2.00 ± 0.58 ^{a}	91.37 ± 3.07 ^{abc}	74.89 ± 8.95 ^{a}
		7	5.00 ± 1.53 ^{b}	1.00 ± 0.58 ^{a}	89.97 ± 4.77 ^{bcd}	86.10 ± 10.0 ^{ab}
		10	7.00 ± 1.53 ^{b}	1.67 ± 0.67 ^{a}	87.33 ± 1.33 ^{abc}	86.26 ± 6.78 ^{ab}
		1	10.0 ± 1.53 ^{b}	1.67 ± 0.33 ^{a}	62.10 ± 15.0 ^{ab}	86.40 ± 2.86 ^{ab}
		3	8.67 ± 1.20 ^{b}	1.00 ± 0.58 ^{a}	57.40 ± 10.7 ^{a}	89.63 ± 5.79 ^{ab}
	Gaboubaba	5	5.67 ± 2.03 ^{b}	1.33 ± 0.33 ^{a}	89.23 ± 5.84 ^{bcd}	82.68 ± 5.82 ^{ab}
		7	3.33 ± 0.82 ^{b}	0.67 ± 0.33 ^{a}	93.42 ± 2.85 ^{cd}	92.59 ± 4.90 ^{ab}
B. ferruginea		10	8.00 ± 2.08 ^{b}	2.33 ± 0.88 ^{a}	84.43 ± 4.08 ^{abc}	83.04 ± 5.03 ^{ab}
		1	8.00 ± 2.52 ^{b}	1.00 ± 0.58 ^{a}	72.50 ± 10.6 ^{abc}	92.46 ± 4.14 ^{ab}
		3	5.67 ± 0.33 ^{b}	2.33 ± 0.68 ^{a}	69.30 ± 2.00 ^{abc}	77.21 ± 5.89 ^{ab}
	Wonmangou	5	5.67 ± 2.40 ^{b}	2.00 ± 1.15 ^{a}	89.88 ± 4.72 ^{bcd}	74.90 ± 16.9 ^{ab}
		7	5.33 ± 0.88 ^{b}	1.00 ± 0.58 ^{a}	90.71 ± 1.01 ^{bcd}	88.89 ± 5.56 ^{ab}
		10	5.33 ± 0.88 ^{b}	1.67 ± 0.68 ^{a}	88.88 ± 3.97 ^{bcd}	88.16 ± 3.48 ^{ab}
		1	7.00 ± 0.58 ^{b}	1.33 ± 0.88 ^{a}	75.06 ± 9.07 ^{abc}	88.64 ± 7.31 ^{ab}
		3	6.33 ± 1.20 ^{b}	1.67 ± 0.33 ^{a}	70.83 ± 3.99 ^{abc}	83.20 ± 3.60 ^{ab}
	Yakanougo	5	9.00 ± 2.08 ^{b}	1.00 ± 0.00 ^{a}	83.58 ± 7.73 ^{abc}	87.45 ± 1.73 ^{ab}
		7	6.00 ± 0.58 ^{b}	1.67 ± 0.33 ^{a}	88.80 ± 2.96 ^{bcd}	82.41 ± 7.91 ^{ab}
		10	6.67 ± 1.20 ^{b}	1.00 ± 0.58 ^{a}	87.63 ± 1.10 ^{abc}	93.27 ± 3.64 ^{ab}
Control +	Antouka	0.05	0.07 ± 0.04 ^{a}	0.00 ± 0.00 ^{a}	99.82 ± 0.12 ^{d}	100.00 ± 0.00 ^{b}
Control -	Untreated yam chips	-	45.36 ± 20.27 ^{c}	11.56 ± 3.42 ^{b}	-	-

Means within the same rows followed by the same letter are not significantly different using Student Newman Keuls test ($p < 0.05$).

characterised by a high mortality of *D. porcellus*.

DISCUSSION

The results of this study showed that the combination of yam chips from resistant landraces with leaves powder of *B. ferruginea*, *B. sapida* and *K. senegalensis* has a repellent effect similar to synthetic insecticide Antouka on *D. porcellus.* These results were not surprising because in previous studies leaves powder of *B. ferruginea*, *B. sapida* and *K. senegalensis* (Loko et al., 2017a) as well as yam chips from yam landraces (Loko et al., 2017b) were repellent to *D. porcellus*. Although the interaction between resistant yam chips and medicinal plants has not been significant, the high repellence observed on *D.*

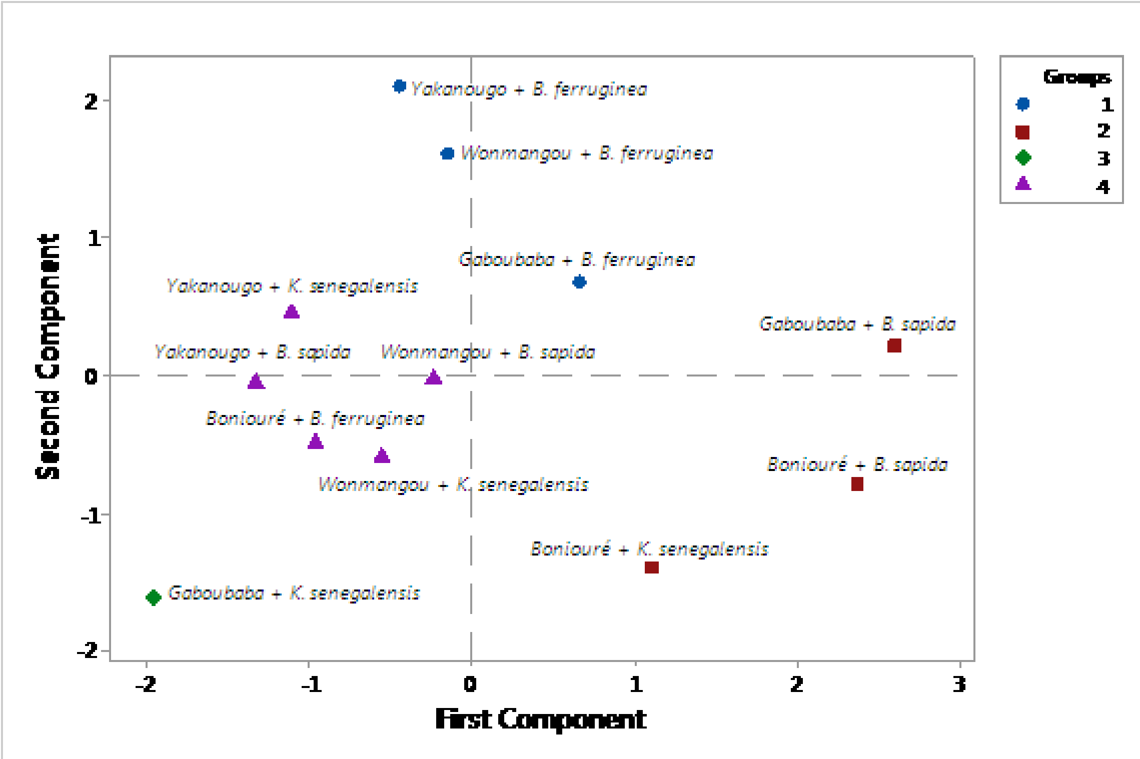

Figure 2. Principal Component Analysis clustering based on repellence, mortality, reproduction inhibition, and weight loss reduction effect of four resistant landraces combined with leaves powder of the three medicinal plants. Group 1: high reproduction inhibition rate of *D. porcellus*; Group 2: strong repellency effect on *D. porcellus*; Group 3: low weight loss; Group 4: high mortality of *D. porcellus*.

porcellus could be due, on one hand to the effect of physicochemical compounds in yam chips and in the other hand to the presence of repulsive volatile substances in the leaves of each of the three medicinal plants (Table 1). Indeed, the color, smell and texture of yam chips could play a determining role in the repulsion of *D. porcellus* (Onzo et al., 2015). In addition, the triterpenoid, tannins and saponoside contained in the leaves powder of *B. ferruginea* (Addae-Mensah and Achenbach, 1985), *B. sapida* (Ubulom et al., 2012) and *K. senegalensis* (Makut et al., 2008) are known repulsive for phytophagous insects because of vapor acting on their olfactory receptors (Moore and Lenglet, 2004). The fact that some associations of resistant landraces and powders of medicinal plants have given a high repulsion values which is above 60% (class IV), revealed the importance of their use in the long-term conservation of yam chips against *D. porcellus;* because stocks can effectively be protected against this pest, thereby tendency for infestation will be reduced.

The weight losses caused by *D. porcellus* on yam chips treated at different concentrations of *B. sapida*, *K. senegalensis* and *B. ferruginea* leaves powder were lower than the one caused on the negative control. According to a previous research, the losses caused by storage insects on the chips depend on some factors such as chips texture (Campbell and Runnion, 2003), partial starch gelatinization after the pre-cooking (which causes the curing of the chips) (Rajamma et al., 1996), biochemical composition of chips (which could encourageor discourage the survival and multiplication of pests) (Wong and Lee, 2011), and environmental conditions (temperature, humidity, etc.) (Chukwulobe and Echezona, 2014). In addition, the combined effect of anti-nutritional factors such as tannins, saponins and phytic acid contained in yam chips (Djeri et al., 2015) and leaves powder of the three medicinal plants tested (*B. sapida*, *K. senegalensis* and *B. ferruginea*) could explain the low weight losses caused by *D. porcellus*. All these factors put together influence the development of *D. porcellus* and therefore reduce the consumption rate of yam chips by this main pest.

The results also showed that the mortality of *D. porcellus* induced by treated yam chips with different concentrations of leaves powder of *B. sapida*, *K. senegalensis* and *B. ferruginea*. This could be explained by the synergistic effect of antinutritional compounds present in yam chips (Djeri et al., 2015) and the chemical compounds present in leaves powder of medicinal plants (Chebet et al., 2013). Indeed, leaves powder of medicinal plants caused an asphyxiation of insects by penetrating into the internal organs of the insect through its respiratory systems (Fernando and Karunaratne, 2012; Kedia et al., 2015). According to Sousa et al. (2005) vegetables powder involve the dehydration of insects by erosion of cuticle layer which causes the death of the insect. The fact that some combinations of resistant yam chips with leaves powder of medicinal plants at some given concentrations caused mortality rates higher than 50% of *D. porcellus* is promising for the adoption and the use of this integrated method for the management of this pest by farmers. These results are similar to those of Maina and Lale (2004), Babarinde et al. (2008), and Lale and Mustapha (2000), who showed the potential that the integration of insect repellent/insecticidal plant extracts with varietal resistance in the protection of stored products against harmful insects. Thus, the combination of the yam chips of four landraces with leaves powder of *B. ferruginea*, *B. sapida* and *K. senegalensis* must be promoted for the integrated management of *D. porcellus*.

The combination of *B. ferruginea*, *B. sapida* and *K. senegalensis* leaves powder with resistant yam chips caused an inhibition in the reproduction of *D. porcellus* and also affected the mean number of *D. porcellus* adult emerged (F1 progeny). Based on previous studies, the reproductive inhibition of *D. porcellus* may be caused by physiological and behavioral changes in adult insects due to their contact with plant products. This contact could affect their egg-laying ability (Kedia et al., 2015). However, the reduction in the emergence of insects by different plant products is largely related to the ovicidal properties, which prevents the hatching of eggs (Jadhav and Jadhav, 1984) and/or linked to the larvicidal activity, which prevents the larval maturity into adults. Similar studies reported by Mukanga et al. (2010) showed that the powders of five botanical species (eucalyptus, guava, neem, tephrosia and water hyacinth) reduced weight loss and the emergence of *Prostephanus truncatus* populations in dried cassava chips. Nevertheless, exhaustive studies are necessary to identify the active compounds in each of the three medicinal plants and in the yam chips of the four landraces as well as their syntheses for an effective scientific formulation in the control of *D. porcellus*.

Conclusion

Our results showed that the combined use of resistant yam chips and leaves powder of *B. ferruginea*, *B. sapida* and *K. senegalensis* at all concentrations have a great potential for the management of *D. porcellus*. However, further studies will be necessary to identify the active components contained both in the yam chips and in the leaves powder of the three medicinal plants responsible for the repellent and insecticidal effect on *D. porcellus*. Biological activities of leaves powder of these three medicinal plants and resistant landraces associated with their availabilities in Beninese agriculture, make them less expensive than synthetic pesticides for poor-resources farmers. Moreover, combination of resistant yam chips with repellent and insecticidal plants such as *B. ferruginea*, *B. sapida* and *K. senegalensis* for integrated management of *D. porcellus* is an environmental friendly alternative method adapted for small farm holder of the republic of Benin. Because of their strong repellent effect on *D. porcellus*, we recommend for yam chips short term conservation (3-6 months) the use of Boniouré or Gaboubaba landraces treated with leaves powder of *B. sapida*. While for yam chips long term conservation we recommend the use of Yakanougo, Wonmangou or Gaboubaba landraces combined with leaves powder of *K. senegalensis* because of their high reproductive inhibition rate of *D. porcellus*.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENT

This study was supported by L'Oréal-UNESCO for Women in Science in Sub Saharan Africa through the 2014 postdoctoral fellowship won by the first author.

REFERENCES

Abalaka ME, Adeyemo SO, Daniyan SY (2011). Evaluation of the antimicrobial potentials of leaf extracts of *Khaya senegalensis.* Journal of Pharmaceutical Research and Opinion 1(2):48-51.

Abbott WS (1925). A method for computing the effectiveness of an insecticide. Journal of Economic Entomology 18:265-267.

Abubakar L, Bagna EA, Dogarai BBS (2017). Effects of column fractions of the leaves extract of *Bridelia ferruginea* on bacteria. Bayero Journal of Pure and Applied Sciences 10(1):137-141.

Addae-Mensah I, Achenbach H (1985). Terpenoids and flavonoids of *Bridelia ferruginea.* Phytochemistry 24(8):1817-1819.

Adebayo EA, Ishola OR (2009). Phytochemical and antimicrobial screening of the crude extracts from the root, stem bark and leaves of *Bridelia ferruginea.* African Journal of Biotechnology 8(4):650-653.

Adedoyin OT, Ojuawo A, Adesiyun OO, Mark F, Anigilage EA (2008). Poisoning due to the yam flour consumption in five families in Ilorin, Central Nigeria. West African Journal of Medicine 27(1):41-43.

Adeiza AA, Mohammed A, Mamman M (2010). Comparative in vivo evaluation of the trypanocidal activities of aqueous leaf, stem-bark and root extracts of *Khaya senegalensis* on *Trypanosoma evansi.* Journal of Medicinal Plants Research 4(17):1770-1777.

Adeleke SI (2009). Food poisoning due to yam flour consumption in Kano (Northwest) Nigeria. The Online Journal of Health and Allied Sciences 8(2):10.

Aka LO, Obidike RI (2010). Time Profile Antidiabetic Activity of the Aqueous Leaf Extracts of *Bridelia ferruginea* in Albino Rats. Nigerian Journal of Experimental and Applied Biology 11(1):7-11.

Ameyaw Y, Barku VYA, Ayivor J, Forson A (2012). Phytochemical screening of some indigenous medicinal plant species used in the management of diabetes mellitus in Ghana. Journal of Medicinal Plants Research 6(30):4573-4581.

Asawalam EF, Emosairue SO, Hassanali A (2006). Bioactivity of *Xylopia aetiopica* (Dunal) a rich essential oil constituent on maize weevil *Sitophilus zeamais* Motch (Coleoptera: Curculionidae). Electronic Journal of Environmental, Agricultural and Food Chemistry 5:1195-1204.

Ategbo E, Bricas N, Hounhouigan J, Mitchikpe E, Nkpenu KE, Orkwor G, Vernier P (1998). Le développement de la filière cossettes d'igname pour l'approvisionnement des villes au Nigeria, au Bénin et au Togo In Berthaud, J, Bricas, N, Marchand, J-L (Eds) L'igname, plante séculaire et culture d'avenir : actes du séminaire international, Cirad, Inra, Orstom, Coraf, Cirad, Inra, Orstom, Coraf, Coll Colloques pp. 339-341.

yodeji SP, Olabanji OM, Adeyeri MK (2012). Design of a process plant for the production of poundo yam. International Journal of Engineering 6:10-24.

Babajide JM, Atanda OO, Ibrahim TA, Majolagbe HO, Akinbayode SA (2008). Quantitative effect of 'abafe' (*Piliostigma thionnigii*) and 'agehu' (*Khaya ivorensis*) leaves on the microbial load of dry-yam 'gbodo'. African Journal of Microbiology Research 2:292-298.

Babajide JM, Oyewole OB, Henshaw FO, Babajide SO, Olasantan FO (2006). Effect of local preservatives on quality of traditional dry-yam slices "gbodo" and its products. World Journal of Agricultural Science 2(3):267-273.

Babarinde SA, Adebayo MA, Oduyemi K (2008). Integrating varietal resistance with *Xylopia aethiopica* (Dunal) A Richard seed extract for the management of *Sitophilus zeamais* Motschulsky in stored maize. African Journal of Biotechnology 7(8):1187-1191.

Babarinde SA, Babarinde GO, Odewole AF, Alagbe OO (2013). Effect of the prevalent insect species of yam chips on consumers' acceptability of yam paste. Journal of Agricultural Extension and Rural Development 46(3):97-101.

Baco MN, Tostain S, Mongbo RL, Dainou O, Agbangla C (2004). Gestion dynamique de la diversité variétale des ignames cultivées (*Dioscorea cayenensis-D rotundata*) dans la commune de Sinendé au nord Bénin. Plant Genetic Resources Newsletter 139:18-24.

Campbell JF, Runnion C (2003). Patch exploitation by female red flour beetles, *Tribolium castaneum.* Journal of Insect Science 3:20-27.

Chebet F, Deng AL, Ogendo JO, Kamau AW, Bett PK (2013). Bioactivity of selected plant powders against *Prostephanus truncatus* (Coleoptera: Bostrichidae) in stored maize grains. Plant Protection Science 49(1):34-43.

Chijindu EN, Boateng BA (2008). Effect of Nutritional Content of Processed Cassava Chips on Development of *Prostephanus truncatus* (Horn). World Journal of Agricultural Science 4(3):404-408.

Chijindu EN, Boateng BA, Ayertey JN, Cudjoe AR, Okonkwo NJ (2008). The effect of processing method of cassava chips on the development of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). African Journal of Agricultural Research 3(8):537-541.

Chukwulobe MN, Echezona BC (2014). Relative susceptibility of dried root/tuber and Musa chips to red flour beetle *Tribolium casteneum* (Herbst) (Coleoptera: Tenebrionidae) Infestation. International Journal of Plant and Soil Science 3:1398-1414. https://doiorg/109734/IJPSS

Djeri B, Tchobo PF, Adjrah Y, Karou DS, Ameyapoh Y, Soumanou MM, Souza C (2015). Nutritional potential of yam chips (*Dioscorea cayenensis-Dioscorea rotundata* Poir) obtained using two methods of production in Togo. African Journal of Food Science 9(5):278-284.

Dutra KA, d'Oliveira JV, Navarro DMAF, Barbosa DRS, Santos JPO (2016). Control of *Callosobruchus maculatus* (FABR) (Coleoptera: Chrysomelidae: Bruchinae) in *Vigna unguiculata* (L) WALP with essential oils from four Citrus spp Plants. Journal of Stored Products Research 68:25-32.

Food and Agriculture Organization (FAO) (2016). FAOSTAT Database Food and Agriculture Organization, Roma, Italy. Available online at URL: www.fao.org

Fernando HS, Karunaratne MM (2012). Ethnobotanicals for storage insect pest management: Effect of powdered leaves of *Olax zeylanica* in suppressing infestations of rice weevil *Sitophilus oryzae* (L) (Coleoptera: Curculionidae). Journal of Tropical Forestry and Environment 2(1):20-25.

Gusmão NMS, d'Oliveira JV, Navarro DMAF, Dutra KA, da Silva WA, Wanderley MJA (2013). Contact and fumigant toxicity and repellency of *Eucalyptus citriodora* Hook, *Eucalyptus staigeriana* F, *Cymbopogon winterianus* Jowitt and *Foeniculum vulgare* Mill essential oils in the management of *Callosobruchus maculatus* (Fabr) (Coleoptera: Chrysomelidae, Bruchinae). Journal of Stored Products Research 54:41-47.

Hikal WM, Baeshen RS, Said-Al Ahl HAH, Ujházy K (2017). Botanical insecticide as simple extractives for pest control. Cogent Biology 3:1.

Houndjo CF, Agbodjogbe W, Assogba FM, Kohoude JM, Ayedoun MA, Dansou PH, Moudachirou M, Gbénou JD (2017). Comparative study of Antihyperglycemic activity of aqueous extracts from the leaves of *Bridelia ferruginea*, *Lophira lanceolata* and *Oxytenanthera abyssinica*, with their mixture. International Journal of Current Research in Chemistry and Pharmaceutical Sciences 4(11):22-33.

Hounhouigan JD, Kayodé APP, Bricas N, Nago MC (2003). Les caractéristiques culinaires et organoleptiques des ignames recherchées en milieu urbain au Bénin. Annales des Sciences Agronomiques du Bénin 4:143-160.

Isah MD, Ayertey JN, Boateng BA (2009). Suitability of dried chips of plantain, cocoyam, yam and cassava for the development of the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). International Journal of Applied Sciences 3(4):12-20.

Isah MD, Ayertey JN, Ukeh DA, Umoetok SBA (2012). Damage and weight loss to dried chips of cassava, cocoyam, yam and plantain exposed to *Prostephanus truncatus* (horn) (Coleoptera: Bostrichidae) over three different time durations. Entomology Journal 9(3):137-145.

Jadhav KD, Jadhav LD (1984). Use of vegetable oils, plant extracts and synthetic Products as protectants from pulse beetle *Callosobruchus maculatus* in stored grain. Journal of Food Science and Technology 14:100-113.

Kawo AH, Suleiman ZA, Yusha'u M (2011). Studies on the antibacterial activity and chemical constituents of *Khaya senegalensis* and *Ximenia americana* leaf extracts. African Journal of Microbiology Research 5(26):4562-4568.

Kazeem MI, Raimi OG, Balogun RM, Ogundajo AL (2013). Comparative study on the α-amylase and α-glucosidase inhibitory potential of different extracts of *Blighia sapida* Koenig. American Journal of Research Communication 1(7):178-192.

Kedia A, Prakash B, Mishra PK, Singh P, Dubey NK (2015). Botanicals as ecofriendly biorational alternatives of synthetic pesticides against *Callosobruchus* spp (Coleoptera: Bruchidae)-a review. Journal of Food Science and Technology 52(3):1239-1257.

Keneni G, Bekele E, Getu E, Imtiaz M, Damte T, Mulatu B, Dagne K (2011). Breeding food legumes for resistance to storage insect pests: potential and limitations. Sustainability 3:1399-1415.

Kubmarawa D, Khan ME, Punah AM, Hassan M (2008). Phytochemical screening and antimicrobial efficacy of extracts from *Khaya senegalensis* against human pathogenic bacteria. African Journal of Biotechnology 7(24):4563-4566.

Lale NES, Mustapha A (2000). Potential of combining neem (*Azadirachta indica* A Juss) seed oil with varietal resistance for the management of the cowpea bruchid, *Callosobruchus maculatus* (F). Journal of Stored Products Research 36:215-222.

Loko YL, Adjatin A, Dansi A, Vodouhè R, Sanni A (2015). Participatory evaluation of Guinea yam (*Dioscorea cayenensis* Lam– *D rotundata* Poir complex) landraces from Benin and agro-morphological characterization of cultivars tolerant to drought, high soil moisture and chips storage insects. Genetic Resources and Crop Evolution 62(8):1181-1192.

Loko YL, Alagbe O, Dannon EA, Datinon B, Orobiyi A, Thomas-Odjo A, Dansi A, Tamò M (2017a). Repellent effect and insecticidal activities of *Bridelia ferruginea*, *Blighia sapida*, and *Khaya senegalensis* leaves powders and extracts against *Dinoderus porcellus* in infested dried yam chips. Psyche Article ID 5468202, 18 https://doiorg/101155/2017/5468202

Loko YL, Dansi A, Tamo M, Bokonon-Ganta AH, Assogba P, Dansi M, Sanni A (2013). Storage insects on yam chips and their traditional management in Northern Benin. ScientificWorldJournal, Article ID 484536. doi:101155/2013/484536

Loko YL, Gnaho AC, Orobiyi A, Agre P, Dansi A, Tamo M (2017b). Resistance of dried chips of yam (*Dioscorea cayenensis-D rotundata* complex) landraces to *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae). Cogent Food and Agriculture 3(1):1411180.

Maina YT, Lale NES (2004). Integrated Management of *Callosobruchus maculatus* (F) Infesting Cowpea Seeds in Storage Using Varietal

Resistance, Application of Neem (*Azadirachta indica* A Juss) Seed Oil and Solar Heat. International Journal of Agriculture and Biology 6(3):440-446.

Makut MD, Gyar SD, Pennap GRI, Anthony P (2008). Phytochemical screening and antimicrobial activity of the ethanolic and methanolic extracts of the leaf and bark of *Khaya senegalensis.* African Journal of Biotechnology 7(9):1216-1219.

McDonald LL, Guy RH, Speirs RD (1970). Preliminary evaluation of new candidate materials as toxicants, repellents and attractants against stored product insects. Marketing Res Report No 882, Agricultural Research Service United States Department of Agriculture, Washington, DC 8.

Moore SJ, Lenglet AD (2004). An overview of plants used as insect repellents In: Willcox M, Bodeker G, Rasoanaivo P (eds): Traditional Medicinal Plants and Malaria Vol 4 Traditional Herbal Medicine for Modern Times Series CRC Press, Boca Raton.

Mukanga M, Deedat Y, Mwangala FS (2010). Toxic effects of five plant extracts against the larger grain borer, *Prostephanus truncates.* African Journal of Agricultural Research 5(24):3369-3378.

Olmo LRV, da Silva MFGF, Fo ER, Vieira PC, Fernandes JB, Pinheiro AL, Vilela EF (1997). Limonoids from leaves of *Khaya senegalensis* Phytochemistry 44(6):1157-1161.

Oni MO, Omoniyi AO (2012). Studies on Temperature Influence on Oviposition and Development of Immature Stages of the Yam Beetle *Dinoderus Porcellus* Lesne Coleoptera: Bostrichidae on Dried Yam Species. The Journal of Agricultural Science 4(2):213-218.

Onzo A, Biaou JT, Loko LY, Tamo M, Dansi A (2015). Vulnérabilité des cossettes issues de quelques cultivars d'igname à l'attaque de *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae) en conditions de laboratoire. International Journal of Biological and Chemical Sciences 8(6):2494-2507.

Opara LU (1999). Yam storage In: Bakker-Arkema (ed); Handbook of Agricultural Engineering, The American Society of Agricultural Engineers 4:182-214.

Oreagba IA, Ishola IO, Oremule BO (2016). Gastroprotective and antisecretory properties of the hydroethanolic leaf extract of *Blighia Sapida* (Sapindaceae) in rats. International Journal of Medical and Dental Science Invention 1(2):38-47.

Othira JO, Onek LA, Deng LA, Omolo EO (2009). Insecticidal potency of *Hyptis spicigera* preparations against *Sitophilus zeamais* (l) and *Tribolium castaneum* (herbst) on stored maize grains. African Journal of Agricultural Research 4(3):187-192.

Padín SB, Fusé C, Urrutia MI, Dal Bello GM (2013). Toxicity and repellency of nine medicinal plants against *Tribolium castaneum* in stored wheat. Bulletin of Insectology 66(1):45-49.

Rajamma P, Premkumar T, Kurup GT, Palaniswami MS, Potty VP, Padmaja G (1996). Influence of varieties and method of processing on insect infestation in dry cassava chips tropical tuber crops: Problem Prospects and Future Strategies pp. 321-328.

Schäfer K, Goergen G, Borgemeister C (2000). An illustrated identification key to four different species of adult Dinoderus (Coleoptera: Bostrichidae), commonly attacking dried cassava chips in West Africa. Journal of Stored Products Research 36(3):245-252.

Sousa AH, Maracaja PB, Silva RM, Moura MN, Andrade WG (2005). Bioactivity of vegetal powders against *Callosobruchus maculatus* (Coleoptera: Bruchidae) in Caupi bean and seed physiological analysis. Revista de Biolo E Ciencias Da Terr 5:19-23.

Tapondjou LA, Adler C, Bouda H, Fontem DA (2002). Efficacy of powder and essential oil from *Chenopodium ambrosioides* leaves as post-harvest grain protectants against six-stored product beetles. Journal of Stored Products Research 38:395-402.

Tortoe C, Johnson PNT, Abbey L, Baidoo E, Anang D, Acquaah SG, Saka E (2012). Sensory properties of pre-treated blast-chilled yam (*Dioscorea rotundata*) as a convenience food product. African Journal of Food Science and Technology 3(2):59-65.

Ubulom PME, Imandeh GN, Ettebong EO, Udobi CE (2012). Potential Larvicidal Properties of *Blighia sapida* leaf extracts against larvae of *An gambiae, Cu quinquefasciatus* and *Ae aegypti.* British Journal of Pharmaceutical Research 2(4):259-268.

Vernier P, Goergen G, Dossou RA, Letourmy P, Chaume J (2005). Utilization of biological insecticides for the protection of stored yam chips. Outlook on Agriculture 34(3):173-179

Wong L, Lee C (2011). Relationship between population growth of the red flour beetle *Tribolium castaneum* and protein and carbohydrate content in flour and starch. Journal of Economic Entomology 104:2087-2094.

Vol. 13(40), pp. 2134-2145, 4 October, 2018
DOI: 10.5897/AJAR2018.13491
Article Number: 1400BD758721
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

The Production and prediction of major chinese agricultural fruits using an econometric analysis and machine learning technique

Abdul Rehman[1*], Zhang Deyuan[1] and Luan Jingdong[2]

[1]Research Center of Agricultural-Rural-Peasants, Anhui University Hefei, China.
[2]College of Economics and Management, Anhui Agricultural University Hefei, China.

Received 26 August, 2018; Accepted 19 September, 2018

This paper investigates and explores the relationship between agricultural gross domestic product (AGDP) and major fruit output: apple, citrus, pears, grapes and bananas in China. The ordinary least square (OLS) method and the augmented Dickey-Fuller (ADF) test were used to analyze the data, and the Johansen co-integration test was used to interpret the results. The machine learning technique was used to examine and to predict future agricultural productivity in China. Our study found that the coefficient of the apple fruit output has a significant or positive relationship with the AGDP. The results also show that the output of citrus, grapes and pears have coefficients that demonstrate a positive relationship with the AGDP, while the banana fruit output bears a negative relationship with China's AGDP and is statistically insignificant. The use of an econometric analysis and machine learning technique to examine the relationship between the AGDP and the output from major fruits production in China makes the current study unique. A review of the literature suggests that only limited research has been conducted in this area.

Key words: Major fruits, AGDP, ADF, production, machine learning technique.

INTRODUCTION

China's population continues to grow, and China is now the world's largest food consumer. Each year, China consumes about 5 million tonnes of food and feeds about 20% of the world's population. Currently, agriculture accounts for 36% of the world's land cover area (Xiao et al., 2014; Rehman et al., 2017). In a broad sense, the cultivation of agricultural crops is important for environment and socio-economic growth in most countries (Rajalahti et al., 2012; Rehman et al., 2017). Developing countries face challenges and constraints regarding agricultural development and food security, and food security are required for subsistence and rural development. Socio-economic and protective development requires robust infrastructure for innovative management systems, facilities and operations for agricultural output. It has been reported that agricultural output, facilities and operations will increase by at least 70% of agricultural production over the next 40 years

*Corresponding author. E-mail: abdlrehman@ahu.edu.cn

(Kilelu and Leeuwis, 2013).

Through new policies and increased financial support, China's government has made systematic efforts to accelerate the development of agricultural cooperatives. Because of these efforts, new laws governing farming cooperatives were introduced in 2007 with the goal of promoting sustainable agricultural development. The Chinese Ministry of Agriculture reported that about 25.2% of the country's farmers participated in agricultural cooperatives in 2013 (Ma and Abdulai, 2016). However, farmers are affected by high transaction costs, which affect the ability of several villages to participate in the cooperatives (Deng et al., 2010; Francesconi and Wouterse, 2015). Many studies have shown that agricultural cooperatives have been used to develop and to modernize agricultural technology to improve the welfare of farmers and their families (Fischer and Qaim, 2012; Ito et al., 2012; Abebaw and Haile, 2013).

In the last few decades, China's agricultural productivity has increased rapidly; however, this has led to serious environmental and ecological problems (Ju et al., 2004; Na et al., 2016; Zhang et al., 2011; Fan et al., 2011). In addition, compared to that of other developed countries, China's nitrogen use efficiency is low for its economic crops. Because of the large amount of fertilizer emissions and pesticides in the soil, atmosphere and surface water, the combination of chemical fertilizer and low nutrient use has caused serious environmental problems (Ju et al., 2009). The world recognizes the negative effects of agriculture on ecosystems and the environment. The sustained increase in crop production should be accompanied by the management and protection of ecosystems, even as crop productivity is maximized (FAO, 2014). The major objective of this study was to investigate the relationship between agricultural gross domestic product AGDP and major fruit output including apple, citrus, pears, grapes and bananas in China. Data were analysed by employing the ordinary least square (OLS) method and the augmented Dickey-Fuller (ADF) unit root test. The Johansen co-integration test was used to interpret the results, and the machine learning technique was used to examine and predict the future agricultural productivity in China.

MAJOR FRUITS PRODUCTION IN CHINA

Apple production

The apple industry plays a vital role in China's national economy. China accounted for nearly 30% of the world's total apple output, exporting nearly 24,000 tonnes of apples (Yang et al., 2006a). With 2.13 million hectares under cultivation, China has the world's largest apple production with an output of 31 billion tonnes, accounting for about 43% to 54% of the world's total production. Major issues affecting the production of high-quality apples include out-dated orchard management methods and models as well as major pests and other fruit trees. About 90% of apple orchards in China use out-dated compactly populated systems that are inefficient and expensive (Sun and Liu, 2012; Yang et al., 2006b; Zhou et al., 2013). Rigorous modern apple cultivation methods using dwarf stocks and wide rows have not yet been adopted. Pest control is still an obstacle to improving the efficiency and production of apples. In apple orchards, out-dated pest control methods rely on chemicals, and this frequently leads to very high pesticide usage, genetic mutations and insecticide resistance that cause serious ecological problems (Zhai et al., 2007; Chen et al., 2010).

Fruit trees are rich in flowers, and fruit ripening cannot be supported. For example, only about 7% of flowers are essential, such as in the apple's lucrative harvest (Untiedt et al., 2001). Too many flowers on a tree can reduce the size and quality of the fruit, deplete the tree's reserves and reduce its cold resistance (Dennis et al., 2000). The relationship between the plant and reproductive growth is key for ensuring good quality and high yields (Solomakhin et al., 2010; Janoudi and Flore, 2005). Thinning is accomplished by removing certain flowers or fruits from chemicals, manually, mechanically and by a combination of mechanical and chemical methods (Seehuber et al., 2011).

In the previous decade, apple production gradually increased, but growth is likely to be modest as less land becomes available for apple production. In 2014, the export of apples dropped nearly 20% as domestic prices reached a record high. The production of apples from 1980 to 2015 is shown in Figure 1 in tens of thousands of tonnes.

Citrus production

In the global market, citrus is the most popular and delicious fruit. In the early 1960s, the global production of citrus was 16 million tons. By 2012, it had increased to 68 million tons (FAO, 2012). Citrus trees tend to bloom in the spring; the fruit may need 6–8 months to mature (Steduto et al., 2012; Qin et al., 2016). The other important citrus producing countries are the United States (Florida), Brazil and Spain. It is necessary to supplement any shortage of rainfall with irrigation (Morgan et al., 2010; Ballester et al., 2013; Romero et al., 2009).

Citrus has become one of China's high-quality agricultural products; it is also the principal industry in southern rural China. Since the early 1970s, Chinese scientists have made scientific and technological progress in improving the quality of citrus products. This includes advances in areas such as breeding, germplasm utilization, pest control and fruit storage processing (Shen et al., 2009). China has more than 74 species of insect pests (Yang et al., 2004; Niu et al., 2013).

In 2010, production increased dramatically, and a

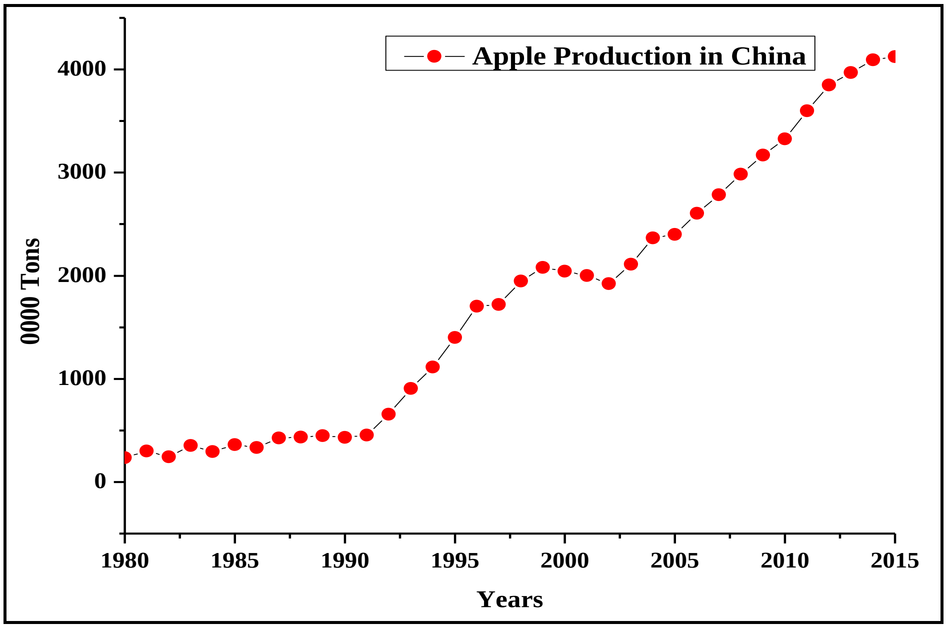

Figure 1. Apple production in China from 1980-2015.

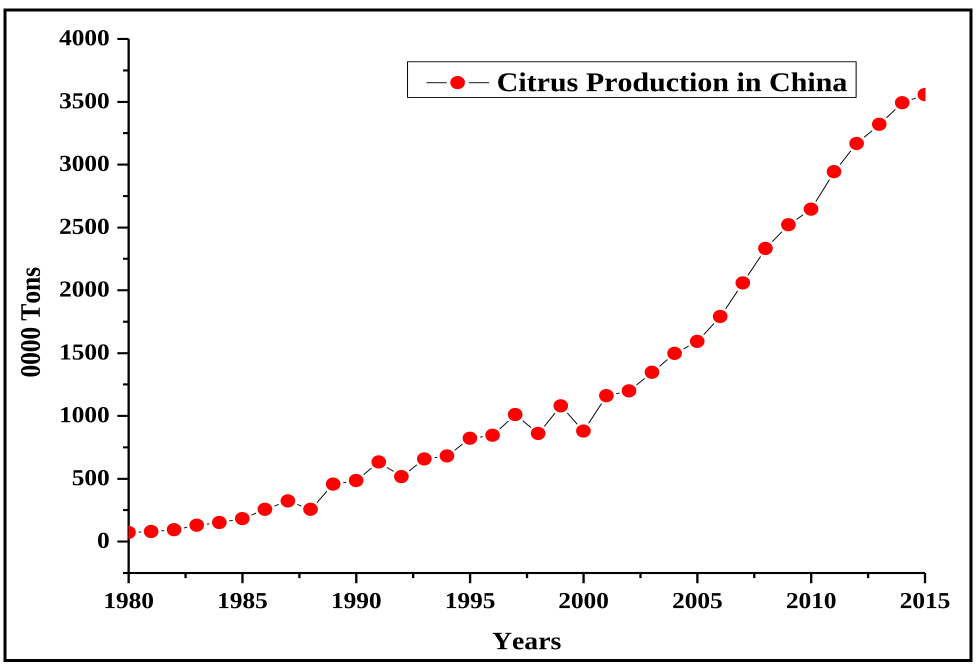

Figure 2. Citrus Production in China from 1980-2015.

significant number of navel oranges were planted. The production of citrus fruits from 1980 to 2015 is shown in Figure 2 in tens of thousands of tonnes.

Pear production

The sand pears of China are cultivated widely in Korea and Japan, and the colour of the fruit can vary from green or yellow to russet-brown (Teng and Tanabe, 2004). In recent decades, China has discovered and developed several varieties of red fruit (Tao et al., 2004). These red pearls are favoured by consumers because of their seductive appearance and nutritional value; however, the red colour is uneven because of variations in growth conditions (Huang et al., 2009). The quality of the pear is

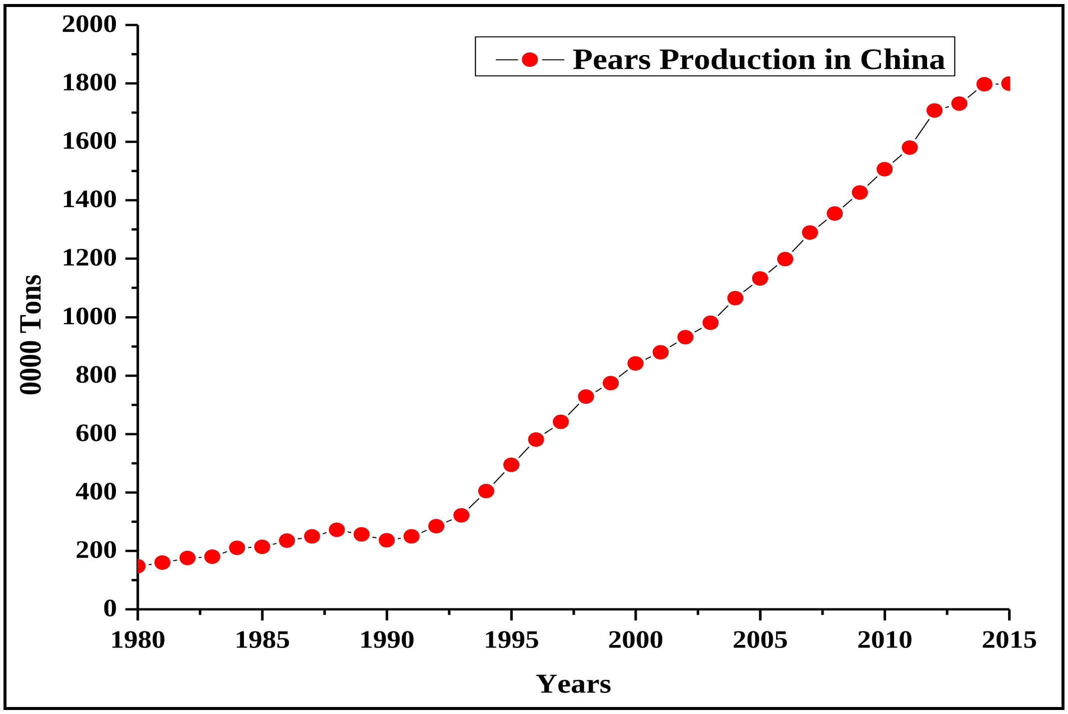

Figure 3. Pear production in China from 1980-2015.

affected by internal and external characteristics (quality of taste and nutrition) (Choi et al., 2007). Pears have a high nutritional value with an appropriate amount of amino acids, sugar and raw materials such as calcium, sodium, potassium, magnesium and iron (Yim and Nam, 2016). They also have a higher dietary fiber level than most common fruits and vegetables and have produced excellent results in the treatment of constipation and intestinal inflammation (Silva et al., 2014). The production of pear fruit from 1980 to 2015 is shown in Figure 3 in tens of thousands of tonnes.

Grape production

Grapes are very important fruits. There are eight million varieties of grapes in the world (Ramezani et al., 2009). China is one of the main producers of grapes. The country grows a wide variety of grapes and is therefore one of the world's richest germplasm resources. Grape wild relatives (GWRs) are important quality sources for cultivation. They have significant resistance to cold, drought, pests and other biological stresses. The breeding of grapevines has demonstrated the importance of wild germplasm resources for disease resistance gene breeding (Wan et al., 2008). In wine production, grapes are the main source of natural yeast. The grapevine flora can determine whether a wine product is beneficial or harmful. Thus, yeast producers have a great deal of information that is very important for helping wine producers to produce high-quality wines (Chavan et al., 2009; González et al., 2007).

Grape growers may have significantly different breed selection criteria than breeders or nurseries. Previous studies of crops in developed and developing countries have shown that farmers use biological and economic criteria that are more complex than those of breeders. Farmers' choices are also strongly influenced by other factors in the agricultural supply chain, such as agrichemical and extension services (Mulatu et al., 2002; Vanloqueren et al., 2008; Macholdt and Honermeier, 2016).

As a grower of grapes, China is now a large producer of red grape wine, in particular. In 2015, table grape production was 9.7 million tonnes, which was greater than that of the previous year, and the acreage of vineyards is expected to increase by 5%. The production of grapes from 1980 to 2015 is shown in Figure 4 in tens of thousands of tonnes.

Banana production

Bananas are considered the fourth largest crop in the world after rice, wheat and corn. They account for about 15% of the world's total fruit production. Bananas play an essential role in food security in developing countries. Cavendish, the most traded bananas, have accounted for half of the world's banana production (FAO, 2006; FAO, 2015). Bananas (Musa parasdisiac), of the Musaceae

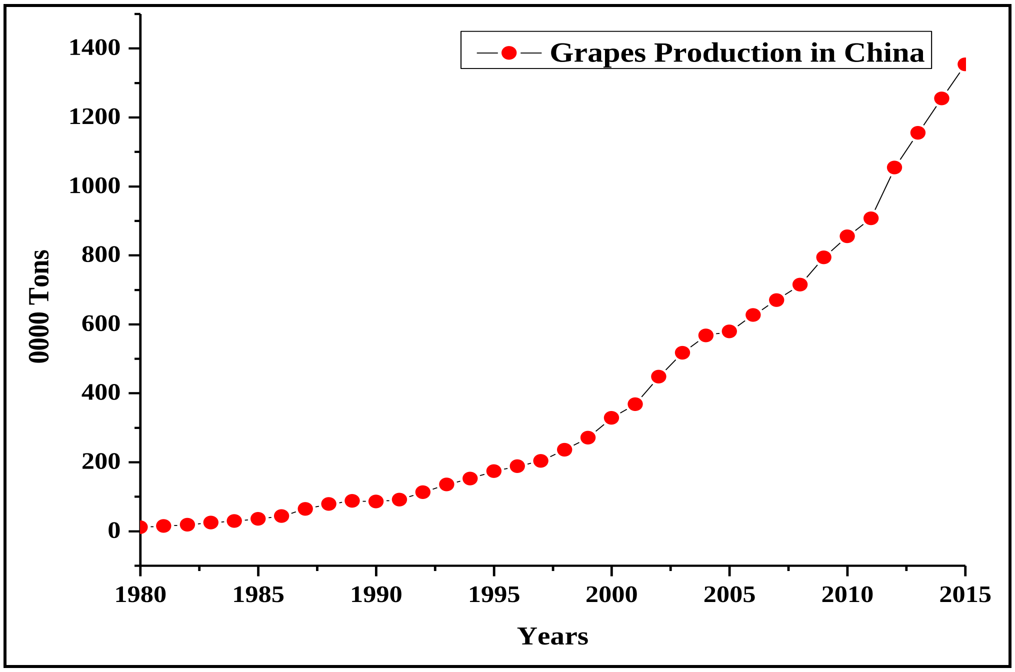

Figure 4. Grapes production in China from 1980-2015.

and Musa families, are perennial herbs that are widely distributed in tropical and subtropical regions (Pelissari et al., 2012). It is estimated that about 20–25% (10–15 million tons) of bananas are rejected each year because they do not meet quality standards and are not suitable for retail sales (Pillay and Tenkouano, 2011). From an economic perspective, banana production is the fifth most important crop in the world trade after coffee, grain, sugar and cocoa. Bananas are cultivated in more than 130 countries. India, China, the Philippines and Brazil are the main producers (Singh et al., 2016). Brazil is ranked fourth in the world in terms of banana production (FAO, 2013).

Banana intensive farming produces many types of organic residues, such as pseudo-stems, peduncle, bulbs, leaf sheaths and shafts. These account for about 70% of the total weight of the plant. These residues tend to accumulate in large roadside piles. The fermentation from these bananas contributes to greenhouse gas emissions, volatile organic compounds and feasts for pathogens and mosquitoes (Awedem et al., 2016). Some of these residues are composed mainly of cellulose and lignin, which are difficult to reduce with the usual windrow composting (Chanakya and Sreesha, 2012; Kamdem et al., 2015).

According to the Food and Agricultural Organization of the United Nations (FAO) estimates, 413,000 hectares of land was used for the cultivation of bananas, with a total production of about 9.85 million tonnes (FAO, 2010). The production of bananas from 1980 to 2015 is shown in Figure 5 in tens of thousands of tonnes.

MATERIALS AND METHODS

Time series data from 1980 to 2015 were used to determine the relationship between AGDP and production outputs for major fruits, including apples, bananas, citrus, grapes and pears. The data were taken from the Ministry of Agriculture (MOA) of China and the China Bureau of Statistics. In the current study, the variables were AGDP (in million RMB), production output of apples (in 0000 tonnes), output of bananas (in 0000 tonnes), output of citrus (in 0000 tonnes), output of grapes (in 0000 tonnes) and output of pears (in 0000 tonnes).

Econometric model

The following model was created for checking the relationship between agricultural gross domestic product (AGDP) and the outputs of major fruits:

$$Y = f(X_1, X_2, X_3, X_4, X_5) \quad (1)$$

Where, Y =*AGDP*, X_1 = *OPAPPLES*, X_2 = *OPBANANA*, X_3 = *OPCITRUS*, X_4 = *OPGRAPES*, X_5 = *OPPEARS*

Equation (1) can also be written as:

AGDP = f (OPAPPLES, OPBANANA, OPCITRUS, OPGRAPES, OPPEARS) (2)

The log-linear stipulations of the variables have been used and the following equation has been estimated (Equation 3);

$$\ln(AGDP) = \beta_0 + \beta_1 \ln(OPAPPLES) + \beta_2 \ln(OPBANANA) + \beta_3 \ln(OPCITRUS) + \beta_4 \ln(OPGRAPES) + \beta_5 \ln(OPPEARS) + \mu \quad (3)$$

Where, *AGDP* indicates the agricultural GDP in million RMB, β_0 =

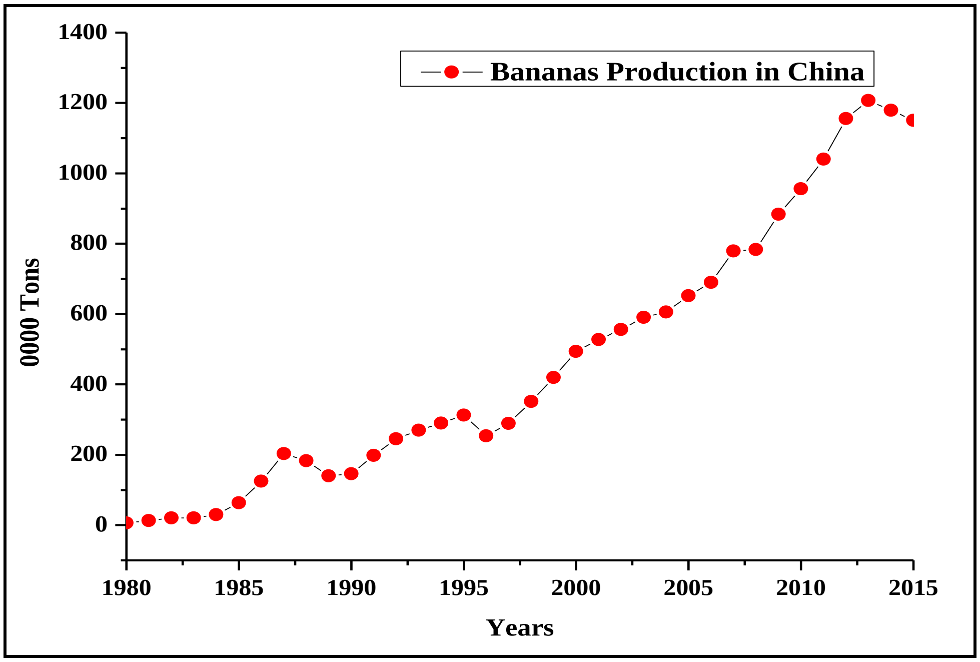

Figure 5. Banana production in China from 1980-2015.

Natural logarithm of *A*, the Intercept; *In (OPAPPLES)* indicates the natural logarithm of output of apples (in 0000 tonnes); *In (OPBANANA)* indicates the natural logarithm of output of bananas (in 0000 tonnes); *In (OPCITRUS)* indicates the natural logarithm of output of citrus fruit (in 0000 tonnes); *In (OPGRAPES)* indicates the natural logarithm of output of grapes (in 0000 tonnes); *In (OPPEARS)* indicates the natural logarithm of output of pears (in 0000 tonnes); and μ is the error term.

Ordinary least squares method

The ordinary least squares (OLS) method results demonstrated the model's predictive ability and provided the parameters for the short-run relationship. The Johansen co-integration test was used to check the long-run relationship between the AGDP and the production output of the major fruits.

RESULTS AND DISCUSSION

Results of ADF unit root test

To check the stationarity of each variable, the augmented Dickey-Fuller (ADF) unit root test was used. The modelled results and statistics of the ADF test are presented in Table 1.

Co-integration test results

The Johansen co-integration tests based on trace statistics and the Max-Eigenvalue are presented in Tables 2 and 3. The co-integration test presence showed that the dependent and independent variables have a long-run equilibrium relationship. The trace statistic and the Max-Eigenvalue statistic revealed one (1) co-integrating equation at the 5% level.

Results of regression

Table 4 presents the results of the regression analysis. The value of R-squared was 0.995, and the adjusted *R*-squared was 0.994. The F-statistic computed value was 1348.737 with a p-value of 0.000000. This demonstrates the model's overall goodness of fit.

The result of the regression analysis, as seen in Table 4, demonstrates that the coefficient of the output of the apple fruit has a positive relationship with the AGDP. The results also show that the output of citrus, grapes and pears have coefficients that demonstrate a positive relationship with the AGDP, but statistically these are insignificant. A 1% rise in the output of apples, citrus fruits, grapes and pears causes the AGDP to increase by 0.153, 0.736, 0.153 and 0.781%. The output of apples, citrus fruits, grapes and pears shows a positive relationship with the AGDP, but this is not statistically significant. Moreover, the coefficient of the output of bananas is not significant at the 1% and 5% levels of significance. In addition, there was a negative relationship between the AGDP and the output of bananas. This means that a 1% rise in the output of bananas leads to a *decrease* of 0.203806% in AGDP. This negative result was not expected. The major reasons for this negative

Table 1. ADF unit root test including (Trend and Intercept).

Variables	At level		First difference	
	t-Statistic	Critical values	*t*-Statistic	Critical values
LnAGDP	-0.863039 (0.9478)	1% -4.284580 5% -3.562882 10%-3.215267	-3.684241** (0.0387)	1% -4.284580 5% -3.562882 10% -3.215267
LnOPAPPLE	-1.949731 (0.6075)	1% -4.243644 5% -3.544284 10%-3.204699	-4.084942** (0.0150)	1% -4.252879 5% -3.548490 10% -3.207094
LnOPBANANA	-2.530090 (0.3127)	1% -4.252879 5% -3.548490 10%-3.207094	-5.180023* (0.0010)	1% -4.262735 5% -3.552973 10% -3.209642
LnOPCITRUS	-3.040990 (0.1369)	1% -4.262735 5% -3.552973 10%-3.209642	-4.056770** (0.0166)	1% -4.273277 5% -3.557759 10% -3.212361
LnOPGRAPES	-2.250207 (0.4483)	1% -4.252879 5% -3.548490 10%-3.207094	-3.988111** (0.0188)	1% -4.252879 5% -3.548490 10% -3.207094
LnOPPEARS	-1.677385 (0.7394)	1% -4.252879 5% -3.548490 10%-3.207094	-4.750955* (0.0046)	1% -4.394309 5% -3.612199 10% -3.243079

* and ** show the 1%, and 5% levels of significance.

Table 2. Johansen Co-integration test using trace statistic.

Lags interval: 1 to 1				
Eigenvalue	**Trace Statistic**	**5 Percent Critical Value**	**Prob.****	**Hypothesized no. of co-integration equations**
0.867122	158.3669	95.75366	0.0000	None *
0.684966	89.74380	69.81889	0.0006	At most 1 *
0.506617	50.47128	47.85613	0.0278	At most 2
0.380478	26.45134	29.79707	0.1158	At most 3
0.157600	10.17190	15.49471	0.2677	At most 4
0.119859	4.340904	3.841466	0.0372	At most 5 *

*Denotes rejection of the hypothesis is at the 0.05 level; ** Indicates values are accurate. The trace test indicates 2 co-integrating equations at the 0.05 level of significance.

Table 3. Johansen co-integration test using the Max-Eigenvalue Statistic.

Lags interval: 1 to 1				
Eigenvalue	**Max-Eigen Statistic**	**5 Percent Critical Value**	**Prob.****	**Hypothesized no. of co-integration equations**
0.867122	68.62310	40.07757	0.0000	None *
0.684966	39.27252	33.87687	0.0103	At most 1 *
0.506617	24.01993	27.58434	0.1340	At most 2
0.380478	16.27944	21.13162	0.2090	At most 3
0.157600	5.830997	14.26460	0.6350	At most 4
0.119859	4.340904	3.841466	0.0372	At most 5 *

*Denotes rejection of the hypothesis is at the 0.05 level of significance. ** Indicates values are accurate.The max-eigenvalue test indicates 2 co-integrating equations at the 0.05 level of significance.

Table 4. Regression analysis.

Dependent Variable: In(AGDP)				
Method: Least Squares				
Sample: 1980-2015. Included observations: 36				
Explanatory Variables	**Coefficient**	**Std. Error**	***t*-Statistic**	**Prob.**
C	-1.859912	0.670983	-2.771922	0.0095
Ln(OPAPPLE)	0.153336	0.078039	1.964872	0.0587
Ln(OPBANANA)	-0.203806	0.076376	-2.668452	0.0122
Ln(OPCITRUS)	0.736342	0.132981	5.537205	0.0000
Ln(OPGRAPES)	0.153436	0.196923	0.779168	0.4420
Ln(OPPEARS)	0.781842	0.165828	4.714776	0.0001
R-squared	0.995571	Adjusted *R*-squared		0.994833
F-statistic	1348.737	(F-statistic)		0.000000
Durbin-Watson statistic	1.297530			

relationship are probably variations in climatic conditions and operating costs.

Prediction of major Chinese agricultural fruits

In the prediction of major Chinese agricultural fruits production, linear regression was used among the study variables. Statistical classification was used to interpret the results (Figure 6). Time series data was used in this analysis, and it was collected from the Economic Survey of Pakistan. The model for linear regression is specified as:

$$Y_i = \beta_0 1 + \beta_p x_{i1} + \cdots + \beta_p x_{ip} = X^T i\, \beta + \varepsilon_i \text{ , } i = 1 \dots n \quad (4)$$

In Equation 4; $X^T i\, \beta$ Indicates the inner product among the vectors x_i and β and ^{T} is the transpose.

Thus, the form of vector is = $Y = X\beta + \varepsilon$ (5)

The confidence interval of E (y|x^*) and the average of expected value of y for a specific given x^*:

$$\hat{y} \pm t^*_{n-2} s_y \sqrt{\frac{1}{n} + \frac{(x^* - \bar{x})^2}{(n-1)s_x^2}} \quad (6)$$

In the Equation 6; S_y shows the standard deviation of the residuals, intended as and S_x is known as residual standard error in R regression output.

$$s_y = \sqrt{\frac{\sum (y_i - \hat{y}))^2}{n-2}} \quad (7)$$

The proposed model consists of m vectors in a dimensional feature space. In the feature space x points, which project it on m and convert it into z real number, the range of the real number is −∞ to +∞.

$$Z = C + m.x = C + m_1x_1 + m_2x_2 + \cdots + m_dx_d \quad (8)$$

Through a confusion matrix, accuracy can be calculated as:

$$Accurcy = \frac{(\mathrm{TP}) + (\mathrm{TN})}{(\mathrm{TP}) + (\mathrm{FP}) + (\mathrm{FN}) + (\mathrm{TN})}$$

Where, TP indicates True Positive, TN indicates True Negative, FP indicates False Positive and FN indicate False Negative. The design of algorithm is stated below;

Algorithm 1:
Agriculture Fruit Production Prediction
Input: A set of fruit data X
Output: Fruit data X future Prediction P

Algorithm
Step 1: Take matrix M of last one year of data, data size 1×6
Step 2: Take matrix P of forty years pervious data, data size 35×6
Step 3: Make sliding window of window size 1×6 for each matrix P as W_1, $W_2 \dots W_{35}$
Step 4: Compute Euclidean distance of sliding window D_1, D_2, $D_3 \dots$ D_{35}
Step 5: Select matrix W_i as
- ○ $W_{i\,=}$ corresponding matrix (min $D_{i)}$
- ○ ∀i ∈ [1,35]

Step 6: For I=1 to n
- For the computer, the moving average of matrix D as Q
- For the computer, the central moving average

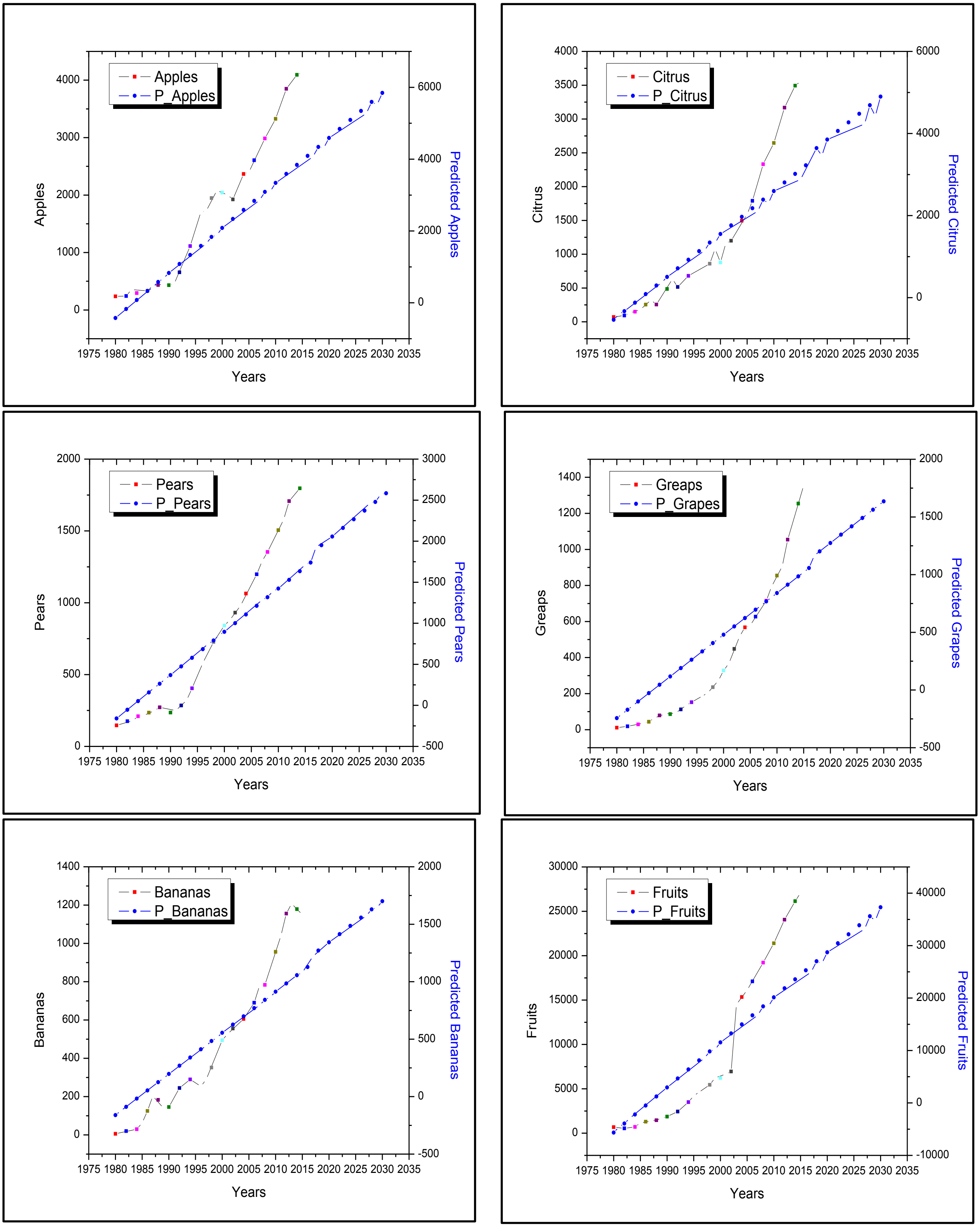

Figure 6. Prediction of major Chinese fruits production.

Table 5. Predicted fruits data and results.

Data Sets	Predicted data	Current Production, Tones (10,000)	Predicted Production, Tones (10,000)	Accuracy (%)
Fruits data of China 1980-2015	1980-2030	27074.5	37318.57	51.26±1
Apples data of China 1980-2015	1980-2030	4131.4	5998.153	50.93±1
Citrus data of China 1980-2015	1980-2030	3556.3	4897.801	45.9±1
Pears data of China 1980-2015	1980-2030	1798	2583.496	46.22±1
Grapes data of China 1980-2015	1980-2030	1353.6	1635.323	50.18±1
Bananas data of China 1980-2015	1980-2030	1150.4	1700.69	48.02±1
Average	Nil	39064.2	54074.033	48.7516±1

matrix Q as R

- Mean 1 = mean of Q
- Mean 2 = mean of R
- Prediction P = (Mean1+Mean2) / 2
- Add F to pervious data for getting forecasting

Step 7: End

Table 5 shows the predicted production of major Chinese fruits up to 2030.

Conclusion and Recommendations

The agriculture sector has made a rich contribution to the Chinese economy. To check the actual performance between the dependent and the independent variables, time series data from 1980 to 2015 were used. The data were collected from the Ministry of Agriculture (MOA) China, China Bureau of Statistics and various publications. The augmented Dickey-Fuller unit root test and the ordinary least squares method were used to analyse the data. The results were interpreted using the Johansen co-integration test. The machine learning technique was used to examine and to predict future agricultural productivity in China. The results of the study show that the coefficient of the output of the apple fruit has a positive relationship with the AGDP. The results also show that the output of citrus, grapes and pears has coefficients that demonstrate a positive relationship with the AGDP, but it is statistically insignificant. The banana fruit output has a negative, but not significant, relationship with China's AGDP. The negative relationship is probably the result of operating costs fluctuations and bad climatic conditions. This negative result was not expected.

The population of China continues to grow; thus, increases in the fruit production are essential. It is the responsibility of the government to provide resources to farmers to increase fruit production. To this end, it is necessary for the Government of China to initiate new programmes and methods of financial support. China also should adopt new policies in the coming decade to improve and to increase yield, a major factor in fruit production.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

REFERENCES

Abebaw D, Haile MG (2013). The impact of cooperatives on agricultural technology adoption: Empirical evidence from Ethiopia. Food Policy 38:82-91.

Awedem WF, Happi ET, Boda M, Fokou E, Deleu M, Gerin PA (2016). Acidogenic fermentation of starchy agroindustrial residues: metabolic profile & influence of thermal pretreatment. In 12th International Conference on Renewable Resources and Biorefineries (RRB12).

Ballester C, Castel J, Intrigliolo DS, Castel JR (2013). Response of Navel Lane Late citrus trees to regulated deficit irrigation: yield components and fruit composition. Irrigation Science 31(3):333-341.

Chanakya HN, Sreesha M (2012). Anaerobic retting of banana and arecanut wastes in a plug flow digester for recovery of fiber, biogas and compost. Energy for Sustainable Development, 16(2):231-235.

Chavan P, Mane S, Kulkarni G, Shaikh S, Ghormade V, Nerkar DP, Shouche Y, Deshpande MV (2009). Natural yeast flora of different varieties of grapes used for wine making in India. Food Microbiology 26(8):801-808.

Chen X, Han M, Su G, Liu F, Guo G, Jiang Y, Mao Z, Peng F, Shu H (2010). Discussion on today's world apple industry trends and the suggestions on sustainable and efficient development of apple industry in China. Journal of Fruit Science 27(4):598-604.

Choi JH, Choi JJ, Hong KH, Kim WS, Lee SH (2007). Cultivar differences of stone cells in pear flesh and their effects on fruit quality. Horticulture Environment and Biotechnology 48(1), 27-31.

Deng H, Huang J, Xu Z, Rozelle S (2010). Policy support and emerging farmer professional cooperatives in rural China. China Economic Review 21(4):495-507.

Dennis FJ (2000). The history of fruit thinning. Plant Growth Regulation 31(1-2):1-16.

Fan M, Shen J, Yuan L, Jiang R, Chen X, Davies WJ, Zhang F (2011). Improving crop productivity and resource use efficiency to ensure food security and environmental quality in China. Journal of Experimental Botany 63(1):13-24.

Food and Agriculture Organization (FAO) (2010). FAO Database. Food and Agriculture Organization. http://faostat. fao.org/.

Food and Agriculture Organization (FAO) (2012). Statistical Database of the Food and Agriculture Organization of the United Nations, (Available in<http://faostat.fao.org/ .>).

Food and Agriculture Organization (FAO) (2013). FAO Database. Food and Agriculture Organization. http://faostat. fao.org/.

Food and Agriculture Organization (FAO) (2014). FAO Database. Food

and Agriculture Organization. http://faostat. fao.org/.
Food and Agriculture Organization (FAO) (2015). Food and agriculture organization of the United Nations: Banana and plantain processing technologies. Retrieved 2017/12/28, from http://faostat3.fao. org/browse/Q/QC/E.
FAO (2006). Food and agriculture organization of the United Nations: Banana and plantain processing technologies. Retrieved 2017/12/12, from http://www.fao.org/ teca/content/banana-and-plantain-processing-technologies.
Fischer E, Qaim M (2012). Linking smallholders to markets: determinants and impacts of farmer collective action in Kenya. World Development, 40(6):1255-1268.
Francesconi GN, Wouterse F (2015). Promoting the role of farmer-based organizations for value chain integration: the tension between a program's targeting and an organization's investment strategy. Agricultural Economics 46(4):527-536.
González SS, Barrio E, Querol A (2007). Molecular identification and characterization of wine yeasts isolated from Tenerife (Canary Island, Spain). Journal of Applied Microbiology 102(4):1018-1025.
Huang C, Yu B, Teng Y, Su J, Shu Q, Cheng Z, Zeng L (2009). Effects of fruit bagging on coloring and related physiology, and qualities of red Chinese sand pears during fruit maturation. Scientia Horticulturae 121(2):149-158.
Ito J, Bao Z, Su Q (2012). Distributional effects of agricultural cooperatives in China: Exclusion of smallholders and potential gains on participation. Food Policy 37(6):700-709.
Janoudi A, Flore JA (2005). Application of ammonium thiosulfate for blossom thinning in apples. Scientia Horticulturae 104(2):161-168.
Ju XT, Xing GX, Chen XP, Zhang SL, Zhang LJ, Liu XJ, Cui ZL, Yin B, Christie P, Zhu ZL, Zhang FS (2009). Reducing environmental risk by improving N management in intensive Chinese agricultural systems. Proceedings of the National Academy of Sciences 106(9):3041-3046.
Ju X, Liu X, Zhang F, Roelcke M (2004). Nitrogen fertilization, soil nitrate accumulation, and policy recommendations in several agricultural regions of China. AMBIO: a Journal of the Human Environmen, 33(6):300-305.
Kamdem I, Jacquet N, Tiappi FM, Hiligsmann S, Vanderghem C, Richel A, Jacques P, Thonart P (2015). Comparative biochemical analysis after steam pretreatment of lignocellulosic agricultural waste biomass from Williams Cavendish banana plant (Triploid Musa AAA group). Waste Management and Research 33(11):1022-1032.
Kilelu CW, Klerkx L, Leeuwis C (2013). Unravelling the role of innovation platforms in supporting co-evolution of innovation: Contributions and tensions in a smallholder dairy development programme. Agricultural Systems 118:65-77.
Ma W, Abdulai A (2016). Does cooperative membership improve household welfare? Evidence from apple farmers in China. Food Policy 58:94-102.
Macholdt J, Honermeier B (2016). Impact of climate change on cultivar choice: adaptation strategies of farmers and advisors in German cereal production. Agronomy 6(3):40.
Morgan KT, Zotarelli L, Dukes MD (2010). Use of irrigation technologies for citrus trees in Florida. Horttechnology 20(1):74-81.
Mulatu E, Zelleke H (2002). Farmers' highland maize (Zea mays L.) selection criteria: Implication for maize breeding for the Hararghe highlands of eastern Ethiopia. Euphytica 127(1):11-30.
Na W, Wolf J, Zhang FS (2016). Towards sustainable intensification of apple production in China—Yield gaps and nutrient use efficiency in apple farming systems. Journal of Integrative Agriculture 15(4):716-725.
Niu JZ, Hull-Sanders H, Zhang YX, Lin JZ, Dou W, Wang JJ (2014). Biological control of arthropod pests in citrus orchards in China. Biological Control 68:15-22.
Pelissari FM, Andrade-Mahecha MM, Sobral PJDA, Menegalli FC (2012). Isolation and characterization of the flour and starch of plantain bananas (Musa paradisiaca). Starch-Stärke 64(5):382-391.
Pillay M, Tenkouano A (2011). Banana breeding: progress and challenges. CRC Press.
Qin W, Assinck FB, Heinen M, Oenema O (2016). Water and nitrogen use efficiencies in citrus production: A meta-analysis. Agriculture, Ecosystems and Environment 222:103-111.
Rajalahti R (2012). Agricultural Innovation Systems. An Investment Source Book. , sourcebook overview and user guide, agriculture and rural development Washington, DC: Author. P. 1.
Ramezani A, Haddad R, Dorostkar M, Mardi M, Naghavi M (2009). Evaluation of genetic diversity of Iranian grapevine accessions using microsatellite markers. Vitis 48(3):151-152.
Rehman A, Jingdong L, Chandio AA, Shabbir M, Hussain I (2017). Economic outlook of rice crops in Pakistan: a time series analysis (1970–2015). Financial Innovation 3(1):13.
Romero CC, Dukes MD, Baigorria GA, Cohen R (2009). Comparing theoretical irrigation requirement and actual irrigation for citrus in Florida. Agricultural Water Management 96(3):473-483.
Seehuber C, Damerow L, Blanke M (2011). Regulation of source: sink relationship, fruit set, fruit growth and fruit quality in European plum (*Prunus domestica* L.) using thinning for crop load management. Plant Growth Regulation 65(2):335-341.
Shen ZM (2009). The enormous change of citrus industry of China in last 60 years. Fruits Growers Friends 10:3-4.
Silva GJ, Souza TM, Barbieri RL, Costa de Oliveira A (2014). Origin, domestication, and dispersing of pear (*Pyrus* spp.). Advances in Agriculture 8 p.
Singh JP, Kaur A, Singh N, Nim L, Shevkani K, Kaur H, Arora DS (2016). In vitro antioxidant and antimicrobial properties of jambolan (*Syzygium cumini*) fruit polyphenols. LWT-Food Science and Technology 65:1025-1030.
Solomakhin AA, Blanke MM (2010). Mechanical flower thinning improves the fruit quality of apples. Journal of the Science of Food and Agriculture 90(5):735-741.
Steduto P, Hsiao TC, Fereres E, Raes D (2012). FAO Irrigation and Drainage Paper 66, Crop Yield Response to Water. Food and Agriculture Organization of the United Nations.
Sun JJ, Huo XX, Liu P (2012). An Empirical Analysis on the Relationship between Apple Export and Apple Industry Development in China [J]. Northern Horticulture 3:174-177.
Tao P, Shu Q, Wang JJ, Zhang WB (2004). Present situation and prospect of research and utilization on red pear germplasm resources. Southwest China Journal of Agricultural Sciences 17:409-412.
Teng Y, Tanabe K (2002). Reconsideration on the origin of cultivated pears native to East Asia. In XXVI International Horticultural Congress: IV International Symposium on Taxonomy of Cultivated Plants 634:175-182.
Untiedt R, Blanke M (2001). Effects of fruit thinning agents on apple tree canopy photosynthesis and dark respiration. Plant Growth Regulation 35(1):1-9.
Vanloqueren G, Baret PV (2008). Why are ecological, low-input, multi-resistant wheat cultivars slow to develop commercially? A Belgian agricultural 'lock-in'case study. Ecological Economics 66(2):436-446.
Wan Y, Schwaninger H, Li D, Simon CJ, Wang Y, Zhang C (2008). A review of taxonomic research in Chinese wild grapes. VITIS-GEILWEILERHOF- 47(2):81.
Xiao Y, Mignolet C, Mari JF, Benoít M (2014). Modeling the spatial distribution of crop sequences at a large regional scale using land-cover survey data: A case from France. Computers and Electronics in Agriculture 102:51-63.
Yang MQ (2004). The lists of citrus insect pests in Longsheng county. Guangxi Horticulture 15:18-20.
Yang ZF, Cong PH, Nie JY, Li J, Li HF (2006a). Current status, problems and suggestions of apple industry in China. Northern Fruits 5(2006):34-35.
Yang ZF, Cong PH, Nie JY, Li J, Li HF (2006b). Current status, problems and suggestions of apple industry in China. Northern Fruits 5(2006):34-35.
Yim SH, Nam SH (2016). Physiochemical, nutritional and functional characterization of 10 different pear cultivars (*Pyrus* spp.). Journal of Applied Botany and Food Quality P 89.
Zhai H, Shi DC, Shu HR (2007). Current status and developing trend of apple industry in China [J]. Journal of Fruit Science 3:027.
Zhang F, Cui Z, Fan M, Zhang W, Chen X, Jiang R (2011). Integrated soil–crop system management: reducing environmental risk while increasing crop productivity and improving nutrient use efficiency in China. Journal of Environmental Quality 40(4):1051-1057.

Zhou H, Yu Y, Tan X, Chen A, Feng J (2014). Biological control of insect pests in apple orchards in China. Biological Control 68:47-56.

Vol. 13(40), pp. 2146-2153, 4 October, 2018
DOI: 10.5897/AJAR2018.13434
Article Number: 963C6B458723
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Prevalence, cultural and pathogenic characterization of *Zymoseptoria tritici*, agent of wheat septoria leaf blotch, in Algeria

Wahiba HARRAT[1,2*] and Zouaoui BOUZNAD[2]

[1]Unité de Recherche de Constantine (URC), Institut National de Recherche Agronomique (INRAA), Algeria.
[2]Département de botanique, Laboratoire de Phytopathologie et Biologie moléculaire Ecole Nationale Supérieure d'Agronomie (ENSA), El-Harrach, Algeria.

Received 3 August, 2018; Accepted 5 September, 2018

Wheat is the 2nd most important culture in the world. Septoria leaf blotch is one of the most important wheat diseases. It is caused by *Mycosphaerella graminicola* (an: *Zymoseptoria tritici*). The aim of this study is to evaluate the presence and the importance of this disease in Algeria. A collection of 625 isolates was made through the years (2010, 2011, and 2013). Isolates were collected from the Algerian zones of cereal production. Phenotypic and genetic characterization via morphological, cultural and pathogenic analysis showed the presence of Septoria leaf blotch in 72 fields (from 122) in 20 departments (counties). In some fields the disease is highly frequent with an index of 99 according to double digit scale. Two main types of isolates were found; but the yeast-like form dominated with 94.08%. 26 isolates sampled from 25 fields were tested to evaluate isolates aggressiveness variability. Only 2 isolates from 26 inoculated were able to produce symptoms on three cereal species (triticale, durum and bread wheat).

Key words: *Zymoseptoria tritici*, diversity, prevalence, virulence, wheat.

INTRODUCTION

Wheat is the one of the most important crops worldwide. The Septoria leaf blotch (SLB) is one of the most devastating diseases of this culture (Fones and Gurr, 2015). It is caused by *Mycosphaerella graminicola* (Fuckel) J. Schröt., in Cohn (anamorph *Zymoseptoria tritici* (Desm.) Quaedvlieg and Crous) (Quaedvlieg et al., 2011). It is a heterothallic pathogen of *Dothideomycetes* class. Serious epidemics can reduce the yields on wheat from 35 to 50% in particular in Mediterranean regions (Ponomarenko et al., 2011).

In the northern half of Africa, the SLB is considered a serious threat on wheat; in Algeria it is widely present in all the northern region of the country (Sayoud et al., 1999; Zahri et al., 2013; Berraies, 2014; Teferi and Gebreslassie, 2015). Fungicides are widely used in intensive production systems. However, better yields are easily achieved by the combination of adequate cultural practices and the use of resistant varieties in the disease

*Corresponding author. E-mail: w.harrat@yahoo.fr.Tel: +213 559 460 635.

(Eyal, 1999). But the specificity of the *M. graminicola*–wheat pathosystem, frequently observed, can interfere with the use of resistant varieties (Saadaoui, 1987; Kema et al., 1996; Kema and van Silfhout, 1997; Kema et al., 2000; Brading et al., 2002; Grieger et al., 2005; Ware, 2006; Ronny et al., 2014). Several hypotheses were emitted on the gene for gene interaction between *Z. tritici* and wheat (Kema et al., 2000; Brading et al., 2002; Goodwin, 2007). Until now 18 *Stb* identified genes confer the resistance of cultivars to the pathogen (Arraiano et al., 2007; Goodwin, 2007; Chartrain et al., 2009; Tabib Ghaffary et al., 2011).

Recently, Allioui et al. (2014) and Ayad et al. (2014) demonstrated that both idiomorphs (MAT1-1 and MAT1-2) exist in Algeria and were scored at similar frequencies. Teleomorph has been identified in Algeria for the first time by Harrat et al. (2017). Other research works were made concerning the virulence, parasitic specialization and the heritability of wheat resistance to Z. tritici (Kema et al., 1996; Benkorteby, 2004; Allioui et al., 2014; Ayad et al. 2014). Of this fact, a preliminary knowledge of this disease, its distribution and diversity by a cultural and pathogenic characterization are essential to establish an adequate control approach of SLB. The objectives of the present study were to evaluate disease distribution and its importance in various cereal regions in Algeria, to realize cultural characterization and evaluate *Z. tritici* isolates aggressiveness, obtained from the Eastern regions of country, through a set of varieties constituted by wheat and triticale cultivated in Algeria.

MATERIALS AND METHODS

Study areas

Prospecting was realized during April–May of the years 2010, 2011 and 2013 in various wheat-producing areas of the country (Figure 1). In 2010, the survey took place on the West of the country and some localities of Eastern regions. In 2011, they were generalized in the Central region and some localities of the Western region. In 2013 the survey was particularly dedicated to the Eastern region. Surveys were realized between blooming and maturity stage of the wheat. The sampling was regularly made all 15 to 20 km through the cereal-producing regions. For every wheat field, the inspection was made according to the X-shaped method of Campbell and Madden (1990).

Diagnostic and disease assessment in the field

Diagnosis of the disease on wheat is based on the observation of the typical symptom caused by *Z. tritici*. The SLB was identified by lengthened necrosis and bounded by the nervures (Sayoud et al., 1999; Duncan and Howard, 2000). Necrosis is very often lengthened, strewed with many pycnidia (Rapilly et al., 1971). Where disease symptoms are detected, an assessment was realized on 10 plants according to double digit scale (00-99) described by Eyal et al. (1987); the first digit represents the vertical progress of the disease according to the scale 0-9 of Saari and Prescott (Eyal et al., 1987); the second digit indicates the severity of the disease according to the scale 0-9 which every digit corresponds to a percentage of foliar surfaces covered by the disease.

Morphological and cultural study *in vitro*

In laboratory, the diagnosis of the disease and the isolation of pathogen were realized from small fragments of limbs presenting characteristic pycnidia according to Eyal et al. (1987). The isolations were made only on 25 fields, from the year 2013, in East region of country (Annaba [01 field], Sétif [03 field], Constantine [18 field] and Mila [03 field]) (Table 1). Five infected leaves were randomly sampled from every field. From a lesion, five isolates were randomly retained after isolation (a lesion by leaf). In all, 625 isolates were retained for the morphologic and cultural characterizations; among them, 26 isolates were tested for the pathogenic characterization (Table 1). Morphological characterization of the *Z. tritici* isolates was realized according to tint scale described by Siah et al. (2008).

Evaluation of isolates aggressiveness variability

Pathogenicity test was led under greenhouse according to a plan in split plot with three repetitions. 26 isolates sampled from 25 fields (Table 2) were tested on a differential range of 16 varieties (five Bread wheat [Ain Abid, Arz, Anapo, Anforeta and HD1220], ten Durum wheat [Boussalem, Cirta, Colosseo, Cote, GTA-Dur, Ofanto, Simeto, Vitron, Waha et Wahebi] and one Triticale [Juanillo]) approved in Algeria.

Inoculum was prepared from 7 days old *Z. tritici* cultured in 18°C on YMA medium. The conidial suspension was adjusted to 10^8 spore ml^{-1}, adding to it a droplet of Tween 20. The inoculation was executed by pulverizing the conidial suspension at seedling stage (3 leaves) and the humidity was maintained during 48 h according to the modified method described by Zuckerman et al. (1997). After 21 days, the number of infected leaves (NIL) was estimated on the first three leaves and the percentage of *Z. tritici* pycnidial covering (%PC) was estimated according to the scale described by Ziv and Eyal (1978). Statistical analyses were made by variance analysis (ANOVA) and hierarchical classification in dendrogram.

RESULTS AND DISCUSSION

Prevalence of septoria leaf blotch in Algeria

Characteristic symptoms of SLB observed on fields were necrosis more or less lengthened, which can cover, in certain cases, the majority of the foliar surface and strewed with pycnidia, the percentage of covering was variable. During the 2010 campaign, 12 fields from 18 (66.67%) presented typical symptoms of the SLB. For 2011 and 2013 campaigns, in the 104 prospected fields, the disease was present in 60 fields (57.67%). On a total of 122 prospected fields, during three years, 72 fields present the SLB disease (Table 2 and Figure 1), where 59% of the prospected fields were infected. The SLB is present in the majority of wheat-producing areas.

It is admitted that the development of SLB diseases is bound to weather conditions, particularly, humidity and temperature. Disease severity in sub-humid regions was particularly observed. In the counties of Algiers, Annaba and Blida the severity of the disease reached 98 and 99

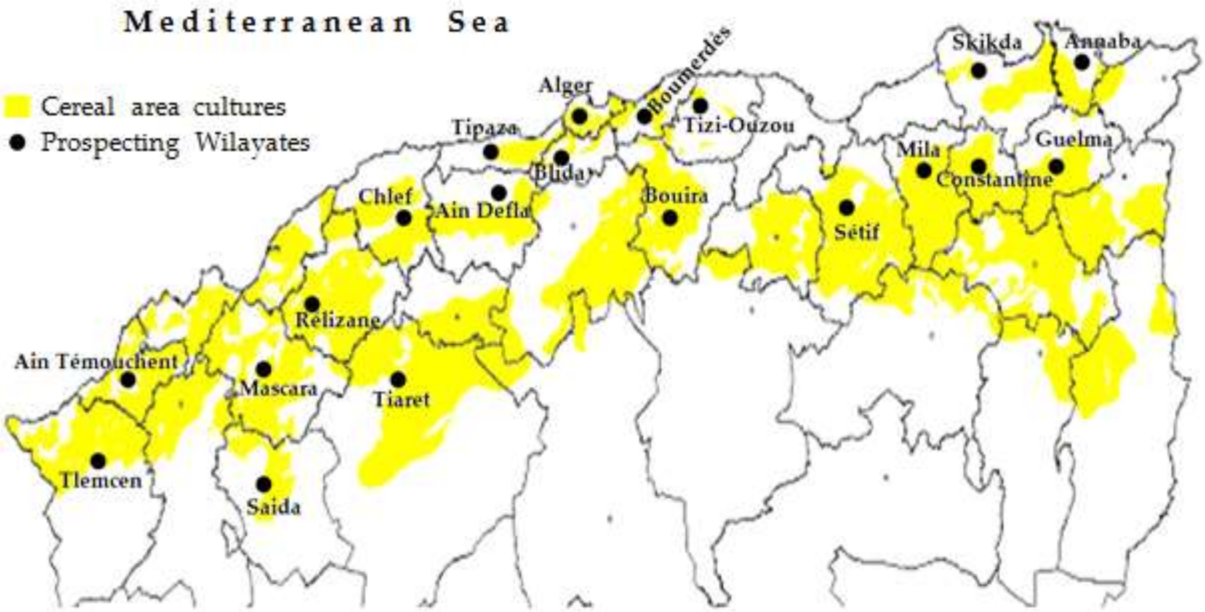

Figure 1. Wheat-producing areas.
Source: Algerian Ministry of Agriculture, Rural Development and Fisheries.

Table 1. Provenance of *Zymoseptoria tritici* isolates.

Isolate code	Wilayats of provenance	Source isolate host
St1	Constantine	Durum wheat (GTA-Dur)
St2	Constantine	Bred wheat (HD1220)
St3	Constantine	Durum wheat(Vitron)
St4	Constantine	Durum wheat
St5	Constantine	Durum wheat
St6	Constantine	Bred wheat
St7	Constantine	Durum wheat (Cirta)
St8	Mila	Bred wheat
St9	Mila	Durum wheat (GTA-Dur)
St10	Sétif	Durum wheat
St11	Constantine	Durum wheat (Gta-Dur)
St12	Sétif	Durum wheat
St13	Constantine	Durum wheat (Cirta)
St14	Mila	Durum wheat
St15	Sétif	Durum wheat
St16	Mila	Bred wheat (Arz)
St17	Mila	Durum wheat
St18	Constantine	Bred wheat
St19	Mila	Durum wheat
St20	Mila	Durum wheat
St21	Constantine	Bred wheat (HD1220)
St22	Constantine	Durum wheat (Gta-Dur)
St23	Constantine	Bred wheat
St24	Constantine	Bred wheat
St25	Constantine	Bred wheat
St26	Annaba	Durum wheat (Gta-Dur)

Table 2. Prevalence and severity of septoria leaf blotch of wheat in Algeria.

Bioclimatic stage	Wilayats	Prospected fields between 2010-2013	Infected fields with *Zymoseptoria tritici*	Double digit 00-99 (vertical progression and disease severity)
Humid	Skikda	1	1	98
	Ain Defla	4	3	33 - 55
	Alger	6	5	53 - 99
	Annaba	1	1	98
	Blida	4	2	31 - 98
Sub-humid	Boumerdès	8	5	51 - 75
	Guelma	1	1	75
	Mila	14	7	75
	Tipaza	4	1	31
	Tizi-Ouzou	2	2	31
Sub - Total 1		44	27/44 (**61%**)	-
	Ain Témouchent	6	4	53 - 98
	Bouira	6	2	11 - 31
	Chlef	4	2	31 - 73
	Constantine	30	22	75
Semi-arid	Mascara	5	1	11
	Rélizane	3	2	53
	Saida	2	1	11
	Sétif	10	3	51 - 53
	Tiaret	9	6	75 - 98
	Tlemcen	2	1	51
Sub – Total 2		77	44/77 **(57%)**	-
Totals		**122 fields**	**72/122 fields**	**-**

according to "double digit" scale because of climatic conditions (according to data from ONM). For example, during 2010 the annual pluviometry in Annaba was 596 mm, and that for the first four months was 237 mm, which represent period for the disease development.

The year 2011 was characterized by a sum of 673 mm pluviometry in Algiers, 314 mm registered during the first four months (ONM source) and the average temperatures between 17 and 20°C; the meteorological conditions were favorable for the dissemination of SLB. However, we also noticed that in some Wilayate of the semi-arid regions, particularly, Constantine and Tiaret, where an important severity of the disease was observed. It can be explained by the special agricultural features of Algeria, where the cereals cultivation is in intense monoculture system in semi-arid regions rather than diversified as cultivated in the sub-humid regions.

In the regions where the drought caused damage during the 2011 campaign, the disease was observed only on the first leaves. Indeed, the results indicate that the severity of the disease does not exceed 11 according to the "double digit" scale. It was the case of Saïda and Mascara where the sum of precipitation of the first four months did not exceed 130 mm (ONM source). According to Danon et al. (1982) and Cowger et al. (2000), the SLB engenders major losses of yields, in particular, when the spring rains persist, after the emergence of the flag leaf. These losses vary with weather conditions, cultivated varieties and precocity of attacks (Devale et al., 2000).

Morphologic and cultural characterizations

Phenotypic observations, of colonies stemming, from isolates of *Z. tritici* of 10 days on solid YMA (Yeast Malt Agar) medium show a big diversity of texture and color. The isolates of pinkish color have a creamy texture (Yeast Like), which can cover completely the culture medium or in the form of colonies which follow the lines of sowing. The isolates of dark color are solid and compact. It is noticed that the pink color is the most dominant (darkened 42.88%, clear 24.16% and very clear 27.04%), whereas the dark brown occupied 5.92% group cultures. These results corresponding to those of Bentata et al. (2011) and Ayad et al. (2014) which realized a cultural characterization of the Moroccan and Algerian isolates of *Z. tritici*; also, those of Siah et al. (2008) on the distribution of “mating type” according to the colonies phenotype. According to Quaedvlieg et al., (2011) variants of *Z. tritici* can appear on culture medium.

Table 3. Classification in homogeneous groups of the 26 studied isolates of *Z. tritici* according to their aggressiveness.

***Z. tritici* isolate**	**NIL**	**%PC**
ST1	0.03^{cde}	1.87^{f}
ST2	0.11^{cde}	8.75^{bcdef}
ST3	0.02^{de}	4.37^{def}
ST4	0.27^{abc}	21.25^{ab}
ST5	0.10^{cde}	5.93^{cdef}
ST6	0.22^{abcde}	10.62^{abcdef}
ST7	0.27^{abc}	17.50^{abcd}
ST8	0.02^{de}	0.31^{f}
ST9	$\mathbf{0.39^{a}}$	16.87^{abcde}
ST10	0.01^{e}	1.25^{f}
ST11	0.26^{abcd}	10.62^{abcdef}
ST12	0.00^{e}	0.00^{f}
ST13	0.04^{cde}	1.56^{f}
ST14	0.06^{cde}	8.75^{bcdef}
ST15	0.02^{de}	2.50^{f}
ST16	0.02^{de}	3.43^{ef}
ST17	0.37^{ab}	$\mathbf{22.5^{a}}$
ST18	0.04^{cde}	3.12^{f}
ST19	0.22^{abcde}	18.43^{abc}
ST20	0.13^{bcde}	9.37^{abcdef}
ST21	$\mathbf{0.41^{a}}$	21.25^{ab}
ST22	0.13^{bcde}	11.87^{abcdef}
ST23	0.02^{de}	4.37^{def}
ST24	0.01^{e}	1.25^{f}
ST25	0.01^{e}	1.25^{f}
ST26	0.03^{cde}	3.75^{ef}

NIL: Number of infected leaves; **PC%**: Pycnidial covering. Letters in superscript represent statistically different homogeneous groups.

Isolates aggressiveness and evaluation of the varietal assessment

Variance analysis of the infected leaves number (NIL) and of the pycnidial coverage percentage (%PC) of the 26 isolates tested on the differential set varieties shows a very highly significant difference for both parameters (Table 3). Five pathotypes were distinguished for NIL parameter. The most virulent isolates, according to this parameter, were ST9, ST17 and ST21. For the %PC, six pathotypes were detected. The most virulent isolates, according to this parameter, were ST4, ST17 and ST21 (Figure 2). We noticed that the area from where the isolates are sampled did not influence systematically the level of aggressiveness. Both isolates ST19 and ST20 arise from the same field and have a different behavior towards the studied wheat and triticale varieties. However, isolates ST17 and ST21 were obtained from two different fields and belong to the same pathotype. From 26, 10 isolates showed a physiological specificity for the Bread wheat or the Durum wheat, only ST9 and ST20 presented symptoms on three studied host species.

Statistical study of the 16 host varieties (Durum wheat, Bread wheat and Triticale) comportment (resistance or sensibility) towards the range of isolates showed a very highly significant difference. Four homogeneous groups for both parameters ILN and %PC are observed. The most sensitive varieties were HD1220 and Waha, whereas, the most resistant varieties, with no symptom were Ain Abid, Colosseo and Simeto (Figure 2; Table 4). A qualitative variation of *M. graminicola* virulence was indicated in certain studies (Eyal et al., 1973; Saadaoui, 1987; Kema et al., 1996). Brading et al. (2002) and Kema et al. (2000)'s works brought the proof of gene-for-gene relation between wheat and *M. graminicola*.

Medini and Hamza (2008) study showed that the Algerian isolates have more variability, with eight pathotypes, compared with the Tunisian and Canadian isolates. The strong variability of the Algerian isolates can be associated to the agricultural practices. Indeed, both wheat cultures are important, 24.3% for bread wheat and75.7% for durum wheat according to statistical data of

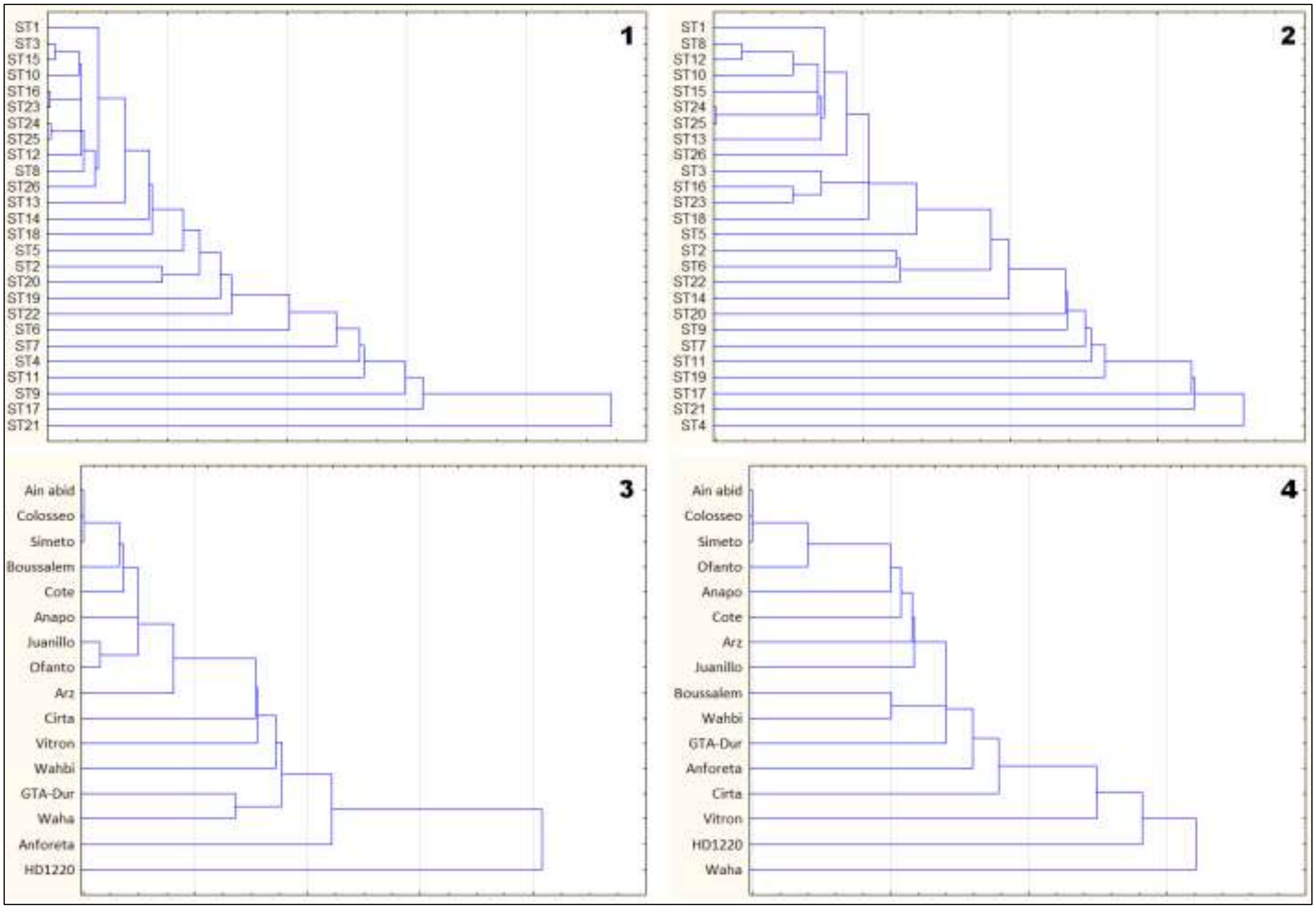

Figure 2. Hierarchical classification (Euclidean Distance).
1: Isolates × Infected Leaves Number per plant; 2: Isolates × Pycnidial Coverage Percentage
3: Varieties × Infected Leaves Number per plant; 4: Varieties × Pycnidial Coverage Percentage.

Ministry of Agriculture, Rural Development and Fisheries. Consequently, *M. graminicola*is is exposed to wide genotype groups having various sources of resistance genes. Kema et al. (1996) suggest the existence of two variants of *M. graminicola*, one adapted to the durum wheat and the other one to the bread wheat. The hypothesis of specificity existence in the pathosystem wheat – *M. graminicola* was emitted since the first report indicating a physiological specialization (Eyal et al., 1973).

According to several authors, the isolates of *Z. tritici* obtained from tetraploids wheat show a bigger virulence on wheat whether it was tetraploids or hexaploids (Kema et al., 1996; Van Ginkel and Scharen, 1988). It was the case of the ST21 of our study. Nevertheless, among the most virulent isolates of the tested range (ST17, ST9 and ST4) were obtained from durum wheat. Shaner and Finney (1982) identified the varietal resistance with *Z. tritici*. More than 12 main genes conferring to the host high levels of resistance were identified. Most of them were mapped in wheat genome specific regions (McCartney et al., 2002; Adhikari et al., 2004; Chartrain et al., 2005; Arraiano et al., 2007).

CONCLUSION

Wheat septoria leaf blotch caused by *M. graminicola* is a disease, present in all the country cereal zones, of both cultivated wheat species (Durum wheat and Bread wheat). According to the importance of attacks, this disease can engender considerable yield losses, in particular, when weather conditions were favorable for pathogen development. Severity of the SLB was more significant on the regions where weather conditions were favorable and the monoculture was widely practiced. Results indicate a big phenotypic variability of the obtained colonies. The 26 tested isolates, of East Algeria

Table 3. Classification in homogeneous groups of the 26 studied isolates of *Z. tritici* according to their aggressiveness.

***Z. tritici* isolate**	**NIL**	**%PC**
ST1	0.03^{cde}	1.87^{f}
ST2	0.11^{cde}	8.75^{bcdef}
ST3	0.02^{de}	4.37^{def}
ST4	0.27^{abc}	21.25^{ab}
ST5	0.10^{cde}	5.93^{cdef}
ST6	0.22^{abcde}	10.62^{abcdef}
ST7	0.27^{abc}	17.50^{abcd}
ST8	0.02^{de}	0.31^{f}
ST9	$\mathbf{0.39^{a}}$	16.87^{abcde}
ST10	0.01^{e}	1.25^{f}
ST11	0.26^{abcd}	10.62^{abcdef}
ST12	0.00^{e}	0.00^{f}
ST13	0.04^{cde}	1.56^{f}
ST14	0.06^{cde}	8.75^{bcdef}
ST15	0.02^{de}	2.50^{f}
ST16	0.02^{de}	3.43^{ef}
ST17	0.37^{ab}	$\mathbf{22.5^{a}}$
ST18	0.04^{cde}	3.12^{f}
ST19	0.22^{abcde}	18.43^{abc}
ST20	0.13^{bcde}	9.37^{abcdef}
ST21	$\mathbf{0.41^{a}}$	21.25^{ab}
ST22	0.13^{bcde}	11.87^{abcdef}
ST23	0.02^{de}	4.37^{def}
ST24	0.01^{e}	1.25^{f}
ST25	0.01^{e}	1.25^{f}
ST26	0.03^{cde}	3.75^{ef}

NIL: Number of infected leaves; **PC%**: Pycnidial covering. Letters in superscript represent statistically different homogeneous groups.

wheat-producing region, show a big variability towards the studied wheat and triticale varieties. Five pathotypes were distinguished for the infected leaves number parameter and six pathotypes for pycnidial coverage parameter. Some isolates have physiological specialization towards hosts. It would be interesting to include the varieties, which have proved resistant characters to this disease, in future wheat improvement program. For a better knowledge of pathogen, it would be useful to study more isolates by molecular markers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Adhikari TB, Cavaletto JR, Dubcovsky J, Gieco JO, Schlatter AR, Goodwin SB (2004). Molecular mapping of the Stb4 gene for resistance to *Septoria tritici* blotch in wheat. Phytopathology 94:1198-1206.

Allioui N, Siah A, Brinis L, Reignault P, Halama P (2014). Mating type distribution provides evidence for sexual reproduction of *Mycosphaerella graminicola* in Algeria. Canadian Journal of Plant Pathology 36(4):475-481.

Arraiano LS, Chartrain L, Bossolini E, Slatter HN, Keller B, Brown JKM (2007). A gene in European wheat cultivars for resistance to an African isolate of *Mycosphaerella graminicola*. Plant Pathology 56: 73-78.

Ayad D, Sayoud R, Benbelkacem K, Bouznad (2014). La tache septorienne du blé : Première signalisation de la présence en Algérie des deux Mating types du téleomorphe *Mycosphaerella graminicola* (Fuckel) Schröter, (anamorphe : *Septoria tritici* Rob ex Desm.) et diversité phénotypique de l'agent pathogène. Nature et Technologie. B- Sciences Agronomiques et Biologiques 11:34-45.

Benkorteby H, Mekliche L, Bouznad Z (2004). Results of screening greenhouse and *in vitro* behaviour to evaluate some durum wheat varieties and their F5 descendents selected in Algeria for resistance to *Septoria tritici*. Communications in Agricultural and Applied Biological Sciences 69(4):403-836.

Bentata F, Labhilili M, Merrahi A, Gaboun F, Ibijbijen J, El Aissami A, Amiri S, Boulif M, Jliben M (2011). Determination of the genetic diversity of a population of *Septoria tritici* on broad wheat via cultural and pathogenic characterization. Revue Marocaine de Protection des Plantes 2:1-10.

Berraies S, Gharbi MS, Belzile F, Yahyaoui A, Hajlaou i MR, Trifi M, Jean M, Rezgui S (2013). High genetic diversity of *Mycospaherella graminicola* (*Zymoseptoria tritici*) from a single wheat field in Tunisia as revealed by SSR markers. African Journal of Biotechnology 12 (12):1344-1349.

Brading PA, Verstappen ECP, Kema GHJ, Brown JKM (2002). A gene-for-gene relationship between wheat and *Mycosphaerella graminicola*, the *Septoria tritici* blotch pathogen. Phytopathology 92:439-445.

Campbell CL, Madden LV (1990). Introduction to Plant Disease Epidemiology. Wiley-Interscience, NY. 532 p.

Chartrain L, Joaquim P, Berry ST, Arraiano LS, Azanza F, Brown JKM (2005). Genetics of resistance to *Septoria tritici* blotch in the Portuguese wheat breeding line TE 9111. Theoretical and Applied Genetics 110:1138-1144.

Chartrain L, Sourdille P, Bernard M, Brown JKM (2009). Identification and location of Stb9, a gene for resistance to *Septoria tritici* blotch in wheat cultivars Courtot and Tonic. Plant Pathology 58:547-555.

Cowger C, Hoffer ME, Mundt CC (2000). Specific adaptation by *Mycosphaerella graminicola* to a resistant wheat cultivar. Plant Pathology 49:445-451.

Danon T, Sacks JM, Eyal Z (1982). The relationships among plant stature, maturity class and susceptibility to Septoria leaf blotch of wheat. Phytopathology 72:1037-1042.

Devale R, Bastard L, Nussbaumer A (2000). Le blé a lui aussi son helminthosporiose. *Phytoma* 526:17-20.

Duncan K, Howard R (2000). Cytological analysis of wheat infection by the leaf blotch pathogen *Mycosphaerella graminicola*. Mycological Research 104 (9):1074-1082.

Eyal Z (1999). The *Septoria tritici* and *Sagonospora nodorum* blotch diseases of wheat. European Journal Plant Pathology 105: 629-614.

Eyal Z, Amiri Z, Wahl I (1973). Physiologic specialization of *Septoria tritici*. Phytopathology 63: 1087-1091.

Eyal Z, Scharen AL, Prescott JM, Ginkel VM (1987). The septoria diseases of wheat: Concepts and methods of disease management. CIMMYT, Mexico. 52 p.

Fones H, Gurr S (2015). The impact of *Septoria tritici* Blotch disease on wheat: An EU perspective. Fungal Genetics and Biology 79: 3-7.

Goodwin SB (2007). Back to basics and beyond: increasing the level of resistance to *Septoria tritici* blotch in wheat. Australasian Plant Pathology 36: 532-538.

Grieger A, Lamari L, Brûlé-Babel A (2005). Physiologic variation in *Mycosphaerella graminicola* from western Canada. Canadian Journal of Plant Pathology 27:71-77.

Harrat W, Meamiche Neddaf H, Keddad A, Bouznad Z (2017). First report of the Zymoseptoria tritici teleomorph stage causing septoria leaf blotch of wheat in Algeria. New Disease Reports 35:30.

Kema GHJ, Sayoud R, Annone JG, van Silfhout CH (1996). Genetic variation for virulence and resistance in the wheat - *Mycosphaerella graminicola* pathosystem II. Analysis of interactions between pathogen isolates and host cultivars. Phytopathology 86: 213-220.

Kema GHJ, Van Silfhout CH (1997). Genetic variation for virulence and resistance in the wheat - *Mycosphaerella graminicola* pathosystem III. Comparative seedling and adult plant experiments. Phytopathology 87:266-272.

Kema GHJ, Verstappen ECP, Waalwijk C (2000). Avirulence in the wheat *Septoria tritici* leaf blotch fungus *Mycosphaerella graminicola* is controlled by a single locus. Molecular Plant-Microbe Interactions Journal 13:1375-1379.

McCartney CA, Brule-Babel AL, Lamari L (2002). Inheritance ofrace-specific resistance to *Mycosphaerella graminicola* in wheat. Phytopathology 92:138-144.

Medini M, Hamza S (2008). Pathotype and molecular polymorphism of *Mycosphaerella graminicola.* Journal of plant pathology 90 (1): 65-73.

Ponomarenko A, Goodwinet SB, Kema GHJ (2011). *Septoria tritici* Blotch (STB) du blé. Plant health instructor (DOI: 10.1094/PHI-I-2011-0407-01).

Quaedvlieg W, Kema GHJ, Groenewald JZ, Verkley GJM, Seifbarghi S, Razavi M, Mirzadi Gohari A, Mehrabi R, Crous PW (2011). *Zymoseptoria* gen. nov.: a new genus to accommodate Septoria-like species occurring on graminicolous hosts. Persoonia 26:57-69.

Rapilly F, Lemaire JM, Cassini R (1971). Les principales maladies cryptogamiques des céréales. Eds. I.N.R.A, Paris 310 p.

Ronny K, Amitava B, Stephan P, Tiffany YH, Rachel BB, Eva HS (2014). Expression Profiling of the Wheat Pathogen *Zymoseptoria tritici* Reveals Genomic Patterns of Transcription and Host-Specific Regulatory Programs. Genome Biology and Evolution 6 (6):1353-1365.

Saadaoui EM (1987). Physiologic specialisation of *Septoria tritici* in Morocco*.* Plant Disease 71:153-155.

Saari EE, Prescott JM (1975). A scale for appraising the foliar intensity of wheat diseases. Plant Disease 59:377-380.

Sayoud R, Ezzahiri B, Bouznad Z (1999). Les maladies des céréales et des légumineuses alimentaires au Maghreb. Eds. I.T.G.C., Alger 64 p.

Shaner G, Finney RE (1982). Resistance in red soft winter wheat program for the simulation and analysis of diallel crosses. Agron to *Mycosphaerella graminicola*. Phytopathology 72:154-158

Siah A, Tisserant B, El-Chartouni L, Duyme F, Deweer C, Fichter C, Sanssené J, Durand R, Reignault Ph, Halama P (2008). Frequencies and molecular polymorphism of mating type idiomorphs in a French population of the wheat pathogen *Mycosphaerella graminicola*. 7th International *Mycosphaerella* and *Stagonospora* Symposium. Monte Veritá Conference Center, Ascona, Switzerland (August 18-22 2008).

Tabib Ghaffary SM, Robert O, Laurent V, Lonnet P, Margalé E, Van Der Lee TAJ, Visser RGF, Kema GHJ (2011). Genetic analysis of resistance to *Septoria tritici* blotch in the French winter wheat cultivars Balance and Apache. Theoretical and Applied Genetics 123(5):741-754.

Teferi TA, Gebreslassie ZS (2015). Occurrence and intensity of wheat *Septoria tritici* blotch and host response in Tigray, Ethiopia. Crop Protection 68:67-71.

Van Ginkel M, Scharen AL (1988). Host-pathogen relationships ofwheat and *Septoria tritici*. Phytopathology 78:762-766.

Ware SB (2006). Aspects of sexual reproduction in *Mycosphaerella* species on wheat and barley: genetic studies on specificity, mapping, and fungicide resistance. PhD Thesis, Wageningen University, The Netherlands 190 p.

Zahri S, Farih A, Douira A (2013). Statut des principales maladies cryptogamiques foliaires du blé au Maroc en 2013. Journal of Applied Biosciences 77:6543-6549.

Ziv O, Eyal Z (1978). Assessment of yield component losses caused in plants of spring wheat cultivars by selected isolates of *Septaria tritici*. Phytopathology 68:791-794.

Zuckerman E, Eshel A, Eyal Z (1997). Physiological aspects related to tolerance of spring wheat cultivars to *Septoria tritici* blotch. Phytopathology 87:60-65.

Vol. 13(40), pp. 2154-2162, 4 October, 2018
DOI: 10.5897/AJAR2018.13283
Article Number: FCEF26158725
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Sandy soil fertility restoration and crops yields after conversion of long term *Acacia senegal* planted fallows in North Cameroon

Simon Djakba Basga[1*], Oumarou Palou Madi[1], Jules Balna[1], Fanta Chimène Abib[2], Désiré Tsozué[3] and Aboubakar Njiemoun[1]

[1]Institute of Agricultural Research for Development (IRAD), P.O. Box 33 Maroua, Cameroon.
[2]Higher Institute of the Sahel (ISS), University of Maroua, P.O. Box 46 Maroua, Cameroon.
[3]Department of Earth Sciences, University of Maroua, P.O. Box 814 Maroua, Cameroon.

Received 1 June, 2018; Accepted 3 September, 2018

Tree planted fallow is an agroforestry system that may restore degraded soils and protect them from erosion. In this study, sandy soils properties of *Acacia senegal* planted fallows (AF) were assessed and compared to those from the continuous cropped system (CC) in 3 sites from Northern Cameroon in order to determine its suitability to restore soil fertility and sustain crop productivity. Soil samples were collected from the topsoil (0 to 20 cm) and the subsoil (20 to 40 cm) and subjected to physicochemical analyses. The trials were established for 2 consecutive years, respectively with sorghum (*Sorghum bicolor*) and cowpea (*Vigna unguiculata*). Results confirmed the sandy (more than 80% of sand) and acidic (4.42 ≤ pH ≤ 6.59) soil characters. In every site, topsoil from AF was relatively more fertile than from CC. Globally, nutrients content were influenced by tree density and fallow duration. The more improved elements were organic matter, nitrogen and pH. Sorghum and cowpea yields were quite variable depending on fallow duration, tree density and conversion form. The highest crop yields (3.4 tha^{-1} for sorghum and 2.4 tha^{-1} for cowpea) were obtained in 19 years old AF converted by partial clear-felling. The intercropping process by partial clear-felling of trees was the best conversion form. Overall findings indicated that fallowing with *A. senegal* can reduce soil acidity, restore nutrients and therefore it constitutes a suitable agroforestry system that may sustain annual crops productivity. However, researches have to determine the best tree density for intercropping and the tools for their sustainable management.

Key words: *Acacia senegal* fallow, agroforestry, sandy soils, continuous cropping, North Cameroon.

INTRODUCTION

Soils in sub-Saharan Africa are characterized by nutrients depletion along with time. In cultivated savannas, natural fallows became unable to restore their fertility and sustain productivity. Hence, the potential solutions to restore

*Corresponding author. E-mail: simonbajak@yahoo.fr. Tel: +237 99 60 86 97.

degraded soils reside in the planting of legume tree and the incorporation of woody perennials into cropping systems (Palm, 1995; El Tahir et al., 2009; Mubarak et al., 2011; Partey et al., 2011; Githae et al., 2013). Therefore, a concept of improved fallows was introduced and agroforestry is known as a common system of improved fallows observed in many parts of African countries (Rao et al., 1998). The almost used trees were *Faidherbia albida, Acacia auculiformis, Acacia nilotica* and *Acacia senegal* (El Tahir et al., 2009; Hadgu et al., 2009; Partey et al., 2011; Harmand et al., 2012; Omar and Muhammad, 2015).

Recent studies show how to arrange and measure of chlorophylls and effect of plants (Cetin, 2016). They also show that the plants have bioactive compounds. They explain how to cause inhibition of root growth, as well as reduced water absorption. Also, they research how on how to cause morphological, biochemical and physiological changes in plants of different species (Ibrahima et al., 2008; Cetin, 2016; Turkyilmaz et al., 2018). Recent studies show that medicinal plants are an important source of new chemical substances with potential materials. They research on both physical, chemical and biological and found that they are very valuable and effective medical plants (Cetin, 2017; Yigit et al., 2016).

When the recent work was being done, it affects the life of the city to spread the leaf of the leafy trees. Although the leaves can absorb CO_2, environmental pollution comes to the forefront when they are poured. Recent studies demonstrate how they affect human health with the air quality through PM_{10} (coarse particles) and CO_2 (Cetin et al., 2017; Sevik et al., 2018). Several studies on air pollution exposure showed that the problems about human health are associated to fine particulate organic matter concentration (Cetin et al., 2017).

Climatic factors are affected by temperature, wind, rain, and drought that people feel comfortable or not comfortable in the area because the planning and management are not well done. Some of these studies show that there is a range of bioclimatic comfort zone which people feel comfortable (Rao et al., 1998; Cetin, 2015; Sevik et al., 2018). Drought evaluation is very important as well as climatic ranges. Drought assessments give people an active scenario in the city to protect the damaging socioeconomic and politic problems. Recent studies with drought stress show monitoring of drought stress through various tools (Dawson, 1996; Yigit et al., 2016; Cetin et al., 2018).

A. senegal is a typical tree adapted to deep sandy soils which is widely observed in arid and semi-arid zones of Africa and is planted for gum arabic, wood production and animal nutrition (Isaac et al., 2011; Harmand et al., 2012). An integration of this tree in agroforestry system as a means of restoring the soil fertility and promoting gum arabic production was observed and has been widely published (Fadl, 2010; Palou Madi et al., 2010; Kissi, 2011). It was recognized and considered as one of the most successful forms of natural forests management in tropical dry lands. Also, the traditional *A. senegal* based agroforestry was observed as sustainable in terms of its environmental, social and economic benefits (Deans et al., 1999; Nasreldin, 2004; Kissi, 2011; Isaac et al., 2011).

In Northern Cameroon, between 1990 and 2006, rural development agencies such as Rural Development and Land Management (DPGT) and ESA/SODECOTON have encouraged smallholders to establish and manage *A. senegal* plantations (Mallet et al., 2002; Palou Madi et al., 2010; Kissi, 2011). These established plantations were extended between 2007 and 2011 through *Acacia* gum project financed by the European Union (Palou Madi et al., 2010). The introduction of this tree in agricultural farms was also to restore soil fertility and diversify sources of income for farmers through the production of gum arabic (Mallet et al., 2002; Palou Madi et al., 2010; Kissi, 2011). So, farmers planted this tree on marginal soils mainly sandy red soils which has been strongly depleted particularly in sudano sahelian zone in order to restore their fertility. After 15 years, gum production was reduced and was not beneficial. The plantations were then converted by farmers to different land resources management. Usually, their cropping by different management systems such as total clear-felling of trees or intercropping was observed (Kissi, 2011).

Sandy soils do not have the capacity to hold enough water and nutrients. The constraints to their cropping reside in their high permeability, their low organic matter content and their low fertility level which are responsible for water and nutrients stresses observed in crops (Basga and Nguetnkam, 2015). Cropping these soils consisted in increasing the organic matter content, nitrogen, nutrients levels and limits their degradation via erosion. Improved tree fallow is one of the possible approaches (Muthuri et al., 2005; Kissi, 2011). In semi-arid sub-Saharan, planting *A. senegal* seemed to be more adapted because of its high adaptation potential to drought and fodder generation for animal as well as wood and gum arabic (Nasreldin, 2004; Palou Madi et al., 2010; Abib et al., 2013). It can also stabilize sandy soils and restore their fertility, protecting them from erosion (Mallet et al., 2002; Harmand et al., 2012).

The effect of *A. senegal* tree on sandy soil fertility has been widely published all over the world mainly in arid environment such as Sudan, Ethiopia and Kenya (Gaafar, 2005; El Tahir et al., 2009; Fadl, 2010; Mubarak et al., 2011; Githae et al., 2013; Berhe and Retta, 2015). Unlike in many countries, an integration of this tree in Cameroon agroforestry systems was neither significant nor documented. Former studies always focused on improving gum arabic production or commercialization (Mallet et al., 2002; Palou Madi et al., 2010; Harmand et al., 2012; Mujawamariya et al., 2013; Abib et al., 2013). Little works had concerned soil fertility restoration at the

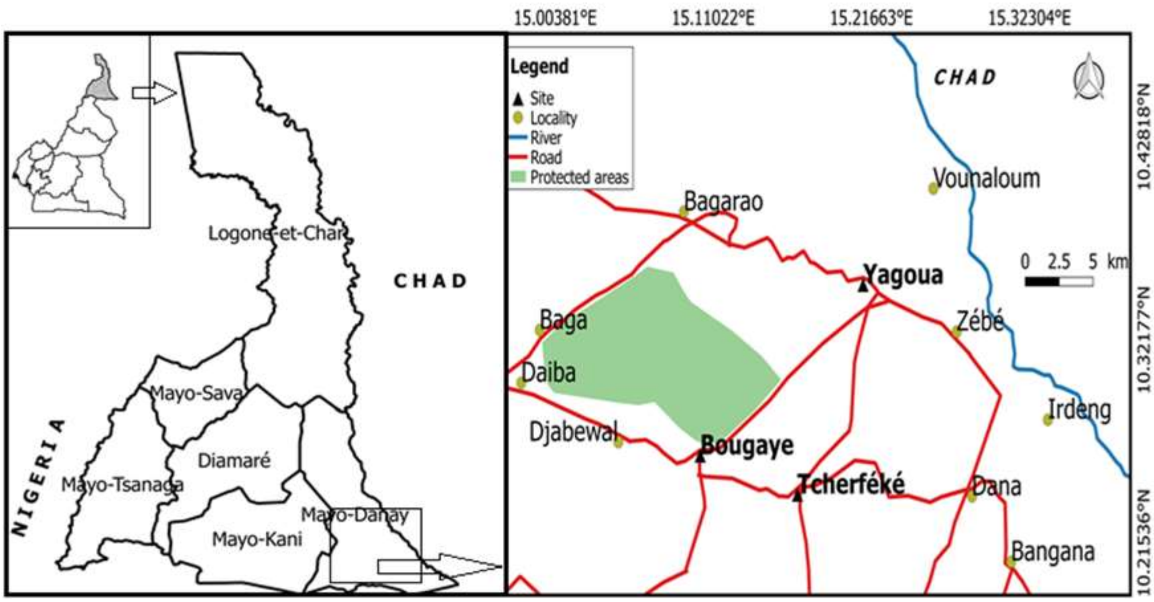

Figure 1. Location of the studied area.

lowest possible cost through their integration in agroforestry systems (Abib et al., 2013; Mujawamariya et al., 2013). So, studies on the conversion of these plantations or cropping these plantations were scarcely approached as well as assessment of soil fertility improvement potentiality (Kissi, 2011). This paper (1) determines the influence of *A. senegal* fallow duration on soil properties; (2) determines the effect of conversion form on sorghum and cowpea production and (3) assesses and compares sorghum and cowpea production of fallowed land to continuous cropping without *A. senegal*.

MATERIALS AND METHODS

Study area

The study was conducted in Northern Cameroon especially in Mayo Danay Division. The experiment was carried out in *A. senegal* plantations located in three sites, Yagoua, Bougaye and Tcherfeke (Figure 1). The main soil groups in studied sites are sandy deep soil developed on dunes sands classified as ferruginous and isolated lowland vertisols (Brabant and Gavaud, 1985; Raunet, 2003). They are acid and display a low content in organic matter and clay which is globally less than 10% (Raunet, 2003). The climate which is tropical made of two contrasting seasons: a humid season which occurs mainly from June to September and a dry season from October to May (L'Hote, 2000). The mean annual rainfall is 800 mm and the mean annual temperature is 28°C. The natural vegetation is savannah dominated by *Guieira senegalensis*, associated to *Balanites aegyptiaca, Faidherbia albida, Tamarindus indica, Zizifus mauritiana, Annona senegalensis* and *Acacia sieberiana* (Letouzey, 1985). Besides the natural vegetation, some *A. senegal* plantations were observed. These trees were tapered at the beginning of the dry season notably around November with regard to defoliation patterns for gum production. It is a source of income for many stakeholders (Harmand et al., 2012; Abib et al., 2013). The relief is smooth with some gentle sand dunes slopes. Geological formations are sedimentary rocks represented by sand dunes deposits. Agriculture, fishing and cattle breeding are the mains activities of populations. The most cultivated crops are millet, sorghum, rice and cowpea. The populations are poor and cannot supply external inputs (fertilizers, manure) to crops cultivated in depleted sandy soils.

Experimental design

A field trial was made during 2014-2015 and 2015-2016 growing seasons. Four *A. senegal* plantations of the farmers with different ages and plant density were selected in 3 sites (Yagoua, Bougaye and Tcherfeke). In Yagoua, *A. senegal* plantation was 16 years old and planted in a 4×4 m with 4 m spacing between the trees on the planting rows. Tcherfeké plantations were 18 and 19 years old and were planted, respectively in a 5×3 m and 5×5 m densities. Bougaye plantation was 15 years old. The overall characteristics of the different plantations are shown in Table 1.

The experimental design consisted of a 2 duplicated complete block design constituted by three treatments each one with 2 replications:

(1) A continuous cropping system without *A. senegal* tree (CC),
(2) *A. senegal* plantation after clear-felling and total removing of trees (AsCb),
(3) *A. senegal* plantation after clear-felling and total removing of one row over three (AsEc).

Each block was divided into 6 plots representing the 3 treatments with replication. Each plot size was 100 m² (10×10 m). AsEc had an average 6 trees per plot, while AsCb and control had no *A. senegal* tree.

Soil sampling and analytical procedure

Soils were sampled at different points of the trials plots mainly at

Table 1. Characteristics of the studied *A. senegal* plantations.

Site	Longitude and latitude	Altitude (m)	Soil type	Textural class	Plantation age (years)	Tree density (m)
Bougaye	10° 14’ 941’’ N; 15° 06’ 661’’ E	327	Ferruginous	Sandy	15	5×5
Yagoua	10° 19’ 584’’ N ; 15° 12' 994’’ E	336	Ferruginous	Sandy	16	4×4
Tcherfeké	10° 14’ 527’’ N; 15° 11’ 045’’ E	342	Ferruginous	Sandy	18	5×3
					19	5×5

topsoil (0 to 20 cm) and subsoil (20 to 40 cm) before tillage. In every site, a composite soil sample was obtained by mixing and quartered all samples collected at plots from *A. senegal* plantation. The same procedure was applied to the continuous cropped soils (control). Samples were air-dried and passed through a 2 mm sieve before analyses at the Institute of Agricultural Research for Development (IRAD) soils and plant laboratory at Yaoundé. Particle size distribution was determined by the pipette method following dispersion with sodium hexametaphosphate. Soil pH was measured in water and in KCl with pH meter equipped with a glass electrode in 1:2.5 soil-water suspensions. The soil organic carbon (OC) was measured by the wet oxidation method (Walkley and Black, 1934). The percentage of organic matter was calculated by multiplying the organic carbon values by the factor 1.72 in cropped soil and by the factor 2 in fallow soil. Total nitrogen was measured by the Kjeldahl method. Available phosphorus was determined by Bray II method. Exchangeable cations (Ca^{++}, Mg^{++}, K^+ and Na^+) were determined by Atomic Absorption Spectroscopy after extraction by ammonium acetate (CH_3COONH_4) using percolation method at pH 7 and cation exchange capacity (CEC) was determined using the sodium saturation method.

Plant materials and data recording

Plant materials were rainfed sorghum (*Sorghum bicolor*) and cowpea (*Vigna unguiculata*) which are among the most important cereals and leguminous cultivated in North Cameroon and are considered as the main foods crop. Sorghum seed (*Zouaye* variety) and cowpea seed (*Lori* variety) were obtained at IRAD and sown at the spacing of 80 × 40 cm as recommended for the agro ecological zone. The seeds rates were 5 in each hole and plants were thinned to 2 plants 2 weeks later. A micro dose (4 g) of fertilizer (NPK, 20 10 10) was added in each hole of plant of replicated treatments. Data were collected only from the central rows of each plot, discarding the four marginal rows. Sorghum was grown for the first year (2015) of conversion and replaced by the cowpea in the second growing season (2016). Sorghum recorded data include stem height at 15, 35 and 75 days after sorghum lift (DAL) and yield by hectare for each treatment. Concerning cowpea, plants height, collar diameter, the number of ramifications and the number of matured pods mainly at the flowering and harvest stages were collected. During the trial, farmers which had *A. senegal* plantations or practice tree tapping were invited in every site to compare and appreciate growth and yield crops at different treatments especially at flowering and harvest time. Farmers were also called to appreciate soil restoration in the fallowed plantations.

RESULTS AND DISCUSSION

Soils physicochemical properties

Results showed that the studied soils have high proportion in sand (up to 88.55%) and a slight amount of fines elements which were globally less than 10% in topsoil (Table 2). This revealed a sandy texture grade of studied soils at surface horizon as mentioned by many researchers (Brabant and Gavaud, 1985; Raunet, 2003). It is also noted an increase of clay content from the topsoil to subsoil while an opposite trend was observed with sand content. This suggests that topsoil was eroded and reflects vertical washing. In the three sites, clay contents were similar between continuous cropping and *A. senegal* fallow. Soils from continuous cropping and from *A. senegal* fallow were not too different. This means that fallowing with *A. senegal* had little effect on soil texture. However, intercropping was recognized to protect soil from erosion and in this order, soils under this system may be more clayey than those under pure annual crop (El Tahir et al., 2009). This is because fine particles (clay and silt) are more susceptible to erosion and especially when cropped.

Soil chemical properties varied widely in different soils samples (Table 3). As noted in Table 3, pH H_2O was higher than pH KCl in all samples. According to Kasongo et al. (2009), a net negative charge is suggested. A decrease of pH values with depth was noted in all studied soils samples. Based to the pH values (H_2O and KCl) which were totally less than 6, these soils are strongly acidic. In *A. senegal* plantations, pH was relatively higher than in continuous cropping. Similarly to pH pattern, H^+ amount decreases according to depth with null values in topsoil from fallowed lands. This highlights a contribution of *A. senegal* tree in soils acidity reduction. This result is different from those published by Kasongo et al. (2009) which stated that the *Acacia auriculiformis* tree induces a clear acidification of topsoil. However, trees globally have potentiality to reduce soil acidity (Berhe and Retta, 2015).

Available phosphorus ranged between 0.207 and 13.746 $mgkg^{-1}$ and almost concentrated in topsoil while in subsoil, it was less than 1 $mgkg^{-1}$. Higher values were observed in *A. senegal* fallows (13.746 $mgkg^{-1}$ in Yagoua, 20.74 $mgkg^{-1}$ in Bougaye and 8.173 $mgkg^{-1}$ in Tcherfeke). The oldest fallow was not characterized by the highest amount of available phosphorus. This suggests that fallow duration did not influence phosphorus accumulation in soils under *A. senegal.* Palm (1995) reported that the pruning of trees species provides sufficient nutrients to meet crop demand except phosphorus. Soil organic

Table 2. Particles size distribution of sampled soils.

Soil depth	Topsoil (0-20cm)						Subsoil (20-40cm)					
	CCB	CCY	CCT	AF15	AF16	AF18	CCB	CCY	CCT	AF15	AF16	AF18
Clay	9.6	10.02	6.98	10.4	9.81	6.82	13.5	13.77	9.71	13.5	17.60	4.54
Fine silt	1.7	2.43	2.88	1.5	1.11	2.43	2.7	2.64	1.67	2.2	1.62	2.77
Coarse silt	9.1	2.73	6.24	6.6	3.10	5.74	7.9	3.19	4.76	5.9	3.49	5.80
Fine sand	61.6	68.81	72.30	56	73.01	73.01	56.3	65.36	70.19	53.4	66.89	74.19
Coarse sand	18	15.61	11.17	25.5	15.54	11.87	19.62	14.86	13.52	25	10.30	12.48

CCB: Continuous cropping system (control) in Bougaye; CCY: continuous cropping system in Yagoua; CCT: continuous cropping system in Tcherfeke; AF15: 15 years old *A. senegal* plantation; AF16: 16 years old *A. senegal* plantation; AF18: 18 years old *A. senegal* plantation.

Table 3. Soils chemical properties.

Parameter	Topsoil (0-20cm)						Subsoil (20-40cm)					
	Bougaye		Yagoua		Tcherfeké		Bougaye		Yagoua		Tcherfeké	
	CC	AF15	CC	AF16	CC	AF18	CC	AF15	CC	AF16	CC	AF18
pH H_2O	6.190	6.590	4.570	4.960	4.420	4.800	5.640	5.890	4.700	4.720	4.530	4.650
pH KCl	4.570	5.520	4.040	4.150	3.970	4.370	3.820	4.400	3.910	3.950	3.940	3.920
H^+	-	-	0.500	-	0.600	-	-	-	1.210	0.100	0.900	0.900
Pav $mgkg^{-1}$	9.066	20.740	3.311	8.173	3.927	13.746	5.150	7.398	0.207	0.518	0.310	2.687
OM gkg^{-1}	2.574	15.466	8.779	15.770	8.530	14.504	1.436	3.342	8.555	8.968	10.385	8.624
N tot gkg^{-1}	0.491	0.802	0.749	1.006	0.701	0.926	0.233	0.432	0.574	0.632	0.597	0.570
Ca^{++} $cmolkg^{-1}$	1.138	2.657	0.103	1.978	-	1.539	2.008	1.994	0.351	0.056	-	0.054
Mg^{++} $cmolkg^{-1}$	0.487	0.785	0.032	0.546	-	0.209	0.705	0.701	-	0.001	-	-
K^+ $cmolkg^{-1}$	1.856	3.420	0.155	0.517	0.066	0.221	1.928	2.152	0.113	0.178	0.012	0.078
Na^+ $cmolkg^{-1}$	1.369	-	0.027	0.018	0.011	0.012	-	1.018	0.026	0.027	0.006	0.018
CEC $cmolkg^{-1}$	1.247	2.825	7.682	6.628	6.120	7.087	2.993	3.514	5.734	8.959	7.655	4.018

CC: Continuous cropping system; AF15: 15 years old *A. senegal* plantation; AF16: 16 years old *A. senegal* plantation; AF18: 18 years old *A. senegal* plantation.

matter (SOM) varied between 8.530 and 15.770 $mgkg^{-1}$ with higher values in topsoil of fallowed plots. In continuous cropping soils, SOM was situated around 8 $mgkg^{-1}$ while in *A. senegal* fallow, these values reached 15 $mgkg^{-1}$ showing a positive effect of *A. senegal* tree on SOM content. The total nitrogen (N tot) which ranged between 0.570 and 1.006 $mgkg^{-1}$ follows similar trend as SOM. In subsoil, there were no significant differences. A significant and steady increase in SOM and N during *Acacia* species tree fallow were widely published (Deans et al., 1999; Kasongo et al., 2009; El Tahir et al., 2009; Mubarak et al., 2011; Berhe and Retta, 2015). The higher content in nitrogen could be linked to a direct N input from tree to soil as a consequence of leaf litter mineralization (Palm, 1995; Gaafar, 2005; Ibrahima et al., 2008; Fadl, 2010). *A.*

senegal is well known as a deciduous tree which shed their leaves during dry season (Gaafar, 2005; Harmand et al., 2012; Abib et al., 2013). The decomposition of leaf litter supplies N and organic carbon in soil inducing an increase of their levels within the soils (Gaafar, 2005; Kasongo et al., 2009; Mubarak et al., 2011; Fadl, 2010; Omar and Muhammad, 2015). Partey et al. (2011) emphasized that an addition of plant residues component to the soil plays an important role by improving soil structure, microbial activities, and nutrient status by recycling of plant nutrients. Its regulation plays an important role in poor soil in savannah from Northern Cameroon (Ibrahima et al., 2008). As all others leguminous species, *A. senegal* is recognized as a N_2-fixing tree and its ability to fix atmospheric nitrogen through their root system symbiosis with rhizobium was well documented (Isaac et al., 2011; El Atta et al., 2013; Githae et al., 2013). Furthermore, N fixed by *Acacia* is released into the soil through litter fall and root decay (El Atta et al., 2013). As expected, CEC was globally low in studied soils (less than 9 $cmolkg^{-1}$). This overall low CEC is in agreement with the sandy texture grade and the mineralogy dominated by kaolinite. Exchangeable bases were low and mainly dominated by Ca^{++}. The highest values of Ca^{++} (2.657 $cmolkg^{-1}$) and Mg^{++} (0.785 $cmolkg^{-1}$) were observed at the *A. senegal* topsoil while the lowest obtained in continuous cropping. In subsoil from these continuous cropped lands, Ca^{++} and Mg^{++} values were not detectable. The high values of Ca^{++} and Mg^{++} in topsoil might be due to the decomposition of fallen leaves which supply exchangeable bases in soil (Palm, 1995; Kasongo et al., 2009; Hadgu et al., 2009; Partey et al., 2011).

Yield and yield components

Sorghum height at 15, 35 and 75 days after lift (DAL) according to treatments are as shown in Figure 2. The higher values were recorded in AsCb while the lesser were obtained in CC (control). At 15 days after lift, sorghum height was not too different between AsEc and AsCb although it was relatively higher in AsCb (Figure 2).

Measured cowpea growth parameters are shown in Table 4. The higher growth data were observed on *A. senegal* fallowed plots. In these plots, AsEc treatment recorded the highest cowpea performance growth. This finding means that the partial clear-felling represents the best conversion form of old plantation than the total clear-felling.

Sorghum grain and cowpea yields in hectare according to the plantation age and the conversion form are presented in Figure 3. The continuous cropping system without tree (control) recorded the less crops yields which are globally less than 1 tha^{-1} and 1.5 tha^{-1}, respectively for sorghum and cowpea. The age of the plantation and the conversion form were highly influencing the crops yield. In fact, the old plantation (19 years) recorded the higher yields while the young (15 years) recorded the less. *A. senegal* fixes nitrogen in the soil and accumulates it during the fallowing period as well as organic carbon, improving soil fertility and leading to higher yields (Mallet et al., 2002; Isaac et al., 2011). The partial tree clear-felling seemed to be a better form of conversion because it recorded the higher sorghum (3.59 tha^{-1}) and cowpea (2.4 tha^{-1}) yields (Figure 3). Commonly, intercropping annual crops with tree species reduces crops yields because of the competition between trees and associated crops caused by tree density and size (Rao et al., 1998; Muthuri et al., 2005; Gaafar et al., 2006; Hadgu et al., 2009; Fadl, 2010). Furthermore, trees use the water in the topsoil where annual crops are grown rather than the water below (Raddad and Luukkanen, 2007). Obtained findings implied that no competition existed between sorghum and cowpea with *A. senegal* tree for water, light and nutrients leading to yield reduction. Furthermore, it shows that *A. senegal* trees in intercropping with sorghum or cowpea enhance their productivity. Several studies reported that the yields of intercrops in combination with pruned trees were not significantly different with their yields when grown alone (Ong et al., 2000; Droppelmann et al., 2000; Hadgu et al., 2009). This was made possible because *A. senegal* leaves area are low. This is in agreement with Dawson (1996) which stated that water use by trees is positively correlated to their leaf area. Also, the decomposition of fallen leaves and nutrient release rates of different agroforestry species are related to the quality of leaf material (Ibrahima et al., 2008; Partey et al., 2011). Muthuri et al. (2005) remarked that tree leafing phenology was also an important parameter promoting annual crops growth and yield in intercropping agroforestry system in Kenya. The high difference in yields observed between crops in fallowed plots (AsEc and AsCb) and in continuous cropped (CC) could be due in one hand to soil fertility improvement through trees litter fall and on the other hand to the microclimate created which were favorable to crops growth. In fact, *A. senegal* remaining tree (in the density of 5×10 m or 4×8 m according to studied sites) created a microclimate condition limiting water evaporation loss and fertility decline through erosion. Former studies obtained similar results (Raddad and Luukkanen, 2007). Research results concerning benefits effect of intercropping annual crops with *A. senegal* abound in literature (Nasreldin, 2004; Raddad and Luukkanen, 2007; Kissi, 2011). Further, N-deficient soils have high potential response to tree fallow (Palm, 1995; Kasongo et al., 2009; El Tahir et al., 2009). The differences observed about yields of sorghum and cowpea between AsCb and AsEc may be related to the fact that the remaining *A. senegal* trees continue to supply nutrients within the soil through litter fall without competing with associated crops. In addition, conversion of old plantations is associated with nutrients content

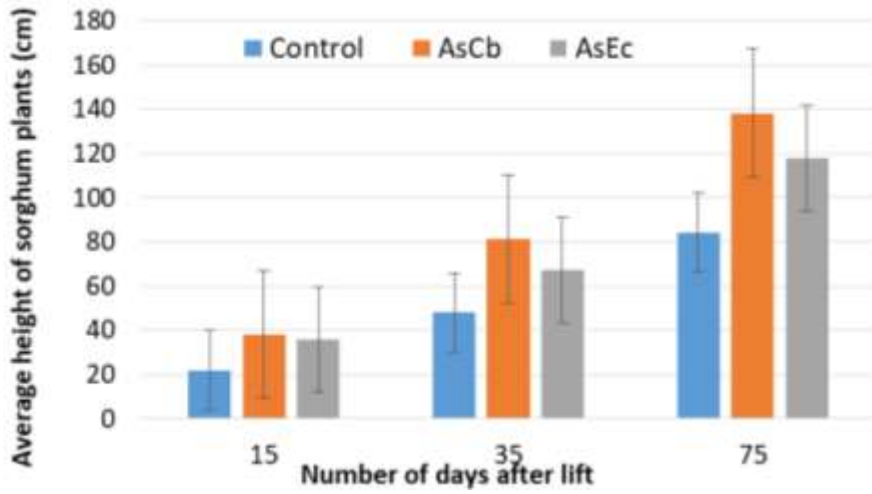

Figure 2. Average height of sorghum according treatments.

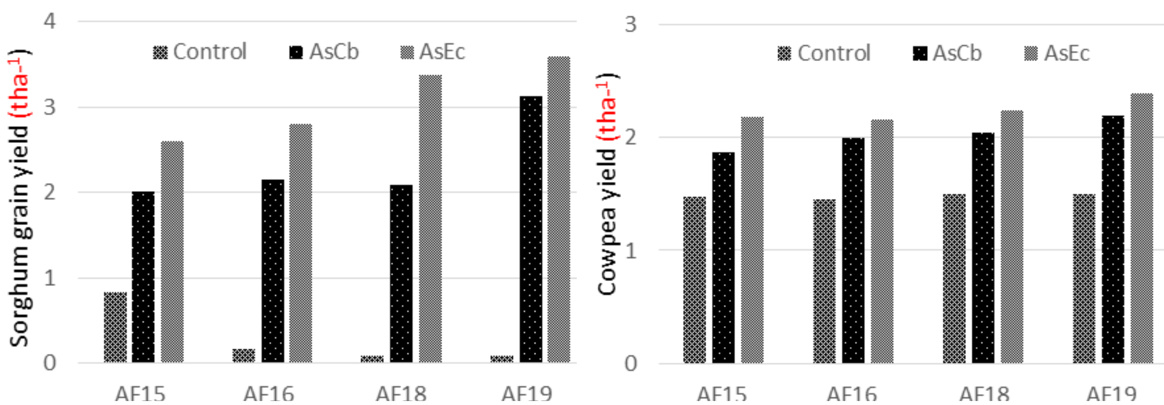

Figure 3. Sorghum grain (a) and cowpea (b) yields according to plantation age.

decrease (El Tahir et al., 2009). These findings were benefit to farmers because intercropping sorghum with *A. senegal* enhances gum arabic production (Gaafar et al., 2006).

Comparing differences between yields of sorghum and cowpea from fallowed lands to continuous cropped systems, it was remarked that the difference was not higher with cowpea. This suggests that cowpea was not significantly affected by N-soil deficiency and less sensitive to soil poverty. Cowpea is also a leguminous capable like *A. senegal* to fix and recycle atmospheric N into the soil via their active root noodles. This is why no fertilizers were provided to this crop by farmers in North Cameroon.

Farmer’s perception of the conversion approaches and soil restoration

In Northern Cameroon savannas, farmers easily distinguish fertile soils from degraded one through indigenous knowledge (Ibrahima et al., 2007). The *Massa* people (dominant ethnic group of the studied area) globally refer to physical and biological indicators (Kossoumna Liba’a, 2007). During field visits, they easily identified the difference between crops growth between fallowed and continuous cropping plots. Another aspect that retained the attention of the visitors was the soil colors in surface horizons. For instance, the relative dark color of fallowed lands as compared to continuous cropping was interpreted by farmers as a sign of fertility recovery and abundance of organic matter. The soil black color and the presence of earthworms were considered as best indicators of soil fertility (Kossoumna Liba’a, 2007; Ibrahima et al., 2007). The farmers nourished an intention to adopt the partial clear-felling process during plantation conversion in cropping fields. Furthermore, they considered wood collected after cutting down or pruned trees as another benefits in this part of the country where *A. senegal* plantations were important sources of firewood. The fruits and leaves constitute a

Table 4. Effect of the *A. senegal* plantation conversion form on cowpea growth parameters (means + standard deviation) at flowering (FS) and harvest (HS) stages.

Treatment	Leaves number at FS	Leaves number at HS	Plants height at FS (cm)	Plants height at HS (cm)	Collar diameter at FS (cm)	Collar diameter at HS (cm)	Plants ramification number at HS	Number of pods by plant
CC	28.155±9.555	14.077±4.777	32.575±13.245	30.77±5.570	6.83±1.505	7.22±1.225	3.04±1.370	10.07±3.845
AsEc	31.080±12.935	27.525±12.650	39.745±13.580	37.36±8.095	7.85±1.610	7.66±1.665	3.93±1.395	10.40±4.810
AsCb	29.545±11.840	26.840±12.085	36.645±13.065	35.65±6.055	7.51±1.380	6.81±1.570	3.06±1.250	10.24±4.735

fodder appreciated by animals. However, the problem of less gum production and the lack of a formal market were considered as major constraints to promote new plantations. The lack of appropriate equipment for gum collection and tree management (pruning) was another constraint to be considered. Similar results were observed in Central and West Africa (Palou Madi et al., 2010; Mujawamariya et al., 2013). The application of ethephon in semi-arid North Cameroon when tapping trees is a way for enhancing gum production (Abib et al., 2013). It was also reported that the time of tapping as well as it intensity and tapping methods strongly influence gum yield by plant (Adam et al., 2009; Harmand et al., 2012; Abib et al., 2013). The needs of farmer's training about this new technology and the organization of the sector were real in order to sustain existed plantations and promote the new implementations. In North Cameroon, tapping is generally manual and traditional while gum collection is made mainly by women and children (Palou Madi et al., 2010; Abib et al., 2013). The rural development agencies have to redefine the speech when vulgarizing *A. senegal* plantations.

Conclusion

This study was focused on the conversion of old *A. senegal* plantation in order to determine their suitability, to restore degraded sandy soils and sustain crop productivity. Obtained results can be summarized as:

(1) *A. senegal* planting fallow restores sandy soil fertility and sustain crop productivity;
(2) The higher is the fallowing period, the more soil fertility is improved and the higher is the crops yields;
(3) The best form of old plantation conversion is the partial clear-felling of trees because it recorded higher sorghum and cowpea yields;
(4) The total clear felling process has to be forbidden, but the partial clear-felling is recommended.

The global findings indicated that fallowing with *A. senegal* can restore sandy degraded soils and therefore constitutes a suitable agroforestry system that may sustain annual crops. Further studies have to be done in order to determine the real tree density to be left when converting and intercropping with annual crops.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Agence Française de Developpement (AFD) through the project 10 of their program C2D/PAR. They are also grateful to the farmers of the studied sites for their whole involvement in the project and the information they provided about plantations and indigenous knowledge concerning soil fertility. Dr. Nanche Billa Robert of the University of Maroua is gratefully acknowledged for English editing. The comments of anonymous reviewers were highly appreciated.

REFERENCES

Abib FC, Ntoupka M, Peltier R, Harmand JM, Thaler P (2013). Ethephon: a tool to boost gum Arabic production from *Acacia senegal* and to enhance gummosis processes. Agroforestry Systems 87:427- 438.
Adam IM, Ballal MEM, Fadl KEM (2009). Effect of tapping direction in relation to sun light on gum arabic *Acacia senegal* (L.) Willd. yields in North Kordofan State, Sudan. Forests, Trees and Livelihoods 19:1-7.
Basga SD, Nguetnkam JP (2015). Fertilizing effect of swelling clay materials on the growth and yield of bean "*Phaseolus vulgaris*'' on the sandy ferruginous soils from Mafa Tchéboa (North Cameroun, Central Africa). International Journal of Plant and Soil Science 5(1):10-24.
Brabant P, Gavaud M (1985). Soils and land resources of North Cameroon (North and Far North provinces). Paris, ORSTOM-MESRES 369 p.
Cetin M (2016). Changes in the amount of chlorophyll in some plants of landscape studies. Kastamonu University Journal of Forestry Faculty 16(1):239-245.
Cetin M, Sevik H, Isınkaralar K (2017). Changes in the particulate matter and CO2 concentrations based on the time and weather conditions: the case of Kastamonu. Oxidation Communications 40(1-2I):477-485.
Cetin M, Sevik H, Yigit N (2018). Climate type-related changes in the leaf micromorphological characters of certain

landscape plants. Environmental Monitoring and Assessment 190:404.

Cetin M (2015). Determining the bioclimatic comfort in Kastamonu City. Environmental Monitoring and Assessment 187(10):640-640

Dawson TE (1996). Determining water use by trees and forests from isotopic, energy balance and transpiration analyses: the roles of tree size and hydraulic lift. Tree Physiology 16:263-272.

Deans JD, Diagne O, Lindley DK, Diones M, Parkinson JA (1999). Nutrient and organic matter accumulation in *Acacia senegal* fallows over 18 years. Forest Ecology and Management 124:153-167.

El Atta H, Aref I, Ahmed A (2013). Effect of *Acacia spp*. on soil properties in the highlands of Saudi Arabia. Life Science Journal 10(4):100-105.

El Tahir BA, Ahmed DM, Ardo J, Gaafar MA, Salih AA (2009). Changes in soil properties following conversion of *Acacia senegal* plantation to other land management systems in North Kordofan State, Sudan. Journal of Arid Environment 73:499-505.

Fadl KM (2010). Growth and yield of groundnut, sesame and roselle in an *Acacia senegal* agroforestry system in North Kordofan, Sudan. Journal of Agriculture and Rural Development in the Tropics and Subtropics 111(1):35-40.

Gaafar AM, Salih AA, Luukkanen O, Fadl EMA, Kaarakka V (2006). Improving the traditional *Acacia senegal*-crop system in Sudan: the effect of tree density on water use, gum production and crop yields. Agroforestry Systems 66:1-11.

Gaafar MA (2005). Improvement of traditional *Acacia senegal* agroforestry: Ecophysiological characteristics as indicators for tree-crop interactions on sandy soil in western Sudan. Ph.D thesis, University of Helsinki 100 p.

Githae EW, Gachene CKK, Njoka JT, Omondi SF (2013). Nitrogen fixation by natural populations of *Acacia senegal* in the dry lands of Kenya using ^{15}N natural abundance. Arid Land Research and Management 27:327-336.

Hadgu MK, Lammert K, Rossing WAH, Van Bruggen AHC (2009). Assessing the effect of *Faidherbia albida* based land use systems on barley yield at field and regional scale in the highlands of Tigray, Northern Ethiopia. Food Security 1:337-350.

Harmand JM, Ntoupka M, Mathieu B, Njiti CF, Tapsou JM, Bois JC, Thaler P, Peltier R (2012). Gum Arabic production in *Acacia senegal* plantations in the sudanian zone of Cameroon: Effects of climate, soil, tapping date and tree provenance. Bois et Forêts des Tropiques 311(1):22-53.

Ibrahima A, Biyanzi P, Halima M (2008). Changes in organic compounds during leaf litter leaching: laboratory experiment on eight plant species of the Sudano-guinea savannas of Ngaounderé, Cameroon. iForest 1:27-33.

Ibrahima A, Nguetnkam JP, Pabame P, Tchimbi B, Guidawa G (2007). Soil degradation in the sudanno-guinea savannas of Mbe, Cameroon: farmer's perception, indicators and soil fertility management strategies. Research Journal of Agriculture and Biological Sciences 3(6):907-916.

Isaac ME, Harmand JM, Lesueur D, Lelon J (2011). Tree age and soil phosphorus conditions influence N_2-fixation rates and soil N dynamics in natural populations of *Acacia senegal*. Forest Ecology and Management 261:582-588.

Kasongo RK, Van Ranst E, Verdoodt A, Kanyankagote P, Baert G (2009). Impact of *Acacia auriculiformis* on the chemical fertility on sandy soils on the Batéké plateau, D.R. Congo. Soil Use and Management 25:21-27.

Kissi AO (2011). Re-cultivation of *Acacia senegal* enriched fallow land in northern Cameroon: forestry and agricultural production, and farmers' perceptions. Master thesis in Sciences and Technologies, AgroParisTech 121 p.

Kossoumna Liba'a N (2007). Farmer's perception of soil fertility management to Massa people in North Cameroon. In proceedings of JSIRAUF, Hanoi, 6-9 november 2007.

L'hote Y (2000). Climatology. In : Atlas of far North Cameroon. Eds. Seignobos C and Iyebi-Mandjek O, IRD. MINREST, Paris pp. 27-33.

Letouzey R (1985). Explanatory note of the Phytogeographic map of Cameroon at 1/500 000. Sahelian and Soudanian domains 25 p.

Mallet B, Besse F, Gautier D, Muller D, Bouba N, Njiti C (2002). Needs for new researches on gum trees in Central Africa Savannah Region. *In*: Jamin J.Y., Seiny Boukar L., Floret C. (Ed.). Savanes africaines : des espaces en mutation, des acteurs face à de nouveaux défis. Garoua, Cameroon, May, 27-31, 2002. Montpellier, France.

Mubarak AR, Abdalla MH, Nortcliff S (2011). Millet (*Pennisetum typhoides*) yield and selected soil attributes as influenced by some trees types of the semi-arid tropics of Sudan. Journal of Arid Environment pp. 1-7.

Mujawamariya G, Palou Madi O, Zoubeirou AM, Sene A, Maisharou A, D'Haese M (2013). Common challenges in gum Arabic production and commercialization in West Africa: a comparative study of Cameroon, Niger and Senegal. International Forestry Review 15(2):182-199.

Muthuri CW, Ong CK, Black CR, Ngumi BW, Mati BM (2005). Tree and crop productivity in Grevillea, Alnus and Paulownia-based agroforestry systems in semi-arid Kenya. Forest Ecology and Management 122:23-39.

Nasreldin MA (2004). The effect of spacing of hashab (*Acacia senegal*, (L.) Wild) plantation on yield of some traditionnal field crops in southern Darfur. Ph.D thesis, University of Khartoum, Sudan.

Omar G, Muhammad I (2015). A comparative study of soil physico-chemical properties under *Acacia senegal* in three different plantations in Maifari, Jigawa state, Nigeria. *Bayero* Journal of Pure and Applied Sciences 8(2):111-116.

Palm CA (1995). Contribution of agroforestry trees to nutrient requirements of intercropped plants. Agroforestry Systems 30:105-124.

Palou Madi O, Peltier R, Balarabe O, Ntoupka M, Sibelet N (2010). Should North Cameroon's Acacia plantations be abandoned or extended? It all depends on development of the arabic gum market chain. Bois et Forêts des Tropiques 306(4):57-68.

Partey ST, Quashie-Sam SJ, Thevathasan NV, Gordon AM (2011). Decomposition and nutrient release patterns of the leaf biomass of the wild sunflower (*Tithonia diversifolia*): a comparative study with four leguminous agroforestry systems. Agroforestry Systems 81:123-134.

Raddad EY, Luukkanen O (2007). The influence of different *Acacia senegal* agroforestry systems on soil water and crop yields in clay soils of the Blue Nile region, Sudan. Agricultural Water Management 87:61-72.

Rao MR, Nair PKR, Ong CK (1998). Biophysical interactions in tropical agroforestry systems. Agroforestry Systems 38:3-50.

Raunet M (2003). Some Key Morpho-Pedological Aspects of North Cameroon of Use to Agronomists, Montpellier: CIRAD 24 p.

Sevik H, Cetin M and Yigit N, Guney K, Belkayali N (2018). The effect of some indoor ornamental plants on CO_2 levels during the day. Polish Journal of Environmental Studies 27(2):1-6.

Turkyilmaz A, Sevik H, Cetin M, Ahmaida Saleh EA (2018). Changes in Heavy Metal Accumulation Depending on Traffic Density in Some Landscape Plants. Polish Journal of Environmental Studies 27(5):2277-2284.

Walkley A, Black IA (1934). Determination of organic matter in soil. Soil Science 37:549-556.

Yigit N, Sevik H, Cetin M, Kaya N (2016). Determination of the effect of drought stress on the seed germination in some plant species, Intech Open, Chapter 3, Water Stress in Plants, Eds: Ismail Md. Mofizur Rahman, Zinnat Ara Begum, Hiroshi Hasegawa, ISBN:978-953-51-2621-8, pp. 43-62.

Vol. 13(40), pp. 2163-2172, 4 October, 2018
DOI: 10.5897/AJAR2018.13332
Article Number: 470743258727
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Intra- and inter-specific interference between slender amaranth and red pepper

Izabela Orzari, Matheus Falcai Barbasso, Bruno Vinícius Rodrigues Silva, Isa Marcela Rodrigues Furlini Braga and Pedro Luis da Costa Aguiar Alves*

Laboratório de Plantas Daninhas (LAPDA), Depto. de Biologia Aplicada – FCAV/UNESP, CEP 14884-900, Jaboticabal, SP, Brazil.

Received 16 June, 2018; Accepted 21 August, 2018

Competition interferes with the growth and development of plants, whether of the same species or not. The aim of this work is to evaluate the intra-specific interference of slender amaranth plants (*Amaranthus viridis*) at different densities and distances, and in an inter-specific interaction with red pepper (*Capsicum baccatum* var. *pendulum*). The experiment was conducted in four replications and in a randomized complete block design using a factorial scheme of 2x4 + 2 controls, which represent two distances (5 and 10 cm) between the weeds and pepper (transplanted in the center of the box) and 4 densities of slender amaranth (3, 6, 9, and 12 plants m^{-2}). Cement-asbestos boxes with a capacity of 90 L were filled with clayey soils (Red Dark Latosol). The pepper seedlings were transferred to the boxes after having three fully expanded leaves, whereas the slender amaranth seedlings were transplanted when they were 5 cm in height. Growth and yield characteristics of the crop and weeds were evaluated. As a result, it was observed that as the density increased, both species suffered more damage; the red pepper showed etiolation and reduced production, and the weeds showed a reduction in growth parameters. The distance between the plants did not interfere with their intra- and inter-specific coexistence.

Key words: *Capsicum baccatum, Amaranthus viridis,* density, competition, weed.

INTRODUCTION

Red pepper (*Capsicum baccatum* L.), belonging to the family Solanaceae, is a shrubby plant, and cultivated as an annual plant (Filgueira, 2008); it has indeterminate growth, continuous flowering and fruiting, and bears fruits at different stages of maturation (Pereira et al., 2014). It is produced mainly in family farms, where value can be added to the product, and in integration systems between the farmer and the industry (Rufino and Penteado, 2006).

*Corresponding author. E-mail: plalves@fcav.unesp.br. Tel: +551632097200.

The presence of weeds is one of the main factors that reduce the yield and quality of pepper fruits (Eure and Culpepperhtps, 2017). Among the plants found in the areas cultivated with vegetables, species of the genus *Amaranthus*, popularly known in Brazil as "caruru" (amaranth), stand out. Belonging to the family *Amaranthaceae*, this genus has about 60 plant species, some being cultivated and others growing as weeds: *A. viridis* (slender amaranth), *A. spinosus* (spiny amaranth), *A. retroflexus* (giant amaranth), and *A. hybridus* (purple amaranth) (Lorenzi, 2000). These plants can produce up to 235000 seeds (Lorenzi, 2000). This shows the importance of the management of these plants in agricultural areas to avoid competition with crops and to minimize the effects on the seed bank, especially considering the difficulty of their control (Robinson et al., 2008).

Amaranthus is one of the major genera of weeds infesting peppers in Mexico and Canada (Amador-Ramirez, 2002; Robinson et al., 2008). It is also one of the most important weeds for various bean cropping areas (Barroso et al., 2012) and vegetable cultivation sites (Marcolini et al., 2010). Barroso et al. (2012), in studies of inter-specific competition between beans and *A. viridis*, reported that the presence of weed decreased yield by 26%, negatively affecting the crop.

Knowledge of weed interference on crops is important in management decision making. The degree of weed interference on crops can be influenced by factors related to the weed community and the crop itself, such as the species present, the distribution, and the density (Barroso et al., 2012; Marcolini et al., 2010).

Competition is the main interference of one plant over another (Pitelli, 2014), and occurs when one or more of the essential resources for the growth and development of a plant becomes limited to meet the number of individuals present at the site (Rigoli et al., 2008). In this context, the density (number of individuals) and the spatial arrangement (plant spacing) of plants are factors that directly interfere with the relationship between plants (Bezerra et al., 2014). According to Carvalho and Christoffoleti (2008), high density is a more important factor for competition than the intrinsic competitive ability of the species. Thus, it is important that plants can remain under adequate conditions and in environments with available resources, so that competition is not established.

Most studies on the competition between plants are focused on comparisons between weeds and cultivated plants (inter-specific competition), seeking to quantify the effect on yield (Christoffoleti and Victoria Filho, 1996). Notwithstanding, intra-specific competition, that is, between plants of the same species, is also of great importance, since the plants have the same vegetative habit and the same needs of resources. Crops such as sunflower (Bezerra et al., 2014) and beans (Carvalho and Christoffoleti, 2008; Barroso et al., 2012) showed a decrease in yield when under intra-specific competition. However, it should be borne in mind that species agronomically considered as weeds may also suffer from intra-specific competition under conditions where resources are limited.

The hypothesis of this work is that amaranth can interfere with pepper and this interference is dependent on the density and distance of the weed crop, which may also undergo density-dependent intra-specific interference. Thus, the aim of this study is to evaluate the intra-specific interference of slender amaranth (*Amaranthus viridis*) plants at different densities and distances, and in an inter-specific interaction with red pepper (*C. baccatum*).

MATERIALS AND METHODS

Two experiments were carried out. The first consisted of the coexistence of *A. viridis* (slender amaranth) and *C. baccatum*; in the second, *A. viridis* plants remained in intra-specific competition.

The seedlings of *A. viridis* and *C. baccatum* were produced in 128-cell trays filled with commercial substrate. The plants for both experiments were transplanted to the experimental unit on the same day, on August 3, 2015, according to each treatment. The pepper showed three fully expanded leaves, and the weeds were approximately 5 cm high. The transplantation was done in cement boxes with a capacity of 90.0 L, and dimensions of 60x60x25 cm, filled with clayey soil (Dark Red Latosol). Fertilizations were performed according to the results of the soil analysis (Table 1), based on Bulletin 100 (Van Raij et al., 1997);h the first fertilization was done 10 days before the transplant of the plants, and the cover fertilization 30 days after transplantation (DAT). Irrigation was done daily, and the insecticide Deltamethrin (concentration of 25 g L^{-1}), with commercial product Decis (BAYER) was applied as recommended by the manufacturer and when necessary for crop protection.

The inter-specific experiment was performed in a randomized complete block design, with a factorial scheme of 2x4 + 2 controls, representing the two distances (5 and 10 cm) between the weeds and the pepper (transplanted in the center of the box), and the four densities of slender amaranth (1, 2, 3, and 4 plants box^{-1}, representing 3, 6, 9, and 12 plants m^{-2}, respectively). A pepper control was maintained without the presence of weeds, and a slender amaranth control without any crop.

For the intra-specific experiment, only the factorial scheme was modified to 2x3 + control, representing the two distances from the center of the box (5 and 10 cm) and the three densities (2, 3, and 4 plants box^{-1}, corresponding to 6, 9 and 12 plants m^{-2}, respectively). For the control treatment, there was only one plant per box (3 plants m^{-2}).

The measurements of height (from the base to the beginning of the branch) and diameter at the stem base of the plants were made at 15, 30, 45, 60, and 75 DAT for *A. viridis* plants (leaves and inflorescence at the beginning of senescence), and at 15, 30, 45, 60, 75, 90, and 105 DAT for pepper (final ripening period). At the end of each experimental period, the following were evaluated: leaf area (LICOR LI3000), dry mass of leaves, and dry mass of stems (after drying in a greenhouse with forced air circulation at 65°C for three days). For the crop, the number of fruits was also counted,

Table 1. Result of the chemical analysis of a soil sample used as substrate.

Crop	pH ($CaCl_2$)	O.M. (g dm^{-3})	P resin (mg dm^{-3})	K	Ca	Mg	H+Al	SB	CEC	V (%)
				Mmolc dm^{-3}						
Pepper	5.8	26	140	2.0	48	11	19	60.5	79.0	77
Amaranth	6.2	31	111	1.8	58	13	12	72.6	84.5	86

Source: Laboratory Athenas Consultoria Agrícola - Jaboticabal/SP.

and, after harvest, the fresh and dry mass of fruits and the dry mass of seeds were evaluated.

The data were submitted to analysis of variance (ANOVA) and the means were analyzed by the Tukey test (p> 0.05).

RESULTS AND DISCUSSION

Inter-specific interference between pepper and *A. viridis*

Regarding the coexistence of pepper with *A. viridis*, a significant difference was observed in plant height from 60 days after transplantation (DAT) in relation to weed distance (Table 2). This effect was more accentuated by the distance the plants occupy, as it can be observed that the pepper showed a higher height at 5 cm from the weeds, mainly at the highest density, of 12 plants m^{-2}. Notwithstanding, this result does not imply that the plant had an effective growth; the crop may have undergone light competition with weeds, which has caused etiolation.

Etiolation is a response of plants to low ambient light (Franco and Dillenburgl, 2007), in which the plant starts to invest more energy to increase stem growth (increase in length) in search of light (Dousseaun et al., 2007). However, this growth does not provide an increase in the dry mass of the plant, that is, this energy expenditure is not being well used and this may cause changes in plant metabolism (Constantin et al., 2008; Pitelli, 2014) and losses in yield. Moreover, the plant is more fragile and susceptible to breakage and to the attack of pests and diseases, which further hinders its development and cultivation (Silva et al., 2016).

This non-effective growth of the pepper plants is also observed in the other characteristics evaluated. There is a significant relation between the factors and the control for the stem diameter of pepper, and the presence of *A. viridis* negatively interfered with this characteristic from 45 DAT, decreasing it by 40% at 105 DAT with the density of 12 plants m^{-2} (Table 3). According to Lima et al. (2008), etiolated plants do not accumulate mass and, therefore, their stem is much thinner when compared to a healthy plant without interference.

For the dry mass of stems and leaves and leaf area (Table 4), a significant difference was observed for the control in relation to the factors, and the presence of weeds, regardless of density and distance, caused a reduction in these characteristics. The reductions reached 74, 71, and 25% for the dry mass of stems and leaves and leaf area at the density of 12 plants m^{-2}, respectively. The plants with higher height did not present higher values of diameter and dry mass of stems and leaves, increasing the chances that the growth occurred as a function of the shading caused by weeds, that is, the pepper plants had etiolation. However, the leaf area was higher with 12 m^{-2} plants than in the other densities. Under low luminosity, plants tend to expand leaf size to compensate for or better use low light (Lima et al., 2008). However, this change in morphology implies other changes in the leaf, such as a decrease in leaf thickness (Benincasa, 2003), which explains the reduction of dry mass of leaves in the pepper plants, a phenomenon that Lima et al. (2008) found in *Caesalpinia ferrea* seedlings.

The interception of solar radiation by weeds, preventing the passage of light into the crop, depends on the composition, density, and distribution of these plants (Pitelli, 2014). Marcolini et al. (2010) verified that the beet crop was very sensitive to the interference imposed by *A. viridis* plants, showing a significant reduction in leaf area, number of leaves, dry mass of leaves, mean root diameter, and fresh mass of roots even at low densities of weed populations.

Based on the analysis of dry mass of leaves (Table 5), there was interaction between the factors distance and density of plants m^{-2}. Comparing the densities of slender amaranth plants for each distance, it was observed that at the distance of 5 cm, there was no significant difference between the treatments. For the distance of 10 cm, it was observed a difference between the treatments with 3 and 12 plants m^{-2}, where the first treatment resulted in a higher dry matter production, probably due to the competition for resources being lower.

For the number of fruits (Table 6), there was a significant difference for the control in relation to the factors. The presence of *A. viridis* caused a mean reduction of 68% at the densities of 3 and 6 plants m^{-2} (Table 6), and 81.5% at the other densities. It was observed that the distance of 5 cm provided higher losses for the number of fruits (Table 7) as density increased, reaching a reduction of 56%.

Table 2. Mean values of height (cm) of red pepper subjected to increasing periods of coexistence with *Amaranthus viridis* at two distances and at increasing densities.

Treatments	15 days	30 days	45 days	60 days	75 days	90 days	105 days
Distance (cm)							
5	6.82	15.16	25.28	26.53 a	27.44 a	27.72 a	27.90 a
10	7.51	15.00	23.09	23.97 b	24.56 b	24.88 b	25.03 b
Densities of *A. viridis* (plants m^{-2})							
3	7.23	15.50	23.00	23.56	24.38	24.56	24.69
6	6.68	16.06	25.38	25.94	26.88	27.19	27.19
9	7.20	14.44	23.56	25.25	25.88	26.50	26.63
12	7.56	14.31	24.81	26.25	26.88	26.94	27.38
Control	7.83	16.00	22.25	22.38	23.25	23.25	24.25
F Dist	3.16 ns	0.06 ns	3.70 ns	4.43 *	5.83 *	5.74 *	6.08*
F Dens	0.90 ns	1.85 ns	0.93 ns	0.97 ns	0.98 ns	1.01 ns	1.11 ns
F DistxDens	0.18 ns	2.84 ns	2.43 ns	2.04 ns	1.89 ns	2.04 ns	1.78 ns
F Test x Fac	1.31 ns	0.98 ns	1.29 ns	2.48 ns	2.37 ns	2.93 ns	1.61 ns
CV%	15.02	11.57	13.41	13.82	13.11	12.93	12.58

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, ns: non-significant.

Table 3. Mean values of stem diameter (cm) of red pepper subjected to competition with *A. viridis* at two distances and at increasing densities.

Treatments	15 days	30 days	45 days	60 days	75 days	90 days	105 days
Distance (cm)							
5	2.03 b	3.46	5.45	7.43	8.43	9.42	11.49
10	2.32 a	3.26	5.49	7.33	8.91	10.12	11.60
Densities of *A. viridis* (plants m^{-2})							
3	2.04	3.54	6.35 a	8.52 ab	10.43 a	11.91 a	13.68 a
6	2.22	3.67	6.08 ab	8.83 a	9.41 a	10.04 ab	11.98 ab
9	2.23	3.12	4.91 bc	6.31 bc	7.65 b	8.78 b	10.19 b
12	2.21	3.12	4.54 c	5.86 c	7.18 b	8.37 b	10.35 b
Control	2.27	4.31	7.39	9.32	12.53	14.98	16.98
F Dist	8.33**	0.47 ns	0.01 ns	0.03 ns	1.14 ns	1.32 ns	0.03 ns
F Dens	0.80 ns	0.89 ns	5.79**	7.04**	11.53**	6.94**	6.73**
F DistxDens	1.66 ns	1.53 ns	0.42 ns	2.67 ns	0.52 ns	0.94 ns	0.95 ns
F test x factorial	2.34 ns	4.34*	12.15**	5.13*	33.40**	33.00**	33.19**
CV%	12.90	24.69	18.26	21.23	13.86	16.50	14.64

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

Regarding the fresh mass of fruits (Table 7), the control significantly differed from the factors; at the distance of 5 cm, the density interfered with fruit production. The treatment with 3 plants m^{-2} was similar only to that with 6 plants m^{-2}.

Regarding the dry mass of fruits, the factors also differed from the control (Table 6). It is observed that the density had greater influence, since the greater the number of *A. viridis* plants, the smaller the dry mass of fruits. This effect is clearly observed in the unfolding of the treatments, where the reductions reach 60% at the distance of 5 cm in the second crop (Table 7).

For the dry mass of seeds (Table 6), the treatments differed from the control, and it was verified that the

Table 4. Mean values for dry mass of stems and leaves and leaf area of red pepper subjected to coexistence with *Amaranthus viridis* at two distances and at increasing densities.

Treatments	DM Stem	DM Leaves	Leaf Area
	(g $plant^{-1}$)		(cm^2 $plant^{-1}$)
Distance (cm)			
5	41.14	12.46	699.06
10	40.00	12.33	668.64
Density (plants m^{-2})			
3	54.49 a	15.52 a	676.76
6	46.58 ab	14.23 ab	694.31
9	28.66 c	9.70 b	644.75
12	32.54 bc	10.13 ab	719.57
Control	124.63	35.55	955.18
F Dist	0.10 ns	0.01 ns	0.29 ns
F Dens	11.17**	4.05*	0.31 ns
F DistxDens	0.65 ns	0.37 ns	0.26 ns
F Test x Fac	241.35**	113.35**	10.16**
CV%	20.44	27.40	22.48

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

Table 5. Unfolding of the interaction between the effects of density and distance of *Amaranthus viridis* on the dry mass of leaves of red pepper.

Density (plants m^{-2})	Dry mass of leaves (g)		
	Distance (cm)		
	5	10	F
3	6.58 Ab	11.83 Aa	10.04**
6	9.35 Aa	9.31 ABa	0.00 ns
9	6.36 Aa	8.83 ABa	2.23 ns
12	10.07 Aa	6.08 Bb	5.80*
F	2.62 ns	4.04	

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

density had a greater influence than the distance.

When plants are competing both for space and for resources in the environment, those with faster growth and greater uptake of solar radiation occupy the space faster, hindering the growth and development of the others (Pitelli, 2014). In agricultural areas, weeds are considered more competitive, since they occur at a higher density, distribution, and with greater adaptive and reproductive capacity, causing greater damage to the cultivated plant (Pitelli, 2014; Bianchi et al., 2006).

Studying the periods of interference of weeds in pepper (*C. annuum*, cv. 'Mirasol') during three years in Mexico, with *A. palmeri* as one of the main weeds, Amador-Ramirez (2002) obtained that the period previous to interference (PPI) was 2.1 weeks after transplantation, tolerating a 5% loss in total production, or 0.9 weeks considering marketable production, with total period of weed interference (TPWI) of 12.2 and 12.3 weeks, respectively. Consequently, critical periods of weed interference (CPWI) were 2.1 to 12.2 and 0.9 to 12.3

Table 6. Mean values for fresh and dry mass of fruits, number of fruits, and dry mass of seeds of red pepper subjected to coexistence with *Amaranthus viridis* at two distances and at increasing densities.

Treatments	Number of fruits	FM fruits	DM fruits	DM seeds
	(N°. plant^{-1})		(g plant^{-1})	
Distance (cm)				
5	33.06	394.31	44.92	7.90
10	32.38	380.60	40.92	6.84
Density (plants m^{-2})				
3	42.38 a	526.59 a	57.53 a	9.89
6	39.75 a	469.93 ab	48.98 ab	7.25
9	26.25 ab	299.21 bc	36.42 b	6.72
12	22.50 b	254.08 c	28.75 b	5.62
Control	129.00	1613.01	190.36	32.77
F Dist	0.03 ns	0.09 ns	0.57 ns	0.61 ns
F Dens	5.59**	8.49**	5.85**	1.80 ns
F DistxDens	4.01*	5.14**	6.56**	2.14 ns
F Test x Fac	239.12**	328.77**	343.43**	157.37**
CV%	27.04	24.34	25.30	37.46

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

Table 7. Unfolding of the interaction between the effects of density and distance of *Amaranthus viridis* on the dry mass of fruits and seeds of red pepper.

Density (plants m^{-2})	Number of fruits			Fresh mass of fruits			Dry mass of fruits		
	Distance (cm)			Distance (cm)			Distance (cm)		
	5	10	F	5	10	F	5	10	F
3	53.75 Aa	31.00 Ab	7.51*	671.81 Aa	381.37ABb	10.39**	77.19 Aa	37.88 Ab	13.73**
6	36.25ABa	43.25 Aa	0.71 ns	438.14ABa	501.73 Aa	0.50 ns	48.23ABa	49.73 Aa	0.02 ns
9	18.25 Ba	34.25 Aa	3.71 ns	264.35 Bb	395.48ABa	4.56*	23.10 Bb	49.73 Aa	6.30*
12	24.00 Ba	21.00 Aa	0.13 ns	202.94 Ba	243.81 Ba	0.05 ns	31.14 Ba	26.36 Aa	0.20 ns
F	7.15**	2.45 ns		10.87**	2.76 ns		10.18**	2.23 ns	

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

weeks, that is these would be the periods in which the crop would have to be kept free of the presence of weeds to obtain at least 95% of the estimated total and marketable fruit production, respectively. In the present study, red pepper coexisted with slender amaranth plants for 105 days after transplantation, that is, 15 weeks, and this period exceeds the critical period obtained by Amador-Ramirez (2002), thus confirming the sensitivity of the crop to weed interference. In the case of this work, it was observed that red pepper suffered with the presence of *A. viridis*, since fruit production was impaired. The higher energy expenditure that pepper plants had to correct cell growth processes and recover the loss of resources (Paulus et al., 2015), especially light, may have led to a decrease in the photosynthetic rate and a lower translocation of energy and sugars for fruit formation.

Another important factor that may have caused the low fruit production is the fact that *A. viridis* has a C_4 carbon fixation pathway (Carvalho and Christofoleti, 2008), and this photosynthetic mechanism confers several advantageous characteristics in relation to C3 plants, mainly in hot and humid environments (Paul and Elmore, 1984), which contributes to the presence of *Amaranthus*

Table 8. Mean values of stem height (cm) of *Amaranthus viridis* coexisting at two distances and at increasing densities with red pepper.

Treatments	15 days	30 days	45 days	60 days	75 days
Distance (cm)					
5	3.44	12.86	40.61	66.95	76.33
10	3.61	13.31	40.14	66.05	77.14
Density (plants m^{-2})					
3	3.31	12.31	43.25	76.63 a	91.25 a
6	3.59	12.34	40.19	67.75 a	75.75 b
9	3.26	13.83	39.06	65.79 ab	73.88 b
12	3.95	13.85	39.00	55.83 b	66.06 b
Control	4.50	12.83	48.63	85.13	91.75
F Dist	0.21 ns	0.13 ns	0.03 ns	0.10 ns	0.07 ns
F Dens	0.71 ns	0.48 ns	0.57 ns	8.68**	11.12**
F DistxDens	0.46 ns	1.20 ns	1.09 ns	1.36 ns	0.44 ns
F test x Fac	2.96 ns	0.02 ns	4.34*	18.38**	10.01**
CV%	29.27	27.33	18.08	11.95	11.41

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

species in areas of production of oil plants such as pepper.

Omazine and Silva (2016) verified that with increasing density of *A. lividus* plants, there was a significant reduction in the cumulative dry mass of *C. annuum*. There was a reduction of 80.8% in the dry mass of pepper when cultivated with only one *A. lividus* plant, and a reduction of 97.7% when the treatment consisted of four *A. lividus* plants, showing that the crop growth was hampered due to the conviviality among the species, even at a low density. In addition, the authors point out that although the greatest damage occurs at high weed densities, the species *A. lividus* is more aggressive on pepper when it is in a smaller number of individuals than at a high population rate, since the competition among plants harms their own development.

Intra- and inter-specific interference of *A. viridis*

When analyzing the height of *A viridis* plants coexisting with pepper (Table 8), it is observed that the control (a single slender amaranth plant in the experimental unit, without pepper) differed from the other treatments from 45 DAT. It was also verified that from 60 DAT, the density caused a decrease in weed height, which reached up to 28% at 12 plants m^{-2}.

The same behavior was observed in relation to the stem diameter (Table 9), in which significant differences were observed from 45 DAT between the treatments and the control. It can be verified that with the increase of the density of plants in coexistence with the pepper crop, there was a decrease in the diameter, but the distance between the plants did not show differences.

Regarding the dry mass of stems and leaves (Table 10), it was observed that the distance did not cause interference in plant growth, while the density gradually reduced the dry matter production. With 12 plants m^{-2}, the reduction in dry mass was 70 and 75% for stem and leaves, respectively, for the distances of 5 and 10 cm. The same behavior was obtained for the leaf area of the plants, with a 35% decrease in the treatment and highest density in relation to the control.

When analyzing the interaction between *C. annuum* and *A. lividus* plants, Omezine and Silva (2016) verified that the dry matter accumulation of *A. lividus* was modified according to the density and the coexisting species. The authors observed that the highest dry matter accumulation of *A. lividus* occurred in the treatment with four *A. lividus* plants associated with a single *C. annuum* plant (52.33 g/pot), while the lowest accumulation occurred in the treatment with one *A. lividus* plant growing in the presence of one *C. annuum* plant (35.77 g/pot).

When *A. viridis* was cultivated alone, that is, only under intra-specific interference, the plants showed a significant difference in plant height as a function of distance only at 30 DAT (Table 11), but density was the factor that mostly interfered with this parameter of plant growth. Notwithstanding, at 75 DAT, only the treatment with the highest number of plants differed from the control, with a 21% reduction in height. In the unfolding at 30 DAT

Table 9. Mean values of stem diameter (mm) of *Amaranthus viridis* coexisting at two distances and at increasing densities with red pepper.

Treatments	15 days	30 days	45 days	60 days	75 days
Distance (cm)					
5	2.26	5.82	9.32	10.49	14.22
10	2.37	5.88	9.17	10.47	14.22
Density (plants m^{-2})					
3	2.34	5.97	10.69 a	11.60 a	18.07 a
6	2.29	5.95	9.13 ab	10.54 ab	14.49 ab
9	2.31	5.84	8.95 ab	10.11 ab	12.58 b
12	2.32	5.60	8.22 b	9.65 b	12.05 b
Control	2.36	6.53	11.61	12.56	17.96
F Dist	1.96 ns	0.01 ns	0.09 ns	0.00 ns	0.00 ns
F Dens	0.06 ns	0.20 ns	4.14*	2.92 ns	5.94**
F DistxDens	0.72 ns	1.19 ns	1.21 ns	1.55 ns	0.40 ns
F test x Fac	0.13 ns	1.43 ns	9.58**	8.06**	5.00*
CV%	10.06	18.48	15.17	12.91	21.57

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

Table 10. Mean values for dry mass of stem and leaves and leaf area of *Amaranthus viridis* coexisting at two distances and at increasing densities with red pepper.

Treatments	DM stem (g $plant^{-1}$)	DM leaves (cm^2 $plant^{-1}$)	Leaf area (cm^2 $plant^{-1}$)
Distance (cm)			
5	81.99	27.71	343.99
10	85.48	27.81	320.65
Density (plants m^{-2})			
3	149.87 a	49.40 a	401.61 a
6	77.78 b	27.98 b	353.58 ab
9	59.83 b	18.90 c	311.11 ab
12	47.47 b	14.76 c	262.97 b
Control	159.18	59.81	406.82
F Dist	0.17 ns	0.00 ns	0.79 ns
F Dens	29.10**	62.77**	5.08**
F DistxDens	0.87 ns	0.51 ns	0.28 ns
F Test x Fac	35.08**	120.04**	3.57 ns
CV%	26.07	17.61	21.82

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

(Table 12), it is observed that when the density is 12 plants m^{-2}, the distance does not interfere with the plant response; instead, the number of competing individuals plays a key role. An important factor in the competition between plants is the availability of resources in the environment, in which the absence of a resource can cause reduction in biomass accumulation and yield (Pitelli, 2014).

As for the diameter under these conditions (Table 13), plant density interferes with plants at 45 DAT; at 75 DAT, the reductions reached up to 27.5% in the treatments with 6 and 9 plants m^{-2}, and 45% in the treatment with 12 m^{-2} plants.

Regarding the dry mass of stems and leaves and leaf

Table 11. Mean values of height (cm) of *Amaranthus viridis* coexisting at two distances and at increasing densities.

Treatments	15 days	30 days	45 days	60 days	75 days
Distance (cm)					
5	3.52	17.51 a	43.24	64.74	71.68
10	3.48	14.06 b	39.58	59.19	66.95
Density (plants m^{-2})					
6	3.13 b	15.15	44.70 a	69.97 a	78.41 a
9	3.51 ab	16.91	42.49 ab	62.25 ab	72.29 a
12	3.87 a	15.29	37.05 b	53.67 b	57.25 b
Control	3.93	15.75	44.38	69.13	72.75
F Dist	0.04 ns	5.19*	4.25 ns	1.35 ns	1.02 ns
F Dens	3.65*	0.55 ns	6.54**	3.88*	7.24**
F DistxDens	0.46 ns	0.20 ns	9.09**	0.51 ns	0.33 ns
F test x Fac	2.07 ns	0.00 ns	1.59 ns	1.28 ns	0.31 ns
CV%	15.25	23.55	10.41	18.60	16.40

Means followed by the same letter in the column do not differ from each other by the Tukey test at 5%, *: significant at 5% by the F-test, **: significant at 1% by the F-test; ns, non-significant.

area (Table 14), it was verified that the factors differed significantly from the control, and that the greatest influence in the coexistence of plants is due to density: the higher the plant density, the smaller the results obtained for the three parameters. When analyzing the lowest and the highest density (6 and 12 plants m^{-2}, respectively), the reductions were 53 and 78% for dry mass of stems; 47 and 71% for dry mass of leaves; and 21 and 45% for leaf area, respectively.

According to Omezine and Silva (2016), for the species *A. lividus*, intra-specific competition may be more important than inter-specific competition, since they verified that the accumulated dry matter of this species decreased when there was an increase in its density, in the same way as the total plot dry matter (*C. annuum* + *A. lividus*) decreased with increasing density of *A. lividus*. Magro et al. (2011), in turn, found that *Cyperus difformis* biotypes are more sensitive to coexistence with rice plants (*Oryza sativa*) than with plants of the same species, that is, inter-specific competition is more important. In contrast, for the rice crop, intra-specific competition was more important.

The results indicate that the factor density caused greater damage to the growth and development of both pepper and *A. viridis* plants, due to morphological changes in the plants of both species and a decrease in the production of pepper. The distance between plants did not prove to be a significant factor in the coexistence of plants. The increase in the density of *A. viridis*, mainly with 12 plants m^{-2}, caused a reduction in stem diameter, leaf area, and in the number and mass of pepper fruits, besides causing plant etiolation; it also led to a reduction in height, stem diameter, leaf area, and dry mass of leaves of *A. viridis*.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

REFERENCES

Amador-Ramirez MD (2002). Critical period of weed control in transplanted chilli pepper. Weed Research 42(3):20-209.

Barroso AAM, Yamauti MS, Nepomuceno MP, Alves PLCA (2012). Efeito da densidade e da distância de caruru-de-mancha e amendoim-bravo na cultura do feijoeiro. Planta Daninha 30:47-53.

Bezerra FT, Dutra AS, Bezerra MAF, Oliveira Filho AF, Barros GL (2014). Comportamento vegetativo e produtividade de girassol em função do arranjo espacial das plantas. Revista Ciência Agronômica 45:335-343.

Bianchi MA, Fleck NG, Lamego FP (2006). Proporção entre plantas de soja e plantas competidoras e as relações de interferência mútua. Ciência Rural 36(5):1380-1387.

Carvalho SJP, Christoffoleti PJ (2008). Competition of *Amaranthus* species with dry bean plants. Scientia Agricola 65(3):239-245.

Christoffoleti PJ, Victoria Filho R (1996). Efeitos da densidade e proporção de plantas de milho (*Zea mays* L.) e caruru (*Amaranthus retroflexus* L.) em competição. Planta Daninha 14:42-47.

Constantin J, Machado MH, Cavalieri SD, Oliveira Jr RS, Rios FA, Roso AC (2008). Influência do glyphosate na dessecação de capim-braquiária e sobre o desenvolvimento inicial da cultura do milho. Planta Daninha 26(3):627-636.

Dousseaun S, Alvarenga AA, Santos MO, Arantes LO (2007). Influência de diferentes condições de sombreamento sobre o crescimento de *Tapirira guianensis* Alb. Revista Brasileira de Biociências 5(2):477-479.

Eure PM, Culpepperhttps AS (2017). Bell pepper and weed response to dimethyl disulfide plus chloropicrin and herbicide systems. Weed

Technology 31(5):694-700.
Franco MAS, Dillenburgl LR (2007). Ajustes morfológicos e fisiológicos em plantas jovens de *Araucaria angustifolia* (Bertol.) em resposta ao sombreamento. Hoehnea 34:135-144.
Filgueira FAR (2008). Novo manual de olericultura: agrotecnologia moderna na produção e comercialização de hortaliças. Viçosa: Editora da UFV. 421 p.
Lima JD, Silva BMS, Moraes WS, Dantas VAV, Almeida CC (2008). Efeitos da luminosidade no crescimento de mudas de *Caesalpinia ferrea* Mart. ex Tul. (Leguminosae, Caesalpinoideae). Acta Amazônica 38(1):5-10.
Lorenzi H (2000). Plantas Daninhas do Brasil: Terrestres, aquáticas, parasitas e tóxicas. Nova Odessa: Instituto Plantarum 608p.
Magro TD, Shaedler CE, Fontana LC, Agostinetto D, Vargas L (2011). Habilidade competitiva entre biótipos de *Cyperus difformis* L. resistente ou suscetível a herbicidas inibidores de ALS e destes com arroz irrigado. Bragantia 70(2):294-301.
Marcolini LW, Carvalho LB, Cruz MB, Alves PLCA, Cecílio Filho AB (2010). Interferência de caruru-de-mancha sobre características de crescimento e produção da beterraba. Planta Daninha 28(1):41-46.
Omezine A, Silva JAT (2016). Competitive ability of *Capsicum annuum* L. relative to the weed *Amaranthus lividus* L. Journal of Horticultural Research 24(1):79-91.
Paul R, Elmore CD (1984). Weeds and the C_4 syndrome. Weeds Today 15:3-4.
Paulus D, Valmorbida R, Santin A, Toffoli E, Paulus E (2015). Crescimento, produção e qualidade de frutos de pimenta (*Capsicum annuum*) em diferentes espaçamentos. Horticultura Brasileira 33(1):91-100.
Pereira FECB, Torres SB, Silva ML, Grangeiros LC, Benedito CP (2014). Qualidade fisiológica de sementes de pimenta em função da idade e do tempo de repouso pós-colheita dos frutos. Revista Ciência Agronômica 45:737-744.
Pitelli RA (2014). Competição entre Plantas Daninhas e Plantas Cultivadas. In: Aspectos da Biologia e Manejo de Plantas Daninhas (ed. by Monquero PA). Rima, São Carlos pp. 61-82.
Rigoli RP, Agostinetto D, Schaedler CE, Dal Magro T, Tironi S (2008). Habilidade competitiva relativa do trigo (*Triticum aestivum*) em convivência com azevém (*Lolium multiflorum*) ou nabo (*Raphanus raphanistrum*). Planta Daninha 26(1):93-100.
Robinson DE, McNaughton K, Soltani N (2008). Weed management in transplanted bell pepper (*Capsicum annuum*) with pre-transplant tank mixes of sulfentrazone, s-metolachlor, and dimethenamid-p. Hortscience 43(5):1492-1494.
Rufino JLS, Penteado DCS (2006). Importância econômica, perspectiva e potencialidades no mercado para pimenta. Informe Agropecuário 27:7-15.
Silva FJ, Hisatugo EY, Souza JP (2016). Efeito da luz na germinação e desenvolvimento de plântulas de pinhão-manso (*Jatropha curcas* L.) de distintas procedências. Hoehnea 43(2):195-202.
Van Raij B, Cantarella H, Quaggio JA, Furlani AMC (1997). Boletim Técnico 100 – Recomendações de adubação e calagem para o Estado de São Paulo. Campinas: Instituto Agronômico/Fundação IAC. 258 p.

Vol. 13(40), pp. 2173-2182, 4 October, 2018
DOI: 10.5897/AJAR2018.13252
Article Number: 56D073758729
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Pasture quality of *Panicum maximum* cv. Tanzania subjected to different rest periods for milk production

Alberto Chambela Neto[1], José Fernando Coelho da Silva[2], Bruno Borges Deminicis[3*], Ismail Ramalho Haddade[1], Gustavo Haddad Souza Vieira[1], Leonardo Barros Dobbss[4] and Thiago Lopes Rosado[1]

[1]Federal Institute of Education, Science and Technology of Espírito Santo, Santa Teresa-ES, Brazil.
[2]Laboratory of Animal Science and Animal Nutrition, State University of Northern Fluminense, Campos dos Goytacazes-RJ, Brazil.
[3]Center of Agroforestry Technologies, Federal University of Southern Bahia, Ilhéus-BA, Brazil
[4]Institute of Agrarian Sciences, Federal University of Jequitinhonha and Mucuri Valleys, Unaí-MG, Brazil.

Received 17 May, 2018; Accepted 21 August, 2018

The objective of this study was to evaluate the effect of two defoliation intervals on the morphological characteristics of the experimental group. Chemical composition characteristics of a Tanzania grass pasture (*Panicum maximum*) and the performance of crossbred cows on intermittent grazing were examined. The digestibility of the dry matter, the digestibility of the organic matter fibrous, the voluntary dry matter intake and the voluntary intake of the organic matter fibrous were also determined. Milk production of cows was obtained in two daily milks. The levels of fat, protein, lactose, liquid energy and total milk solids were also quantified. The treatments consisted of evaluations of two pasture management strategies: 95% interception of photosynthetically active radiation and pasture managed with 30 days of defoliation interval. The study thus revealed that management causes differences in the chemical composition of Tanzania grass, but does not allow individual productive increases. Management based on IL 95% leads to higher milk production per unit area.

Key words: Cattle dung, environmental sustainability, overcoming dormancy, rumen.

INTRODUCTION

A balanced, good quality diet is a basic condition for the success of dairy farming. Traditionally, national production focused on the use of pasture-based production systems, with little planning and application of technologies, which results in low productivity and higher costs.

Thus, the nutritive value of forages is considered one of the most important factors in the evaluation of pastures, since it is the first determinant of nutrients necessary to meet maintenance requirements, besides having a high correlation with animal production; this productive response is related to the consumption, digestibility and

*Corresponding author. E-mail: brunodeminicis@gmail.com Tel: 55-73-3214-3288.

metabolism of dietary nutrients. From these factors, consumption and digestibility should be of importance, since 60 to 90% of the variation observed in the intake of digestible energy between animals and diets related to their differences.

However, the recommendations of the rotational management of pastures are misleading because in rotational stocking management, the duration of the interval of successive defoliation is the variable that determines the recovery of the leaf area index and, consequently, maximizes the forage mass production.

Forage production is a continuous process both in the plant (tissue flow) and in the population (considering the population density of tillers in the area); however, extremely dependent on factors limiting photosynthesis (eg temperature, luminosity, light quality), so that in intervals of time (although short) there would be accumulation of forage (Da Silva et al., 2015).

Usually, the defoliation interval is determined according to chronological criteria such as number of days. However, due to variations in plant growth rates and the seasonality of forage production, this criterion is not the best recommendation. This is probably due to the fact that during the lowering period of pastures managed under intermittent stocking there is accumulation of forage and it is linear and inversely associated with the proportion of the leaf area removed (Diavão et al., 2017).

It is believed that management proposals that respect the phenology and physiology of each cultivar could promote improvements in productivity indexes and perennial pasture. Moreover, defoliation can reduce leaf elongation due to damage caused in part of meristems. In this sense, the magnitude and rates of removal of these structures were determined by the management criteria, by the defoliation severity and the stocking density (Gastal and Lemaire, 2015).

Thus, this study aims to evaluate forage quality and milk yield and composition of crossbred Holstein x Zebu cows in pastures of *Panicum maximum* cv. Tanzania, using two treatments of defoliation with fixed post-grazing residue.

MATERIALS AND METHODS

Geographic location

The project was conducted at EMBRAPA Gado de Leite, in the Experimental field of Coronel Pacheco (CECP), municipality of Coronel Pacheco, in the *Zona da Mata* of the State of Minas Gerais, Brazil. The CECP is located at 21° 32` 38`` South latitude and at 43° 15` 10`` West longitude and the altitude is 451 m. The climate of the region, according to Köppen classification, is mesothermal (Cw), defined as being temperate rainy in the summer and with a dry winter between June and September.

The experimental area consisted of four hectares, having 11 pickets of approximately 909 m^2 each. The pasture was fertilized with 220 $kg.ha^{-1}.year^{-1}$ of N and K_2O and 55 $kg.ha^{-1}.year^{-1}$ of P_2O_5. The distribution of fertilization was made when the animals changed pickets during the grazing cycles, so that nutrients were supplied at all pickets when the pasture presented the same physiological age (one day after grazing or post-weighed according to the smallest cycles under IL95% treatment). Thus, about 3.7 $kg.picket^{-1}.cycle^{-1}$ of N and K_2O and 0.9 $kg.picket^{-1}.cycle^{-1}$ of P_2O_5 were supplied in the commercial formula 20:05:20.

Ten freshly bred cows (Holstein x Zebu) were used per treatment, which were composed of one pasture with three years of grazing and another three months before the beginning of the experiment.

The distribution of the cows per repetition occurred according to milk production, number of lactations, live weight and genetic group, so that the groups were homogeneous. Cows were supplemented with 2 $kg.day^{-1}$ of corn meal during the experimental period and a supply of minerals was given *ad libitum*. The nutritional value of the corn meal was 86.08% of dry matter (DM), 6.63% of crude protein (CP) and 9.77% of neutral detergent fiber (NDF). The cows milked daily, at 06:30 am and at 02:30 pm, without the presence of calves in mechanical milking, and the picket exchange, when scheduled, was performed after the milking of the morning.

The treatments consisted of evaluations of two management strategies in pastures of *P. maximum* cv. Tanzania: (1) IL95 entry of the animals in the pickets when pasture reached 95% light interception (IL) with three days of picket occupation and (2) FIXED pasture managed with 30 days of defoliation interval (ID) and three days occupancy of the picket. In the IL95 treatment, there were three extra pickets, aiming to adjust the IL in the different grazing cycles, since the ID could be shorter or longer than 30 days, depending on the IL.

However, depending on the climatic conditions, the ID observed in IL95 was always less than or equal to 30 days. The pastures, in the two treatments, before the beginning of data collection, managed picket picking to establish the heights of the post-grazing residue of 30 cm. This management consisted of mechanical roughing with costal trimmer, which allowed forming an age gradient of the plants in each picket. Thereafter, picket management in the IL95 treatment followed this criterion, while the FIXED treatment pickets were managed with 30 days of ID and three days of picket occupation, regardless of the 95% IL, of the forage mass and of the height of the residue, throughout the experimental period.

The interception of light by forage canopy was monitored in the pre-grazing condition and during the period from January to May every seven days; when the IL was near to the 95% target, the monitoring frequency changed totwo days. A variation of ± 2% was considered as criterion of entry of the animals in the pickets due to the little variation observed in the forage mass of the picket. For IL evaluations, a canopy analyzer was used - AccuPAR Linear PAR / LAI ceptometer, Model PAR-80 (Decagon Devices), with which readings were taken at 10 points of the picket Carnevalli et al. (2006).

The total forage biomass under pre-grazing condition was estimated using a metallic frame with an area equal to 1 m^2 at five points representing the average canopy height in each picket. The material contained in each square was cut at ground level (5 cm) and weighed.

The height of the canopy was determined in the pre and post-grazing periods, using a ruler graduated in centimeters, being measured 20 random points per picket.

To obtain representative samples of the diet (extrusa), two animals were used. They were fistulated in the esophagus, according to the technique described by Bishop et al. (1970). Extrusa samples were collected in all grazing cycles and submitted to pre-drying; the dry matter (DM), mineral matter (MM), crude fat (CF) and crude protein (CP) were quantified according to AOAC (1990); neutral detergent insoluble protein (NDIP), acid detergent insoluble protein (ADIP), lignin (LIG), and fibrous organic matter (FOM) were quantified according to Detmann (2012). Carbohydrates were divided into fractions: non-fibrous carbohydrates (NFC) and fibrous carbohydrates (FC), and were determined according to Sniffen et al. (1992).

For estimation of the voluntary intake and digestibility, the 20 Holstein x Zebu cows from the experiment were used. The fecal production was estimated using chromic oxide (Cr_2O_3) as an external indicator. Five grams of Cr_2O_3 were given orally in pellet form, to each animal, twice a day at intervals of approximately 12 h, during 12 days. From the

Table 1. Average yield of biomass (T of DM.ha^{-1}) and mean height (m) of Tanzania grass in pre-grazing condition.

Treatment	Cycle 1	Cycle 2	Cycle 3	Cycle 4	p-value (Cycle)
Average yield of biomass					
IL95	2.04^{b}	3.27^{ab}	4.99^{a}	2.84^{ab}	0.008
FIXED	3.02^{b}	4.55^{ab}	5.65^{a}	2.81^{ab}	0.006
P-value (Treatment)	0.328	0.214	0.506	0.975	CV%= 23.42
Mean Height					
IL95	0.97^{aA}	1.01^{aA}	1.02^{aB}	0.95^{aB}	0.075
FIXED	1.01^{bA}	0.99^{abA}	1.08^{aA}	1.01^{bA}	0.006
P-value (Treatment)	0.116	0.394	0.025	0.045	CV% = 0.05

*Means followed by the same lowercase letter in the row, within each treatment, and the same capital letter in the column, within each cycle, do not differ statistically from each other for α = 0.05.

seventh day of application, period necessary for stabilization of Cr_2O_3 in the digest, fecal samples were collected manually in the rectal at the times of Cr_2O_3 delivery by the twelfth day.

At the end of the collection period, composite samples were collected from each animal over a period of six days. The composite samples were dried and processed for the subsequent laboratory determination of the fecal chromium concentration contained by atomic absorption spectrophotometry, according to the methodology described by Kimura and Miller (1957).

The effective degradability of the extrusa and the fiber mass present in the rumen were evaluated using the gas production technique described by Theodorou et al. (1994) and by the interpretation of the generated profiles, with chrome as an indicator, performed according to Vieira et al. (2008).

Samples of milk were collected and sent to the Milk Analysis Laboratory at EMBRAPA “Gado de Leite”, every 14 days, for determinations of protein, fat, lactose and total dry extract.

The production of milk per area (kg of milk.ha^{-1}) were corrected for all periods, due to the variation of the area used in the treatments according to the management adopted.

The variables measured in the present study were analyzed by means of a mixed model. The parameters were estimated using the MIXED procedure of SAS (1999), where the selection of the best model was based on the Akaike's information criterion (Akaike, 1974). The variance and covariance structures tested were as follows: components of variance, composite symmetry, first order auto-regressive correlations, Toeplitz structure, as well as unrestricted structure (Littell et al., 2006).

RESULTS AND DISCUSSION

After calculating the individual probability for each model, the results indicated that they were equivalent. Then, the model with the lowest Akaike information criterion (Akaike, 1974) was prioritized, except for the observed values for gross fat - where the best fit was the composite symmetry; for all other parameters evaluated, the profile that best fit the model used was that of the component of variance.

It is important to report that, depending on the treatments adopted, the duration of the cycles between grazing varied in the IL95 treatment, being 24, 24, 27 and 30 days while for the FIXO treatment the cycles lasted 30 days.

The biomass production and the height of the pasture (Table 1) in the pre-grazing condition had a significant effect among the grazing cycles, which shows that under these conditions, according to the results observed by Carvalho et al. (2001), the different defoliation intervals observed along the cycles provided higher biomass yields in the treatments.

The lower production of pasture biomass in Cycle 1 in relation to Cycle 3 in both treatments may be due to the grazing gradient carried out in the previous month, since in this month the areas were mechanically grazed in order to standardize a gradient to the beginning of the evaluation period. Thus, this period was the only one in which it was possible to obtain a post-grazing residue of 30 cm, and, thus, Cycle 1 was the only one where biomass residue did not occur prior to its beginning, which may have contributed to these minor values observed. In Cycles 2 and 4, no significant difference was observed in relation to the other cycles.

There was no difference in biomass production between treatments. The heights of the forage plants in the FIXED treatment cycles, in a certain way, followed the production of biomass, since in Cycle 3 the highest average of heights was verified, being higher than Cycles 1 and 4 and not differing from Cycle 2. The Cycles 1, 2 and 4 did not differ from each other.

Both the biomass production and the height of the canopy in the pre-grazing may have been influenced by the grazing efficiency of the previous cycle, since, in Cycle 2, a higher post-grazing residue and a higher pasture height were observed, which gave Cycle 3 greater amount of dead material that integrated the manual samples collected in this cycle.

Among the treatments, it was observed that in Cycles 1 and 2 there was no difference in height; however, those of Cycles 3 and 4 of the FIXED treatment were higher than those observed in IL95.

Although the intervals of leaves were shorter, they were not sufficient to control the height of the canopy that ranged from 0.95 to 1.05 m between grazing cycles. Similar responses were observed by Difante et al. (2009) and Canto et al. (2013). Thus, grass height may compromise forage quality, due to the higher lignin content observed in these grazing cycles, and may also affect dry matter intake, since, with a higher supply of forage, animals can better harvest the crop due to a broader grazing horizon (2013). Difante et al. (2009) also failed to maintain the forage canopy residue in Tanzania grass under intermittent grazing at 30 cm, observing a relatively long defoliation interval. That allowed an almost complete interception of light, as a result of the selective grazing practiced by steers and of its low grazing efficiency in a horizon inferior to that defined by the height of the stems.

The average observed in the treatments between grazing cycles (50 cm) is almost twice as high as that currently considered ideal for Tanzania grass (30 cm), and in more extreme periods the residual height was close to 60 cm.

The same effect could have occurred with the Tanzania grass in this experiment, since the stocking with five cows.ha^{-1} may not have been ideal. In addition, with a low grazing pressure exerted on the pasture the animals would then have better chance of selecting the food, which makes the losses larger and consequently increases the residual height of the pasture.

The dry matter (DM) content of Tanzania grass (mean of 150.2 g.kg^{-1} in natural matter) were observed in treatments (p = 0.324) and in grazing cycles (p = 0.889). Gonzaga Neto et al. (2015) observed higher values for DM (mean of 249.2 g.kg^{-1}).

Although the observed levels may be considered low, possibly because the samples were extruded, "addition" of saliva to the sample could have occurred and influenced on the moisture of the material. Similar results were observed in the literature (Porto et al., 2009).

The mineral matter content (MM) is relatively unimportant in forage evaluation when fertilization is used, since this condition becomes very variable. Therefore, since the treatments were the same in both situations, no significant difference was observed between treatments (p = 0.134) and between grazing cycles (p = 0.291), with mean values of 133.2 g.kg^{-1} in the dry matter. Gonzaga Neto et al. (2015) observed lower values for MM (mean of 79.7 g.kg^{-1}).

The crude fat fraction (CF) represents the most energetic fraction of the food (lipid portion); however, because forages generally present very low levels (NRC, 2001) this component becomes of little relevance for the evaluation of the (p = 0.119) and between grazing cycles (p = 0.675), with mean values of 24.4 g.kg^{-1} in the dry matter.

The essentiality of the protein for the metabolism of maintenance and animal production brings considerable importance to the analysis of crude protein content of foods. According to Van Soest (1994), 70 g/kg of CP (in DM) was needed to guarantee the fermentation of structural carbohydrates in the rumen.

A significant difference was observed in the CP content of Tanzania grass, among treatments, in all grazing cycles. In Cycles 1, 3 and 4, the IL95 treatment presented higher CP values, possibly because this treatment presented a greater amount of leaves in relation to the treatment with FIXO defoliation interval. In Cycle 2 the interpretation of p-value shows that there was little evidence of effect (p = 0.042), since the value is close to the limit (p = 0.05).

In the management where the criterion of IL95 was adopted, the “extrusa” collected in Cycle 1 presented CP content higher than in the other cycles; in Cycle 2, it presented a lower CP content than in Cycle 3 and this did not differ from Cycle 4.

In the management where FIXO defoliation interval was adopted, the “extrusa” collected in Cycle 1 presented PB content higher than in the other cycles. Cycles 2 and 3 did not differ from each other and both had CP levels higher than in Cycle 4.

These differences were expected since the environmental variables have an effect on the physiology of the grass. Thus, as one moves from a rainy season to a dry season, the decrease in temperature and the reduction in nutrient availability, which normally occurs under water limitation conditions, may be responsible for the decrease in the observed CP content.

The CP levels of tropical grasses available in the literature are variable, since they are influenced by factors such as plant age, fertilization, season, soil and climate conditions, and defoliation interval. The CP levels for Tanzania grass observed by Porto et al. (2009) and Fukumoto et al. (2010) are similar to those observed in this study.

Neutral detergent insoluble protein (NDIP) contents are important in determining the potentially digestible protein (PDP), which is characterized by slow degradation in the rumen, as it is associated with the cell wall. This potentially digestible fraction (Table 2) was obtained by subtracting the ADIP content from the NDIP content.

There is a small proportion of CP that is insoluble, as it is associated with cell wall lignin, tannins and Maillard compounds, which are highly resistant to microbial and enzymatic degradation, making it little available in the digestive process of ruminants.

In the determination of the protein fractions proposed by Sniffen et al. (1992), acid detergent insoluble protein (ADIP) corresponds to fraction C, which is insoluble in the rumen and indigestible in the gastrointestinal tract.

The IL95 treatment presented a higher content of PDP in Cycle 2, which may have provided a greater supply of dietary protein for the animals under this treatment. Among grazing cycles, Cycle 4 presented lower levels of PDP than the other cycles, possibly due to climatic

Table 2. Mean crude protein content (g.kg^{-1} DM) and the potentially digestible protein content (g.kg^{-1} DM) in Tanzania grass.

Treatment	Cycle 1	Cycle 2	Cycle 3	Cycle 4	p-value (Cycle)
Crude Protein					
IL95	117.6^{aA}	97.5^{cB}	105.2^{bA}	100.0^{bcA}	<0.001
FIXED	111.2^{aB}	101.1^{bA}	99.7^{bB}	89.6^{cB}	<0.001
P-value (Treatment)	0.002	0.042	0.006	<0.001	CV%= 1.43
Potentially Digestible Protein					
IL95	25.3^{aA}	26.4^{aA}	25.8^{aA}	15.4^{bA}	0.006
FIXED	23.1^{aA}	20.2^{aB}	23.8^{aA}	14.1^{bA}	<0.001
P-value (Treatment)	0.331	0.027	0.395	0.549	CV% = 2.08

*Means followed by the same lowercase letter in the row, within each treatment, and the same capital letter in the column, within each cycle, do not differ statistically from each other for α = 0.05.

Table 3. Average content of fibrous organic matter (g.kg^{-1} MS) and lignin content (g.kg^{-1} DM) in Tanzania grass.

Treatment	Cycle 1	Cycle 2	Cycle 3	Cycle 4	p-value (Cycle)
Fibrous Organic Matter					
IL95	746.7^{aA}	690.6^{bA}	717.0^{abA}	687.4^{bA}	<0.001
FIXED	718.9^{aB}	700.9^{aA}	701.3^{aA}	704.6^{aA}	0.383
P-values (Treatment)	0.028	0.383	0.191	0.154	CV%= 1.62
Lignin					
IL95	57.1^{aA}	66.7^{aA}	66.1^{aA}	69.3^{aB}	0.362
FIXED	59.9^{bA}	79.4^{abA}	66.0^{abA}	86.7^{aA}	0.033
P-value (Treatment)	0.691	0.172	0.983	0.045	CV% = 6.16

*Means followed by the same lowercase letter in the row, within each treatment, and the same capital letter in the column, within each cycle, do not differ statistically from each other for α = 0.05.

factors - mainly the lower rainfall - and vegetative ones, since in this cycle it occurred at the beginning of the inflorescence of the pasture and consequent mobilization of nutrients for the reproductive process.

The higher lignin content (Table 3) observed in Cycle 4 may also have contributed to this lower PDP content. The quantification of NDF contents is important because of their inverse relation with the voluntary ingestion of forage dry matter, because of the ruminal repletion effect, as reported by Mertens (1992), and with the net energy content of the feed material (Van Soest, 1994).

The fiber content (fibrous organic matter - FOM) between treatments (Table 3) varied only in Cycle 1, although this effect was just 3.72% higher in IL95 treatment in relation to FIXO treatment, and did not influence the consumption of dry matter and fiber. No difference was observed between grazing cycles in treatment with FIXO defoliation interval.

In the IL95 treatment, the fiber content varied between grazing cycles, with Cycle 1 being about 8% higher than Cycles 2 and 4, while the other cycles did not differ from each other.

The observed fiber contents can be considered high for tropical grasses and are similar to those observed by Patês et al. (2008), Porto et al. (2009) and Gonzaga Neto et al. (2015), and higher than those observed by Fukumoto et al. (2010).

The lignin content in the IL95 treatment was higher in Cycle 4 than in the FIXED treatment, which shows that the management adopted did not affect the forage lignification process when there was no water stress. However, for both treatments, there were occasional increases in lignin contents throughout grazing cycles (Table 3).

This is an expected behavior for lignin deposition, since the reduction of water content in the environment induces the formation of phenolic compounds: p-coumaric and ferulic acid that represents the fraction called lignin (Nussio et al., 2011).

The content of lignin in fodder is very variable and as its physiological maturation progresses, its lignin content increases. Thus, similar contents were reported in

Table 4. Mean of total carbohydrate (g.kg^{-1} DM) and non- fibrous carbohydrate (g.kg^{-1} DM) in Tanzania grass.

Treatment	Cycle 1	Cycle 2	Cycle 3	Cycle 4	p-value (Cycle)
Total Carbohydrate					
IL95	726.9^{A}	772.3^{A}	745.9^{A}	754.9^{A}	0.061
FIXED	730.9^{A}	742.6^{A}	690.9^{B}	750.7^{A}	0.062
P-value (Treatment)	0.704	0.083	0.019	0.741	CV%= 1.21
Non-Fibrous Carbohydrate					
IL95	137.0^{bA}	237.3^{aA}	164.8^{abA}	174.6^{abA}	0.019
FIXED	161.9^{aA}	149.5^{aB}	98.1^{aB}	88.3^{aB}	0.05
P-value (Treatment)	0.394	0.007	0.033	0.008	CV% = 18.8

*Means followed by the same lowercase letter in the row, within each treatment, and the same capital letter in the column, within each cycle, do not differ statistically from each other for α = 0.05.

management with defoliation interval between 24 and 30 days (Patês et al., 2008) and higher values were reported by Gonzaga Neto et al. (2015).

Tropical forages, as a rule, present 60 - 80% of their carbohydrates as cell wall components (Van Soest, 1994). The mean contents of total carbohydrates and non-fibrous carbohydrates are shown in Table 4.

It was expected that the carbohydrate content would decrease within the months, due to the physiological changes that occur in the drought period; however, there was no difference in the grazing cycles, even with the different biomass productions observed in pre-grazing (Table 1).

Among the treatments, in the IL95 management there was a higher total carbohydrate content. It was only in Cycle 3, despite the levels of fibrous organic matter and lignin (Table 3) observed between the cycles, that they did not differ between treatments.

Higher results were reported by Valente et al. (2010) and Gonzaga Neto et al. (2015) for Tanzania grass, in the condition of interception of photosynthetically active radiation equal to 95%.

The classification of carbohydrates in structural and non-structural refers solely to their function performed in plants. The structural carbohydrates found in the cell wall of plants and are composed of pectin, cellulose and hemicellulose. In addition, the structural components also include lignin, phenolic complexes and proteins (Mertens, 1992).

There was no difference between the treatments (p=0.133) and grazing cycles (p=0.225) for the fibrous carbohydrate content of Tanzania grass, where mean values of 589.3 g.kg^{-1} were observed in the treatments' dry matter.

Probably, this response is similar to the observed behavior of the fibrous organic matter and lignin (Table 3), due to the reduced range of defoliation applied to Tanzania grass in the experimental treatments. This indicates that these defoliation intervals do not allow the physiological maturation of the fodder, which, consequently, was not sufficient to cause thickening of the secondary cell wall. The levels reported here are lower than those reported by Valente et al. (2010).

Non-fibrous carbohydrates are located in cell contents and are found in higher concentrations in seeds, leaves and stems and represent energy reserves used for reproduction, growth and survival during periods of stress (Mertens, 1992) being degraded faster than fibrous carbohydrates, which are constituted of pectin, starch and sugars. Gonzaga Neto et al. (2015) reported lower values than the IL95 treatment; however, they are syllogical to the FIXED treatment.

Thus, in the analysis of non-fibrous carbohydrates, higher levels were observed in the IL95 treatment in comparison to the FIXED treatment in grazing Cycles 2, 3 and 4 (Table 4), for the months of March, April and May. Although lower than those recommended by the NRC (2001), they are higher than those observed by Valente et al. (2010).

In the individual observations of the treatments, in relation to the grazing cycles, no differences in FIXED treatment could be observed. However, in the IL95 treatment, similar behavior to lignin was observed (Table 3). In other words, where higher lignin levels were observed, due to longer maturation periods, the response of the cells to low amounts of cell contents were observed.

Factors such as digestibility, vegetation structure and stage of development of the plant directly and negatively alter forage quality due to changes in its chemical composition and consequent increase in the contents of structural compounds. Moreover, with a decrease in the content, this causes a reduction in voluntary dry matter intake due to ruminal repletion effects (Reis and Da Silva 2011).

In order to evaluate the dry matter intake (DMI) and

Table 5. Mean of voluntary dry matter intake (g DM.kg^{-1} of live weight) and effective fiber degradability (g.kg^{-1} DM.h^{-1}) of Tanzania grass.

Treatment	Cycle 1	Cycle 2	Cycle 3	Cycle 4	P-value (Cycle)
Voluntary Dry Matter Intake					
IL95	21.5^{a}	23.9^{a}	23.7^{a}	21.1^{a}	0.175
FIXED	21.0^{bc}	24.0^{a}	22.0^{ab}	18.8^{c}	0.019
P-value (Treatment)	0.989	0.553	0.233	0.139	CV%= 4.38
Effective Fiber Degradability					
IL95	227.3^{b}	287.0^{a}	288.9^{a}	243.2^{ab}	0.031
FIXED	226.9^{b}	285.7^{a}	291.2^{a}	242.6^{ab}	0.022
P-value (Treatment)	0.809	0.953	0.833	0.939	CV% = 13.36

*Means followed by the same lowercase letter in the row, within each treatment, did not differ statistically from each other for α = 0.05.

fiber intake (FVI), it was initially verified that the average live weight of the cows had no effect on the evaluated parameters.

Fiber represents the carbohydrate fraction of food, slow or even indigestible (Nussio et al., 2011) and its importance comes from its ability to exert a limitation on dry matter and energy consumption.

The DMI (Table 5) did not differ among the treatments studied; however, there is a difference between the grazing cycles in the treatment with FIXED defoliation interval. In Cycle 2, the highest DMI was observed in relation to Cycles 1 and 4, but did not differ from Cycle 3.

These responses probably occurred as a consequence of the average production of Tanzania grass biomass in pre-grazing, reported in Table 1, since in the cycles where there is greater forage availability, the highest DMI was also observed.

Thus, as discussed previously, the grazing efficiency that occurred in the previous cycle may have influenced the biomass production and the height of the forage canopy and, as consequence had an effect on DMI.

The DMI correlates with dry matter digestibility (DMD), because the higher the DMD, the higher the DMI, until energy demand is reached. Allison (1985) states that the passage of food by the rumen-reticulum increases with increasing digestibility, up to a maximum point. Thus, the lower the DMD, the longer the retention time of the "digesta", and the consumption limitation due to the repletion effect.

However, despite the DMI evaluation denotes the existence effect of grazing cycles, there is no difference in the DMD between treatments (p=0.819) and between grazing cycles (p=0.588), with an average digestibility of 495.6 g.kg^{-1} in the dry matter.

Thus, it could be inferred that, despite the variation in the DMI, somehow, there was a compensation by the animals in the digestion of the food. Above all, due to the mean mass of fiber present in the rumen (4.6 kg), the equilibrium condition was similar between treatments (p = 0,808) and grazing cycles (p = 0.052).

There was no difference between fiber voluntary intake and fiber digestibility between treatments and grazing cycles evaluated.

For fiber voluntary intake, a mean of 12.8 g of FOM.kg^{-1} of live weight was observed, with p=0.614 for treatments and p=0.115 for grazing cycles, while for fiber digestibility a mean of 563.2 g.kg^{-1} of NDF, with p=0.292 for treatments and p=0.17 for grazing cycles was observed.

It is possible that the grazing pressure applied to the Tanzania grass modulus was low, which may have allowed animals to select their diets composition, favoring the selection of more palatable and nutritious parts (Oliveira et al., 2007); thus, allowing the diets of the cows in both treatments to be similar in their chemical composition.

Thus, no differences were noticed in these variables even though differences were observed between forage biomass in the pre-grazing condition (Table 1).

Lignin is the indigestible fraction of fodder and, although in animal nutrition there is a high negative correlation with the digestibility of the fibrous portion of the plants, the levels observed in Table 3 did not influence fiber voluntary intake and digestibility.

No difference was observed in the effective degradability of the fiber between the treatments; however, variation occurred throughout the grazing cycles (Table 5).

In contrast to that observed by Prado et al. (2004), the higher level of cellular content in forage (non-fibrous carbohydrates) did not determine the lowest effective degradability of same. Probably, where there were lower lignin contents, greater effective fiber degradability occurred.

Dias-Salman et al. (2000) and Velásquez et al. (2009) reported higher values for effective fiber degradability than those observed in this study.

These answers affirmed that the dynamics and the quality of the forage did not change due to the adopted management, nor during the grazing cycles, since the individual production of the cows was not different from

Table 6. Monthly average of milk production (kg milk.ha^{-1}), mean values of protein in milk (g.kg^{-1} of milk) and lactose in milk (g.kg^{-1} of milk) during experimental period.

Treatment	Cycle 1	Cycle 2	Cycle 3	Cycle 4	P-value (Cycle)
Milk Production					
IL95	2745.0^{aA}	2755.2^{aA}	1979.2^{bA}	1467.1^{bA}	< 0.001
FIXED	2017.8^{aB}	1885.8^{aB}	1721.8^{abA}	1245.4^{bA}	0.006
P-value (Treatment)	0.002	0.001	0.109	0.156	CV% = 23.42
Protein in Milk					
IL95	29.4^{b}	28.6^{b}	29.6^{b}	31.7^{a}	0.012
FIXED	30.5^{b}	30.3^{b}	28.8^{b}	33.4^{a}	0.036
P-value (Treatment)	0.124	0.406	0.457	0.224	CV% = 1.27
Lactose in Milk					
IL95	42.9^{a}	43.4^{a}	43.9^{a}	40.9^{b}	0.006
FIXED	42.4^{a}	44.9^{a}	43.0^{a}	39.1^{a}	0.013
P-value (Treatment)	0.231	0.244	0.198	0.208	CV% = 2.47

*Means followed by the same lowercase letter in the row, within each treatment, did not differ statistically from each other for α = 0.05.

each other.

In the literature, it is reported that cows with access to water only at milking time have their milk production influenced negatively (Rocha, 1993) and that cows kept in an environment with temperatures above 25°C present reduced milk production (NRC, 2001). Such factors may have limited the productions observed in the present work.

Due to variation in the defoliation interval for the IL95 treatment because of the interception of photosynthetically active radiation equal to 95%, it was necessary to adjust the milk production observed in this treatment to 1 ha in order to match the productivity by area.

Thus, there was difference in mean milk yield (Table 6) between treatments and between grazing cycles. Milk production in Cycles 1 and 2 for IL95 treatment was 26.5 and 31.5% higher than for FIXED treatment. This difference is probably due to the interval of defoliation adopted in FIXED treatment (not indicated for this period of the year), since similar individual production was obtained in IL95 treatment, but in a reduced area.

Among the grazing cycles, a similar behavior was perceived in both treatments, with decreasing productivity along the cycles due to the advancement of the lactation period of the cows and with the lower availability and lower quality of the forage in the driest periods.

The production observed in the literature for Tanzania grass systems is very variable, although, in general, they are punctually smaller (Fukumoto et al., 2010; Santo et al., 2005) than those described in this paper.

There was no difference in any of the components of the milk evaluated for the experimental management; although, for some variables, grazing cycles were delayed.

The component of the milk that suffers most variation is the fat content, since the diet, the productive volume and the fiber content in the diet can influence the fat content. Fats from bovine milk are characterized as mixed triglycerides, with a large proportion of short chain fatty acids (C4 - C16), derived from glycerol-3-phosphate, derived from the glycolytic pathway or triglyceride lipolysis during the uptake of fatty acids by the mammary gland. Thus, there was no difference in fat content between treatments (p=0.601) and grazing cycles (p=0.727) over the experimental period, with mean values being 38.5 g.kg^{-1} of milk , similar to those observed by Fukumoto et al. (2010) and Porto et al. (2009).

The term "dry stratum" or "total solids" encompasses all components of milk, except water. The total solids content did not differ between the treatments (p=0.657) and the grazing cycles (p=0.52), with the average levels being 120.2 g.kg^{-1} of milk, similar to those observed by Fukumoto et al. (2010) and Porto et al. (2009).

Milk proteins synthesized in the mammary gland from amino acids absorbed into the blood, with the casein class being the major part of bovine milk proteins.

There was no difference in the milk protein content (Table 6) among the treatments studied; however, there was difference throughout the grazing cycles. In Cycle 4, higher protein content was recorded in milk in relation to the other cycles. These responses are associated with the crude protein content of the pasture, since changes in the protein intake have a discrete effect on the milk composition (Park et al., 2017). In this way, crude protein consumption may have occurred in Cycle 4.

The levels observed in the literature (Kumoto et al., 2010; Porto et al., 2009) corroborate with the levels reported in this study.

There was no effect of the average lactose content (Table 6) on cows' milk in the management, but in Cycle 4, there were lower levels in comparison to the other grazing cycles. This trend was observed in the non-fibrous carbohydrate content (Table 4), which may have provided higher amounts of glucose, the only precursor of lactose in the mammary glands.

Conclusions

The management causes certain differences in the chemical composition of Tanzania grass and these do not mean individual increases in productivity. Management based on the interception of photosynthetically active radiation equal to 95% implies greater efficiency in the use of the area, that is, higher milk production per unit area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors express sincere thanks to FAPEMIG for financing this research project; EMBRAPA – Gado de Leite for the area provided for the experiment; and all others whose contributions made this research possible.

REFERENCES

Akaike H (1974). A new look at the statistical model identification. IEEE Transaction on Automatic Control 19:716-723.

Allison CD (1985). Factors affesting forage intake by range ruminants: A Review. Journal of Range Management 38(4):305–311.

Association of Official Analytical Chemistry – AOAC (1990). Official methods of analysis. 15th. Ed. Arlington 1117 p.

Bishop JP, Froseth JA (1970). Improved techniques in esophageal fistulization of sheep. American Journal of Veterinary Research 31(8):1505-1507.

Canto MW, Hoeschl AR, Bona Filho A, Moraes A, Gasparino E (2013). Características do pasto e eficiência agronômica de nitrogênio em capim-tanzânia sob pastejo contínuo, adubado com doses de nitrogênio. Ciência Rural, Santa Maria 43(4):682-688.

Carnevalli RA, Silva SC, Oliveira AA, Uebele MC, Bueno FO, Hodgson J, Silva GN, Moraes JP (2006). Herbage production and grazing losses in Panicum maximum cv. Mombaça pastures under four grazing managements. Tropical Grasslands 40(3):1-8.

Carvalho PCF (2013). Harry Stobbs Memorial Lecture: Can grazing behaviour support innovations in grassland management? Tropical Grasslands - Forrajes Tropicales 1:137-155.

Carvalho PCF, Marçal GK, Ribeiro Filho HMN (2001). Pastagens altas podem limitar o consumo dos animais. In: Reunião da Sociedade Brasileira de Zootecnia, 38., 2001, Piracicaba. Anais... Piracicaba: Sociedade Brasileira de Zootecnia (cd-rom).

Da Silva SC, Sbrissia AF, Pereira LET (2015). Ecophysiology of C4 forage grasses - Understanding plant growth for optimising their use and management. Agriculture 5(3):598-625.

Detmann E (2012). Métodos para Análise de Alimentos. 1ª ed. Produção Independente 214 p.

Dias-Salman AK, Berchielli TT, Silveira RN (2000). Degradabilidade *in situ* do capim *Panicum maximum* cv.Tanzânia incubado cortado ou na forma de extrusa. Brazilian Journal of Veterinary Research and Animal Science 29(6/Supl.1):2142-2149.

Diavão J, Schmitt D, Medeiros-Neto CM, Martins CDM, Sbrissia AF (2017). Forage accumulation during the stocking period on pastures subjected to intermittent stocking. Ciência Animal Brasileira Goiânia 18:1-11, e-41359.

Difante GS, Nascimento Jr D, Euclides VPB, Carneiro da Silva S, Barbosa RA, Gonçalves WV (2009). Sward structure and nutritive value of tanzania guinea grass subjected to rotational stocking managements. Revista Brasileira de Zootecnia 38(1):9-19.

Fukumoto NM, Damasceno JC, Deresz F, Martins CE, Cóser AC, Santos GT (2010). Produção e composição do leite, consumo de matéria seca e taxa de lotação em pastagens de gramíneas tropicais manejadas sob lotação rotacionada. Brazilian Journal of Veterinary Research and Animal Science 39(7):1548-1557.

Gastal F, Lemaire G (2015). Defoliation, shoot plasticity, sward structure and herbage utilization in pasture: review of the underlying ecophysiological processes. Agriculture 5(4):1146-1471.

Gonzaga Neto S, Oliveira RL, Lima FHS, Medeiros AN, Bezerra LR, Viégas J, Nascimento Jr NG, Freitas Neto MD (2015). Milk production, intake, digestion, blood parameters, and ingestive behavior of cows supplemented with by-products from the biodiesel industry. Tropical Animal Health and Production 47(1):191-200.

Kimura FT, Miller VL (1957). Chromic oxide measurement. Improved determination of chromic oxide in cow feed and feces. Journal of Agricultural and Food Chemistry 5:216.

Lima MLP, Berchielli TT, Leme PR, Nogueira JR, Pinheiro MG (2004). Grazing time and milk production of crossbred cows in a rotational area of Elephant grass and Tanzania grass. Livestock Research for Rural Development Colômbia 16(11):88.

Littell RC, Milliken GA, Stroup WW, Wolfinger RD, Schabenberger O (2006). SAS® for Mixed Models, SAS Institute Inc., Cary, USA.

Mertens DR (1992). Nonstructural and structural carbohydrates. In: Van Horn HH, Wilcox CJ. Large dairy herd management. Anim. Dairy Sci. Association. Champaign, IL 25:219-235.

National Research Council (NRC) (2001). Nutrient Requirements of Dairy Cattle. 7th rev. ed. National Academy Press, Washington, DC.

Nussio LG, Campos FP, Lima MLM (2011). Metabolismo de carboidratos estruturais. In: Berchielli, TT, Pires AV, Oliveira SG. Nutrição de Ruminantes. 2ª ed. FUNEP. Jaboticabal, pp. 183-228.

Oliveira AB, Pires AJV, Matos Neto U, Carvalho GGP, Veloso CM, Silva FF (2007). Morfogênese do capim-tanzânia submetido a adubações e intensidades de corte. Brazilian Journal of Veterinary Research and Animal Science 36(4):1006-1013.

Park CS, Lindberg GL (2017). Glândula mamária e lactação. In: William O. Reece. Dukes: Fisiologia dos animais domésticos. 13ª ed. 740 p.

Patês NMS, Pires AJV, Carvalho GGP, Oliveira AC, Fonseca MP, Veloso CM (2008). Produção e valor nutritivo do capim-tanzânia fertilizado com nitrogênio e fósforo. Brazilian Journal of Veterinary Research and Animal Science 37(11):1934-1939.

Porto PP, Deresz F, Santos GT, Lopes FCF, Cecato U, Cóser AC (2009). Produção e composição química do leite, consumo e digestibilidade de forragens tropicais manejadas em sistema de lotação intermitente. Brazilian Journal of Animal Science 38(8):1422-1431.

Prado IN, Moreira FB, Zeoula LM, Wada FY, Mizubuti IY, Neves CA (2004). Degradabilidade in situ da Matéria Seca, Proteína Bruta e Fibra em Detergente Neutro de Algumas Gramíneas sob Pastejo Contínuo. Brazilian Journal of Veterinary Research and Animal Science 33(5):1332-1339.

Reis RA, Da Silva SC (2011). Consumo de forragens. In: Berchielli, TT, Pires AV, Oliveira SG. Nutrição de Ruminantes. 2ª ed. FUNEP. Jaboticabal pp. 79-110.

Rocha R (1993). Importância da água para produção de leite.

Agropecuária Catarinense, Florianópolis 6(4):16-18.
Santos AL, Lima MLP, Berchielli TT, Leme PR, Malheiros EB, Nogueira JR, Pinheiro MG, Lima NC, Simili FF (2005). Efeito do dia de ocupação sobre a produção leiteira de vacas mestiças em pastejo rotacionado de forrageiras tropicais. Brazilian Journal of Veterinary Research and Animal Science 34(3):1051-1059.
Statistical Analysis Systems (SAS) (1999). User's guide: SAS Institute Inc.
Sniffen CJ, O'Connor JD, Van Soest PJ, Fox DG, Russell JB (1992). A Net Carbohydrate and Protein System for Evaluating Cattle Diets. II. Carbohydrate and Protein Availability. Journal of Animal Science 70(12):3562-3577.
Theodorou MK, Williams BA, Dhanoa MS, MCallan AB, France J (1994). A new gas production method using a pressure transducer to determine the fermentation kinetics of ruminal feeds. Animal Feed Science and Technology 48:185-197.
Valente BSM, Cândido MJD, Cutim Júnior JAA, Pereira ES, Bomfim MAD, Feitosa JV (2010). Composição químico-química, digestibilidade e degradação in situ da dieta de ovinos em capim-tanzânia sob três frequências de desfolhação. Brazilian Journal of Veterinary Research and Animal Science 39(1):113-120.
Van Soest PJ (1994). Nutritional Ecology of the Ruminant. 2ed. New York: Cornell University Press 476 p.
Velásquez PAT, Berchielli TT, Reis RA, Rivera AR, Dian PHM, Teixeira IAMA (2009). Cinética da fermentação e taxas de degradação de forrageiras tropicais em diferentes idades de corte estimadas pela técnica de produção de gases in vitro. Brazilian Journal of Veterinary Research and Animal Science 38(9):1695-1705.
Vieira RAM, Tedeschi LO, Cannas A (2008). A generalized compartmental model to estimate the fibre mass in the ruminoreticulum: 1. Estimating parameters of digestion. Journal of Theoretical Biology 255:345-356.

Vol. 13(40), pp. 2183-2191, 4 October, 2018
DOI: 10.5897/AJAR2018.13350
Article Number: C1C61E458731
ISSN: 1991-637X

http://www.academicjournals.org/AJAR

ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Coffee growers' local knowledge on shade tree species in Adola Rede District, Guji Zone, Southern Ethiopia

Aschalew Emire[1*] and Zebene Asfaw[2]

[1]Oromia Agricultural Research Institute, Bore Agricultural Research Center, Guji Zone, Southern Ethiopia.
[2]Hawassa University, Wondogenet College of Forestry and Natural Resources, Shashemane, Ethiopia.

Received 27 June, 2018; Accepted 21 August, 2018

Farmers have a detailed local knowledge about different tree species which are either retained or planted on their farms. Thus, it is possible to learn from farmers' observations to enhance understanding of local agro-ecological knowledge. This study aimed to investigate coffee growers' local knowledge on shade tree species. The study was conducted at Adola Rede District, in Guji Zone, Southern Ethiopia. To address the objectives of this study, necessary data were collected through key informant interview and questionnaire survey. A total of 30 key informants and 90 households participated in the household interview. The study results revealed that coffee growers preferred shade grown coffee plants for better coffee yields, to protect coffee plants from unsuitable environmental stress, for soil fertility improvement and for longer life span of coffee plants. Coffee growers also encountered wilting and stunted growth of coffee plants, coffee yield reduction, poor soil fertility, less coffee stems and branches, besides coffee plants need more management when grown open. In the study district, eleven commonly used coffee shade tree species were identified. Based on their criteria of suitability identification, coffee growers preferred compatible shade tree species such as *Ficus sur, Millettia ferruginea, Cordia africana, Albizia gummifera, Croton macrostachyus* and *Vernonia amygdalina,* in this order. In the study area, the scale of shade tree species preferences for coffee growers varies. However, their main preferences of shade tree characteristics were mainly based on shade tree height, crown shape and evergreen or deciduous quality of the shade tree species. Coffee growers of the study area managed their owned shade tree species through pruning, thinning, pollarding and coppicing tending operations. They practiced various shade tree managements such as to cud dead or over grown branches, to collect wood used for various uses and to reduce of the shade for coffee plants. Therefore, based on the finding of this study, if the knowledge of local farmers is recorded and effectively used with scientific findings, it can provide valuable information that can give feedback synergistically to channel the direction of conventional science to meet the needs of local people.

Key words: Adola Rede District, coffee growers, local knowledge, coffee shade tree species.

INTRODUCTION

Ethiopia is the home and cradle of biodiversity of Arabica coffee seeds and more genetically diverse strains of *Coffee arabica* exist in Ethiopia than anywhere else in the world (Bayetta, 2001). Moreover, Ethiopia is the largest

*Corresponding author. E-mail: Aschu1511@gmail.com.

producer of coffee in sub-Saharan Africa, fifth largest coffee producer in the world, contributing about 7 to 10% of total world coffee production (Abu and Tedy, 2013). Coffee has economical, environmental as well as social significance to the country and 25% of the total population of the country depends on coffee production (MARD, 2008; FAO, 2012).

Coffee is the most important source of foreign currency for many developing countries and 70% of the world coffee is contributed by smallholder farmers who grow coffee mostly on farms of less than 5 ha (Mohan and Love, 2004). In Ethiopia, estimated numbers of coffee growers are 1.3 million and coffee is growing on 662,000 ha, of which 496,000 ha are estimated to be productive, yielding an average of 350,000 tons of coffee beans per annum (Agrisystems, 2001; Muleta et al., 2007).

The major coffee production systems of Ethiopia include: forest coffee, semi-forest coffee, garden coffee and plantation coffee, which respectively cover 5, 35, 50 and 10% of the productive coffee area (Aga et al., 2003; Mekuria et al., 2004). The forest ecosystem of Ethiopia includes forest and semi-forest coffee production that occupies nearly 33% of land used for coffee production and contributes 25% of the national coffee production (Taye, 2009). Accordingly, Ethiopian coffee plants grow understory of evergreen natural forest and under managed agroforestry systems above 500,000 ha (Aga et al., 2003).

Based on their acquired inherited local knowledge, coffee growers had been cultivating coffee plants as an important cash crop under the canopy of shade tree species (Gole, 2003). They have detailed local knowledge about different tree species growing in their farm lands. They recognize physical, biological and phonological attributes and interactions between tree species cover and components of the farm; and this is as a result of their experience, acquired and inherited local knowledge (Munoz et al., 2001). That is, the longer time farmers had worked with trees on their farms or in the landscape, the more detailed local knowledge they accumulated through experimentation and experience (Ruth, 2010).

Their local knowledge is a part and parcel of communities' identity that is unique to a culture and society. It is embedded in the communities' practices, institutions, relationships, customs, ethical principles, religious beliefs and rituals (WWF, 2013). Local knowledge provides a powerful basis from which alternative ways of managing resources can be developed. Rural communities in a number of developing countries use their traditional knowledge to generate income, food and health care materials, like traditional medicine. Therefore, local knowledge systems also serve as a reference when designing any management plan (Twarog and Kapoor, 2004).

The study result of Close and Hall (2005), carried in Turkey indicated that, despite heavy reliance on scientific knowledge as the primary source of information in resource management, many resources are in decline. To combat this trend, researchers have been drowning upon the knowledge of local resource users as an important supplement to scientific knowledge in designing and implementing management strategies. Therefore, to establish research priorities on promising coffee shade tree species in the study district, study of coffee growers' local knowledge is fundamental as they have considerable knowledge about coffee shade tree species which has not been documented and utilized. In this regard, recording coffee growers' local knowledge is vital to design systematic plan for sustainable coffee production in the study district through combining their inherited local knowledge with scientific findings. Therefore, this study was conducted (i) to identify coffee growers' local knowledge on management of coffee shade tree species, (ii) to identify coffee growers' local knowledge on suitability identification of shade trees for coffee plants, and (iii) to identify coffee growers' local knowledge on benefits of shade trees for coffee plants.

MATERIALS AND METHODS

Description of the study area

Location

Adola Rede district is located in Guji zone, Oromia Regional State, in Southern part of Ethiopia. The absolute location of the district is between 5°44'10" - 6°12'38" North latitude and 38°45'10" - 39°12'37" East longitude (Figure 1). The total area of Adola Rede district is 1401 km^2 and it is located at 475 km south of Addis Ababa (Yazachew and Kasahun, 2011).

Soil and topography

The major soil of Adola Rede district is nitosols (red basaltic soils) and orthcacrosols. The soil of the study district is dominantly brown. The forest area is characterized by a rolling topography and it is highly dissected by two main rivers of Genale and Dawa. Moreover, it has an elevation ranging from 1500 m above sea level in the southern part of the district. Whereas, in the north-western part of the district, it has an elevation greater than 2000 m above sea level (Yazachew and Kasahun, 2011).

Climate

Adola Rede district is characterized by three agro-climatic zones. The percentage of coverage of each agro-climatic zone of the district is high land 33%, mid-land 47% and low lands 20% (Yazachew and Kasahun, 2011). According to the climatic data from meteorological station of Adola Rede district, the mean annual maximum and minimum temperature of the study district is 23 and 16°C, respectively. The study district has bimodal rainy seasons, summer from June to November and spring from March to May.

Vegetation

Adola Rede district is enriched with both high natural forest resources and plantation forests. The natural vegetation of the Adola Rede district is over 50,000 ha. In the study district, Wadera,

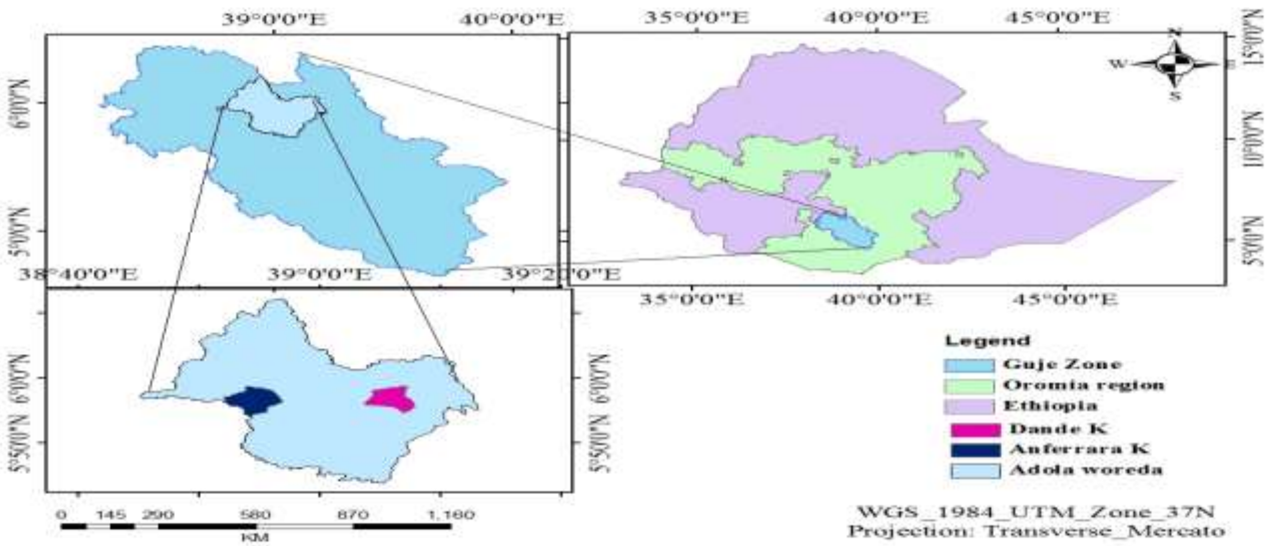

Figure 1. A map showing the study site (Yazachew and Kasahun 2011).

Zenbaba and Anferara forests are identified as the dominant forest coverage of the study district (Yazachew and Kasahun, 2011).

Socioeconomic characteristics

The total population of Adola Rede district is 583,816. From the total area of Adola Rede district, 33% is cultivation land, 30% is pasture land, 20% is forest land, and 17% is swampy or degraded land (CSA, 2008). The livelihood of majority of the inhabitants in the study area is mixed farming, coffee production and semi-nomadic economic activities (CSA, 2008).

Data collection methods

The various data collection tools employed were key informant interview to collect mainly qualitative information. The household survey was used to collect mainly detailed quantitative data about coffee growers' local knowledge on benefits, suitability identification and management of coffee shade tree species from the sampled households.

Selection of sample households

In this study, a household is defined as a basic unit of production and consumption, made up of the persons who have common fields and live under one central decision-maker. There are several approaches used to determine the sample size of households. These include using a census for small populations, imitating a sample size of similar studies, using published tables and applying formulas to calculate a sample size (Israel, 2012). This study applied the simplified formula developed by Yamane (1967) and reviewed by Israel (2012).

$$n = \frac{N}{1 + N(e)^2}$$

where 'n' is the sample size, 'N' is the population size and 'e' is the level of precision.

For this study, to determine the required sample size at 90% confidence interval, a ±10% precision level was used and a total of 90 respondents were randomly selected for the questionnaire interview from the two study kebeles.

Site selection for the study

Primarily, the study district was selected purposively based on the availability of coffee shade tree species and based on probability of coffee production. There are 10 kebeles in the study district known for major shaded coffee production and two were randomly selected for the study.

Selection of key informants

Key informants in this study are persons who are knowledgeable about coffee shade trees, experienced in growing coffee plants under storey of different shade trees and who have always lived in the village and for a long time. The selection of key informants was done using the snowball method. During key informants' selection, in each village at least five farmers were asked to identify and give names of six key informants. Then the identified key informants were ranked and the most frequently appeared top five persons were assigned as key informants. Finally, a total of 30 key informants were selected and used for the study.

Data analysis

The collected data from the questionnaires of household interview responses were coded and entered into Microsoft Office Excel sheet. Data were grouped and summed by response category on the data sheet. After organizing the data on Microsoft Office Excel, the analysis was performed using Statistical Package for Social Science version 20 for windows (IBM SPSS Inc, USA) software. Descriptive statistics was used to show farmers' local knowledge on benefits of shade trees for coffee plants, farmers' local knowledge on suitability identification of shade trees for coffee plants, and farmers' local knowledge on management of coffee shade trees either retained or planted on their landscape.

RESULTS AND DISCUSSION

Coffee growers' local knowledge on management of coffee shade tree species

Coffee growers' source of shade tree planting material

In addition to naturally grown shade tree species, planting of different shade tree species is widely practiced in the study district. Coffee growers' in the study site mentioned several source of shade tree planting material. Of all the respondents, 34.44 and 17.77% of the respondents use self established planting material and from neighbor farmers, respectively. For about 27.7 and 20% of the respondents, source of shade tree planting materials were from natural forest of the area and government nursery respectively (Table 5). Both key informants and sampled households confirmed that, farmers' have the trend of collecting naturally regenerated shade tree species from natural forest and transplanted on their coffee farms. Commonly, they collect seedling of *Cordia africana, Millettia ferruginea, Ficus sur, Croton macrostachyus* and *Albizia gummifera* shade tree species from natural forest and transplant to their coffee farms.

Tending of shade tree for coffee plants

Coffee growers' at the study site have good experience on management of shade tree species through different tending operations. However, the scale of shade tree species managements of coffee growers' of the study district varies. For example, about 83% of the respondents have their own experience on tending of shade tree for coffee plants that consider thinning, pruning, pollarding and coppicing tending operations. However, the remaining 7% of the respondent households did not apply different tending operations for their owned shade tree species.

At the study district, 21.6% of the respondents use thinning operation for densely grown naturally regenerated shade tree species. It is well recognized that shade trees in the natural forest are characterized by high density, closed canopy cover and cast heavy shade on coffee plants. To reduce heavy shade cover on coffee plants, to minimize competition between shade tree and coffee plants and to create good conducive environment for coffee plants, farmers employed thinning operation (Table 6). Consistent with this study findings is Mesele (2007) who indicated in his study that farmers' in Gedio zone, Southern Ethiopia practiced thinning operation, when crowns of different more adjacent tree species started to close and create heavy shade on under storey crops. Moreover, Regina et al. (2012*)*, on their study finding indicated that, in southern Bahia, Brazil, to minimize negative effect of shade tree species on understory cacao trees, cacao growers' deliberately reduced densely grown over storey of cacao trees through thinning management practice.

In the study site, majority (50.7%) of the respondents apply pruning of shade trees when their canopy cover closed and cast heavy shade on coffee plants and collect wood used for various purposes. Moreover, when they need shade trees for timber production, they usually practice pruning to reduce shade tree branches for a better growth (Table 6). The finding of this study is supported with previous findings of Motuma (2006) and Getahun et al. (2014). According to their study findings, farmers' in Arsi Negelle district, East Arsi zone and Ginbo district, South West Ethiopia practiced pruning of indigenous woody species and coffee shade trees to reduce the effect of shade on understory crops, to get other additional benefits and to improve production of under storey crops. About 15.7 and 12% of the respondents employed coppicing and pollarding operation for their owned different shade tree species, respectively (Table 6). According to the respondents, they are employing coppicing operation during harvesting time of shade trees for various purposes for instance for timber and construction value. In the study site, farmers commonly use pollarding at summer time to reduce effect of shade on understory crops mainly growing with shade trees. This idea is also supported by key informants.

Coffee growers' local knowledge on suitability identification of shade tree species

Coffee growers' selection criteria of compatible shade trees with coffee plants

In the study district, 11 shade tree species commonly used to shade coffee plants were identified. However, the frequency occurrence of shade tree species were quite different among respondents coffee farms/fields and some shade tree species were more frequently retained than others (Figure 2). Among shade tree species commonly used to shade coffee plants in the study district, *M. ferruginea, C. africana* and *C. macrostachyus* were the top ranking three shade tree species recorded on coffee farms/fields of 75% of the respondents (Figure 2).

As shown in Table 3, at the study site, coffee growers' select compatible shade tree species with coffee plants using different criteria. Accordingly, about 37.8% of the respondents use better coffee yields under a shade tree as a criteria and 24.4% of the respondents use fast growing ability of coffee plants under a shade tree as a selection criteria. Moreover, about 19% of the respondents use fast decomposition rate of shade tree

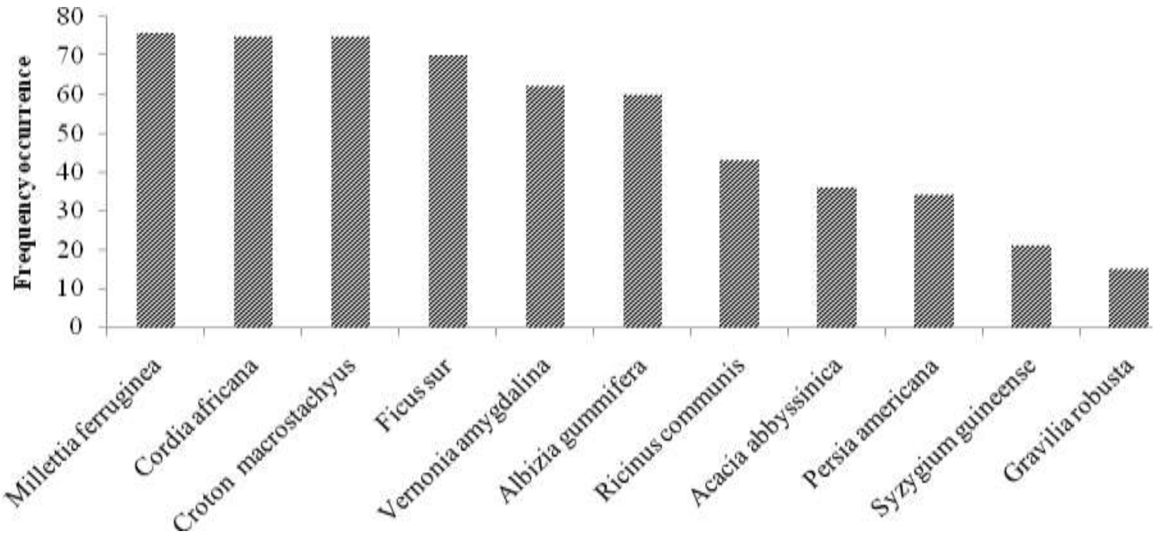

Figure 2. Frequency of the shade tree species commonly used for shading coffee plants in farmers' fields of the study district.

litter fall and the other 19% of the respondents use fast growing ability of a shade trees as a selection criteria. This is in agreement with opinion of key informants.

Therefore, farmers at the study site have profound knowledge on preferences of compatible shade tree species with coffee plants. From commonly used shade tree species in the study district, *F. sur*, *M. ferruginea*, *C. africana*, *A. gummifera*, *C. macrostachyus* and *Vernonia amygdalina* were among listed preferred compatible shade tree species with coffee plants. The finding of this study is relatively similar with the study result of Ashenafi et al. (2014). Their study findings indicated that, in South Ethiopia, farmers preferred compatible shade tree species such as *M. ferruginea, C. africana, E. abyssinica, F. sur* and *G. robustar*, respectively. Contrary, the finding of this study is different from Ashenafi et al. (2014) on farmers' selection criteria of compatible shade tree species, except similarity on fast growing ability of shade tree species. From their observation, Ashenafi et al. (2014) indicated that coffee growing farmers' means of compatible shade tree species selection criteria was based on fast growth rate of shade tree, less competitiveness of shade tree with coffee plants, good light interception and adaptive nature of shade tree species.

Coffee growers' preferences of coffee shade tree species characteristics

At the study site, the scale of shade tree species preferences of respondents varied. For example, about 89% of the respondents have their own preferences of shade tree characteristics that consider shade tree height, crown shape, evergreen or deciduous quality of the shade tree species.

In terms of height, majority (71.3%) of the respondents prefer longer shade tree species on their coffee farms (Table 4). Longer shade trees are preferred for timber production and construction value, since they provide adequate sun light to coffee plants and for bee keeping. Similar to this study finding, Albertin and Nair (2004) and Soto-Pinto et al. (2007), on their study findings indicated that coffee farmers' at the northern Tzeltal zone of the state of Chiapas, Mexico and in Nicoya Peninsula, Costa Rica, prefer longer shade tree species on their coffee farms. However, their findings did not indicate the reason for coffee growing farmers' prefer longer shade tree.

On the other hand, about 16.2% of the respondents prefer shorter shade tree species. Shorter shade trees are suitable for different management and damage to coffee plants from different tending operation is less. The finding of this study is supported with a study of Albertin and Nair (2004) and Samuel (2012). On their study, findings showed that, in Nicoya Peninsula, Costa Rica and in Ghana, Ejisu-Juaben district, farmers' main reason for preferences of shorter shade trees consisted of droplets from shorter shade trees which causes less erosion than taller shade trees and management is easier for shorter shade tree. Whereas, 12.5% of the respondents prefer combination of both shorter and longer shade tree species (Table 4). They indicated that, when longer mature shade trees are harvested to give various uses, the remaining shorter shade tree species provide shade for coffee plants.

In terms of coffee shade trees crown shape, majority (78.8%) of the respondents believe that spreading crown coffee shade trees are more suitable than narrow crown shade tree. The main reasons of their preferences include when shade trees are sparsely retained on their

Table 1. Respondent households (n=90) and their opinion on the benefits of shade trees for under canopy coffee plants.

Benefits of shade trees to coffee plants	Study kebeles and number of respondents			
	Anferara	Dande	Frequency (f)	Percentage
Protect coffee plants from adverse environmental stress	11	18	29	32.2
Soil fertility status under coffee plants improved	11	8	19	21.1
Better coffee yields	13	9	22	24.4
Longer life span of coffee plants	9	11	20	22.3

Source: From Survey Result (2014/2015).

coffee farms, spreading crown provides adequate shade to coffee plants and is easier to manage as well as suitable for bee keeping (Table 4). The finding of this study is strengthened with studies of Albertin (2002) and Albertin and Nair (2004). They indicated in their study, coffee growers in Peninsula of Nicoya, Costa Rica prefer spreading crown shade trees since they provide better shade to coffee plants and for good management practice of the shade tree. On the other hand, about 21.2% of the respondents prefer shade tree species with narrow crown, since they need to have more diverse shade tree species on their small size of coffee farms.

As shown in Table 4, 50% of the respondents' preferred evergreen shade tree species on their coffee farms. Evergreen shade trees are preferred to provide animal fodder during long dry season and crucial to protect coffee plants from extreme sun light throughout the year. In line with this finding, Albertin and Nair (2004), Diriba et al. (2011) and Samuel (2012) on their study results indicated that, farmers in Costa Rica, South Western Ethiopia, and in Ghana, Ejisu-Juaben district, respectively preferred evergreen shade trees above deciduous ones because the shade is obligatory for coffee plants in the dry season.

Of all the respondents, 23.8% of households preferred deciduous shade tree species mainly for nutrient cycling through litter fall. Consistent with this study, Beer (1987) and Ashenafi et al. (2014) on their study findings indicated that coffee farmers only consider deciduous quality of shade tree species and do not consider evergreen nature of the shade trees to be a critical preference. In general, about 26.2% of the respondents preferred both deciduous and evergreen shade tree species (Table 4). According to both key informants and sampled households, during deciduous shade tree species shedding their litter fall, the remaining evergreen shade tree species could protect coffee plants from inappropriate environmental stress.

Coffee growers' local knowledge on benefits of shade trees for coffee plants

At study district the benefits of coffee shade trees are well recognized by respondents. As a result, all the respondents considered shade trees as a prerequisite for coffee production. About 32.2% of the respondents suggested that shade trees are so important to protect coffee plants from adverse environmental stress such as extreme sun light, frost, hail and surplus wind speed (Table 1). According to respondents, shade trees are vital to protect the new planted coffee seedlings from undesirable environmental stress that make them wilted and growth stunted. Moreover, shade trees protect coffee plants from adverse climate conditions during their flowering and fruiting stage. This idea is also supported by key informants. The finding of this study is strengthened with previous studies of Albertin and Nair (2004), Claudia (2010), Santos et al. (2012) and Adugna and Paul (2014). Their study findings note that, shade trees improve the climate for coffee plants by buffering temperature extremes in the air and soil and by reducing wind velocity in coffee plantations.

As shown in Table 1, benefits of shade tree include better coffee yields (24.4% HHs) and enhancing soil fertility under their canopy by 21.1% of the respondents. According to both key informants and respondent households, better coffee yields obtained from shade grown coffee plants due to leaf litter and pruning of shade tree decomposing and maintain soil fertility under coffee plants. Moreover, shade grown coffee plants are protected from adverse environmental stress. As a result, coffee plants grow healthy, flower in time and produce better coffee yields. Similar to this study finding, Soto-Pinto (2000), Diriba et al. (2011), Robert (2011) and Ashenafi et al. (2014) found out that shade trees have a positive effect on coffee plants and better coffee yields are obtained from under shade grown coffee plants than that grown under full sun. However, contrary to this study finding, Adugna et al. (2014) showed that beans developed under shaded condition were heavier, larger in size and had better liquor taste. However, greater coffee yields are obtained from sun grown coffee plants. Haggar et al. (2011) also indicated that shade trees compete with coffee for resources and in a very wet year, shade can promote the growth of moisture-loving fungi, which may reduce the yield of shade-grown coffee plants.

Based on the findings of this study, about 22.3% of the respondents indicated that, shade grown coffee plants have longer life span than that grown under full sun.

Table 2. Respondents households (n=90) and their opinion on problem of growing coffee plants without shade tree species.

Problem of open grown coffee plants	Study kebeles and Number of respondents			
	Anferara	Dande	Frequency (f)	Percentage
Wilting and stunted growth of coffee plants	14	10	24	26.7
Poor soil fertility under coffee plants	11	9	20	22.2
Reduction of coffee yield	10	9	19	21.1
Less coffee stems and branches	6	8	14	15.6
Coffee plants need more managements	9	4	13	14.4

Source: From Survey Result (2014/2015).

Table 3. The sampled households response (n=90) on selection criteria of compatible coffee shade tree species.

Farmers' criteria to select compatible shade tree spoecies	Study kebeles and Number of respondents			
	Anferara	Dande	Frequency(f)	Percentage
Better coffee yield under a shade tree	21	13	34	37.8
Enabling fast growth of a coffee plants under a shade	13	9	22	24.4
Fast growing ability of a shade tree	11	6	17	19
Decomposition rate of shade tree litter fall	8	9	17	19

Source: From Survey Result (2014/2015).

Shade tree protected coffee plants from extreme sun light, from other unsuitable environmental stress and regulates climatic conditions for coffee plants. Open grown coffee plants often suffer a premature death and they need to be replaced much more frequently than shade grown coffee plants. This study finding is in agreement with the observations of Denis (2003), Albertin and Nair (2004), Damatta (2004) and Claudia (2010). From their study findings, shade grown coffee plants have a longer life expectancy than sun grown coffee plants and shade trees have a benefit to reduce coffee plants exhaustion. Moreover, by modifying microclimatic conditions, shade trees stabilize the yields throughout the seasons, making planning and harvesting more efficient for the farmer and prolong the life span of coffee plants.

Based on their accumulated experience and inherited local knowledge, coffee growers in the study district easily recognized problems associated with sun grown coffee plants. Accordingly, 26.7% of the respondents indicated that wilting and stunted growth of coffee plants are a serious problem of open grown coffee plants (Table 2). Moreover, about 21.1 and 22.2% of the respondents reported low coffee yield and poor soil fertility under coffee plants are a major problem (Table 2). Open grown coffee plants are characterized by 15.6% of the respondents as having less number of coffee stems and branches and 14.4% of the respondents confirmed that sun grown coffee plants need more managements as compared to shade grown coffee plants (Table 2). Both key informants and sampled households indicated that, sun grown coffee plants exposed to adverse environmental stress and soil fertility under coffee plants are poor. In addition, sun grown coffee plants easily get damaged with domestic and wild animals; due to this coffee plants could be demanding more management and having less number of coffee stems and branches.

Conclusion

Coffee growers in the study district have been cultivating coffee plants under the shade of natural forest canopy and under plantation shade tree covers for a long time. They enhanced the trend of growing shaded coffee plants through their inherited knowledge and experiences acquired from various sources. Overall, farmers showed a good understanding on the benefits of shade tree for coffee plants. Shade tree reduces undesirable environmental stress on coffee plants by ameliorating adverse climatic conditions. Moreover, yield of shade grown coffee plants increased due to soil fertility enhancements and shade grown coffee plants have longer life span than that grown under full sun. Coffee growers' also encountered wilting and stunted growth of coffee plants which have negative impact on coffee yields when grown open. Moreover, open grown coffee plants have less coffee stems and branches and more management is required for coffee plants.

Coffee growers have profound knowledge about management practice of various shade tree species they owned. The trends of planting different coffee shade trees are commonly known in the study site and farmers have various source of planting material. Their source of shade tree planting material is self-established, from

Table 4. Respondent households (n=80) and their opinion on preferences of shade tree height, crown shape and evergreen or deciduous characteristics of shade tree species.

Shade tree characteristics	Farmers' preference	Study kebeles and Number of respondents			
		Anferara	Dande	Frequency (f)	Percentage
Tree height	Longer shade tree	29	28	57	71.3
	Shorter shade tree	6	7	13	16.2
	Combination of both	7	3	10	12.5
Crown shape	Spreading crown	34	29	63	78.8
	Narrow crown	8	9	17	21.2
Evergreen or deciduous	Evergreen	14	26	40	50
	Deciduous	13	6	19	23.8
	Combination of both	18	3	21	26.2

Source: From Survey Result (2014/2015).

Table 5. The sampled households response (n=90) on source of coffee shade tree planting material.

Farmers' source of shade tree planting material	Number of respondents and Study kebeles			Percentage
	Anferara	Dande	Frequency (f)	
Self-established	20	11	31	34.44
From natural forest	13	12	25	27.77
From government nursery	11	7	18	20
From neighbor farmers	8	8	16	17.77

Source: From Survey Result (2014/2015).

Table 6. Different shade tree management practices undertaken by the coffee growers' at Adola Rede District.

Commonly used tending operation	Study kebeles and Number of respondents			
	Anferara	Dande	Frequency (f)	Percentage
Thinning	10	8	18	21.6
Pruning	25	17	42	50.7
Coppicing	7	6	13	15.7
Pollarding	2	8	10	12

Source: From Survey Result (2014/2015).

neighbor farmers, government nursery and natural forest. Coffee growers' in the study site regularly manage their owned coffee shade trees through employing thinning, pruning, coppicing and pollarding tending operation. Farmers commonly practiced various tending operation for their owned shade tree species; to cud dead or over grown branches, to collect wood used for various purposes and to reduce the shade of coffee plants and for a better production of understory crops.

Coffee growing farmers have an extensive knowledge on preferences of coffee shade tree characteristics. However, the scale of shade tree preferences of farmers was variable and mainly considers shade tree height, crown shape, evergreen or deciduous characteristicsof shade tree species. Therefore, based on the finding of this study if knowledge of local farmers is recorded and effectively used with scientific findings, it can provide valuable information that can give feedback synergistically to channel the direction of conventional science to meet the needs of local people.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors express their gratitude to all staff members for providing them with helpful advice and assisting them during data collection patiently, with commitment and dedication. They are grateful to farmers of Adola Rede District who responded to all questions with patience. Likewise, they are very grateful to the Oromia Agricultural Research Institute for the financial support.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abu T, Tedy T (2013). Annual coffee report of Ethiopia. USDA Foreign Agricultural service, Global Agricultural Information Network.

Adugna D, Paul C (2014). Effects of shade on growth, production and quality of Coffee arabica in Ethiopia. Journal of Horticulture and Forestry 3(11):336-34

Aga E, Bryngelsson T, Bekele E, Solomon B (2003). Genetic diversity of forest Arabica coffee (Coffee arabica L.) in Ethiopia as revealed by random amplified polymorphic DNA(RAPD) analysis. Department of Crop Science, Swedish University of Agricultural Sciences, Alnarp,Sweden, Hereditas 138(1):36-46

Agrisystems Ltd (2001). Coffee Support Project, Ethiopia. Revised draft formulation reportfor the European Commission.

Albertin A (2002). Shade trees for coffee: Farmers' Perspectives in the Peninsula of Nicoya. MSc, Thesis, University of Florida, Florida.

Albertin A, Nair P (2004). Farmers' perspectives on the role of shade trees in coffee production: an assessment from the Nicoya Peninsula, Costa Rica. Journal of Human Systems Ecology 32(4):443-463.

Ashenafi N, Endale T, Guta B (2014). Survey on potentials and constraints of shade tree species for Arabica coffee production in south Ethiopia.International Journal of Recent Research in Life Sciences 1(1):1-11.

Bayetta B (2001). Arabica coffee breeding for yield and resistance to coffee berry disease (Colletotri chumka hawae species). PhD Thesis, University of London, Imperial College Wye, U.K. http://www.eiar.gov.et

Beer J (1987). Advantages, disadvantages and desirable characteristics of shade trees for coffee, cacao and tea. Journal of Agroforestry Systems 5:3-13.

Central Statistics Agency (2008). Summary and Statistical Report of the 2007 Population and Housing Census. Population size by age and sex.FederalDemocratic Republic of Ethiopia Population Census Commission, Addis Ababa,Ethiopia. International Household survey network, ETH-2007-PHC P 1.

Claudia PS (2010). Farmers' knowledge of tree attributes and shade canopy management of cocoa agroforestry systems in waslala, Nicaragua, MSc Thesis, Bangor.uk

Close CH, Hall GB (2005). AGIS-based protocol for the collection and use of local Knowledge in fisheries management planning. Journal of Environmental Management 78:341-352.

Damatta FM (2004). Ecophysiological constraints on the production of shaded and unshaded coffee: a review. Field Crops Research 86:99-114.

Denis A (2003). Shade grown coffee plantations in Northern Latin America: A refuge for more than just birds and Biodiversity. Journal of Environmental Law and Policy 22:1.

Diriba M, Fassil A, Sileshi N, Granhall U (2011). Socio-economic benefits of shade trees in coffee production systems in Bonga and Yayuhurmu Districts, Southern Ethiopia: Farmers' perceptions. Ethiopian Journal of Education and Science P 1.

Food and Agricultural Organization (FAO) (2012). Special report on Crop and food security assessment in Ethiopia.Food and Agricultural Organization of the United Nations, Rome. FAO/WFP and Food security Assessment Mission to Ethiopia, 17 April, 2012.

Getahun Y, Zebene A, Solomon Z (2014). Wood production and management of woody species in Home gardens Agroforestry: The case of small holder farmers in Ginbo district, South west Ethiopia. International Journal of Natural Sciences Research 2(10):165-175.

Gole TM (2003). Vegetation of the Yayu Forest in South west Ethiopia: Impacts of Human Use and Implications for in situConservation of Wild Coffee Arabica L. Populations, PhD Thesis, University of Bonn, Germany.

Israel GD (2012). Determining Sample Size, Agricultural Education and Communication Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Science and Education. An Open Access and Academic Publisher

Mekuria T, Neuhoff D, Kopke U (2004). The status of coffee production and the potential for organic conversion in Ethiopia. Conference on International Agricultural Research for Development, University of Bonn. Institute of Organic Agriculture, Katzenburgweg 3, D-53115, Bonn, Germany, from October 5-7.

Mesele N (2007). Trees management and livelihoods in Gedios Agroforestry, Ethiopia. Journal of Forests, Trees and Livelihoods 17:157-168

Ministry of Agriculture and Rural Development (MARD) (2008). "Agricultural growth in Ethiopia". Ministry of Agriculture and Rural Development year bulletin. Addis Ababa.

Mohan S, Love J (2004). Coffee futures: role in reducing coffee producers' price risk. Journal of International Development 16:983-1002.

Motuma T (2006). Woody species diversity of agricultural landscapes in ArsiNegelle District, Ethiopia: Implications for biodiversity conservation," MSc Thesis, University of Hawassa, Wondo Genet College of Forestry, Wondo Genet, Ethiopia

Muleta D, Aseffa F, Nemmomisa S, Granhall U (2007). Composition of coffee shade tree species and density of indigenous arboscularmycorrhizaal fungi (AMF) spores in Bonga natural coffee forest, Southwestern Ethiopia. Journal of Forest Ecology and Management 241:145-154

Regina HR, Sambuichi DB, Vidal FB, Piasentin JG (2012). Cabruca agroforests in southern Bahia, Brazil: tree component, management practices and tree species conservation, Journal of Biodiversity Conservation 21(4):1055-1077.

Robert R (2011). Fruits from shade trees in coffee: how important are they? Journal of Agroforest System DOI 10.1007/s10457-011-9385-4.

Ruth N (2010). Local knowledge about trees and ecosystem services in coffee plantations in Rubavu and Rutsiro districts, Rwanda. Project submitted in partial of the requirements for the degree of Master of Science, Bangor University, Wales.

Samuel AY (2012). Farmers' Perception about the integration and management of shade trees in Cocoa farm (The *obroma cacao* L) at Ejisu-Juben district, Ghana. https://www.academia.edu

Santos R, Rodrigues L, Lima C, Jaramillo B (2012). Coffee Yield and Micro environmental Factors in a Native Tree Agroforestry System in Southeast Minas Gerais, Brazil. Journal of Sustainable Agriculture 36(1):54-68.

Soto-Pinto L, Villalvazo-Lopez V, Jimenez-Ferrer G, Ramirez-Marcial N, Montoya G, Sinclair FL (2007).The role of local knowledge in determining shade composition of multistrata coffee systems in Chiapas, Mexico.Journal of Biodiversity and Conservation 16:419-436.

Taye K (2009). Environmental Sustainability and Coffee Diversity in Africa. https://www.researgate.net

Twarog S, Kapoor P (2004).Protecting and Promoting Traditional Knowledge: Systems, National experiences and International dimensions, United Nations Conference on Trade and Development, New York and Geneva.

Yazachew E, Kasahun D (2011).). The National regional government of Oromia, Physical and socio economic profile of Guji zone districts. Bureau of Finance and Economic Development. The National Regional Government of Oromia, Addis Abeba

WWF (2013). Working with Indigenous and Local Knowledge Systems for the Conservation and Sustainable Use of Biodiversity and Ecosystem Services, an Analysis of Selected Case Studies, from WWF Projects Worldwide as a Contribution to IPBES-2. http://awsassets.panda.org/downloads/wwf_ipbes_ilk_information_2013.pdf