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Review

Enhancing agricultural sustainability and productivity under changing climate conditions through improved agroforestry practices in smallholder farming systems in Sub-Saharan Africa

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Fighting climate change and its nefarious effects is at the forefront of the United Nations' SDGs, agenda 2030. This comes at a time when the global climate is changing rapidly owing to increasing concentration of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere resulting principally from fossil fuel combustion and agricultural lands taking the place of tropical forests. Climate change threatens human existence in general and the livelihood of smallholder farmers in particular in the 21st century. Research shows that the developing world has about 500 million small-scale farms, with almost two billion people implicated, a majority of them in Asia and sub-Saharan Africa where small-scale farms produce about 80% of the food consumed. Hence, smallholder farmers will bear the greatest brunt of predicted changes in climatic patterns owing to their limited adaptive capacity. Small-scale farmers being appallingly vulnerable, easily succumb to climate-induced extreme weather events, thus threatening food security. It is therefore within this backdrop that the necessity to document and promote climate-smart, sustainable, productive and low cost agricultural practices becomes incumbent. Agroforestry is one of the few existing practices that contribute simultaneously to agricultural sustainability enhancement as well as improved farm productivity owing to its ability to provide many ecosystem services. There are currently very few existing agricultural practices where sustainable agricultural goals can be attained through simultaneous enhancement of agro-ecosystem diversity and farm productivity as in agroforestry systems. Today, few studies have looked into the contribution of agroforestry to beefing up agricultural sustainability and productivity in the context of climate change. This review paper therefore sought to research on what has been done so far as well as look into the way forward with focus on sub-Saharan Africa.

Key words: Climate change, agroforestry practices, agricultural sustainability, agricultural productivity, sub-Saharan Africa

BACKGROUND

Climate change is a key existential threats facing humanity in the 21st century, which explains why combating climate change and it nefarious effects features prominently amongst the seventeen (17) United

Nations Sustainable Development Goals (SDGs), agenda 2030 (FAO, 2016). Scientists have discovered that the major causes of this scourge are anthropogenic activities such as too much fossil fuel combustion and the transformation of tropical forest cover into agricultural lands. These human activities increase the concentration of greenhouse gases (GHGs) in the atmosphere especially carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) which has largely led to global warming and hence variability and changes in climate (IPCC, 2007). The impacts of climate change are wide ranging with one of the most significant being a shift of ecological zones: desertification of the Sahel, sahelization of the Savanna and savannization of the forests. Mankind has only two possibilities to get around the climate change scourge: adaptation and/or mitigation (UNFCCC, 2006; Sanz et al., 2017).

Sub-Saharan Africa which is the most tropical region in the world is already experiencing and is predicted to further face the full wrath of climate change (IPCC, 2001). Amongst those who are already suffering and are expected to suffer the most from exponential changes in climate, are smallholder farmers who depend almost completely on rain-fed agriculture coupled with the deeply entrenched poverty amongst this population strata (Bishaw et al., 2013; World Bank, 2013). This therefore leaves smallholder farmers appallingly vulnerable to the whims and caprices of a variable and changing climate. With the continuous wholesale neglect of rain-fed agriculture by policy makers in sub-Saharan Africa and failure to make adequate investment in inputs such as improved seeds, fertilizer and irrigation, smallholder farmers who are the principal actors involved in rain-fed agriculture increasingly find themselves on the back foot as far as keeping pace with the changing climate conditions is concerned (Cooper, 2004). The prevalent punitive environmental conditions have pushed smallholder farmers to indulge in unsustainable and less productive agricultural practices in their drive to counter the unpredictable climate conditions.

Increasingly, some relatively rich smallholder farmers in sub-Saharan Africa are taking to very intensive agricultural practices as adaptive measures to counter soil fertility loss caused by climate change and other drivers (Mboh et al., 2013a; Tondoh et al., 2015). These adaptive measures include application of mineral fertilizers, pesticides, insecticides and herbicides at rates that are far from being environmentally benign, all in a bid to increase agricultural productivity. Though these practices enhance agricultural productivity in the short run, in the long run, productivity reduces tremendously owing to the unsustainable nature of such intensive agricultural practices (Tondoh et al., 2015). Meanwhile the very poor smallholder farmers in sub-Saharan Africa (who constitute the bulk of the smallholder farmers' population) resort to practices such as clearing their farm plots by setting them on fire, shifting cultivation, and piling of cleared grasses within mounds of soil and burning them (a practice called "Ankara" in the North-West Region of Cameroon). All these practices lead to increased productivity in the short run but in the long run, crop productivity drastically reduces owing to the non-durability of such practices. Shifting cultivation in particular has been identified by various studies as being the main cause of deforestation in sub-Saharan Africa (Alao and Shuaibu, 2013; Vaast and Somarriba, 2014). With smallholder farming systems in sub-Saharan Africa facing sustainability and productivity crises especially under the current changing climate conditions, it therefore becomes incumbent to identify, document and promote sustainable, productive, pro-poor and climate-smart practices that can help smallholder farmers attain the twin goals of agricultural sustainability and productivity.

Factoring in the foregoing, agroforestry practices therefore come in handy as a partial panacea to remedy the deplorable situation of smallholder farmers in sub-Saharan Africa. This is because agroforestry is a dynamic, ecologically based, natural resources management system where in, trees are integrated in farms and in the landscape, thereby diversifying and sustaining production leading to increased social, economic and environmental benefits for land users at all levels (Leakey, 1996). Agroforestry practices constitute one of the most conspicuous farming systems across many parts of sub-Saharan Africa (Mbow et al., 2013a; Kabir et al., 2015; Lasco et al., 2015; CGIAR, 2017; Catacutan et al., 2017). Though very conspicuous, few studies have actually investigated the potential of this practice to enhance agricultural sustainability and productivity in sub-Saharan Africa. This review paper therefore seeks to unearth the potential contributions of agroforestry practices to agricultural sustainability and productivity enhancement in sub-Saharan Africa, in the context of climate change.

Categorization of major agroforestry practices in sub-Saharan Africa

Agroforestry practices can be classified under three (03) major systems (Table 1); agro-silvicultural systems, silvi-pastoral systems and agro-silvi-pastoral systems (Torquebiau, 2000; Garrity et al., 2006; Schoene et al., 2007; Rao et al., 2007). Agro-silvicultural systems are the

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Table 1. Agroforestry systems and practices in sub-Saharan Africa.

Systems	Practices	Combination	Components
Agro-silvicultural Systems	1. Improved fallows	trees planted during non-forest phase if land not expected to revert to forest	t: fast growing h: agricultural crop
	2. Taungya	crops during tree seedling stage	w: plantation species h: agricultural crops
	3. Alley cropping	trees in hedges, crops in alleys	w: coppice trees h: crops
	4. Tree gardens	Multi-species, dense, Mixed	w: vertical structure, fruit trees h: shade tolerant
	5. Multipurpose trees on cropland	trees scattered, boundaries	w: multipurpose trees h: crops
	6. Estate crop Combinations		w: coffee, coconut, fruit trees h: shade tolerant
	7. Homegardens	multistorey combinations around homes	w: fruit trees h: crops
	8. Trees in soil conservation, reclamation		w: multipurpose fruit trees h:crops
	9. Shelterbelts, windbreaks, live hedges	around farmland plots	w: trees h:crops
	10. Fuelwood Production	firewood species around cropland plots	w: firewood species h: crops
Silvi-pastoral Systems	11.Trees on rangelands	scattered trees	w: multipurpose, fodder f: present, a: present
	12. Fodder banks	trees for protein-rich cut fodder	w: leguminous trees h: present, a: present
	13. Estate crops with Pasture	For example cattle under coconut palms	w: estate crops f: present, a: present
Agro-silvi-pastoral Systems	14. Homegardens with Animals	around homes	w: fruit trees a : present
	15.Multipurpose woody hedgerows	trees for browse, mulch, soil protection	w: coppicing fodder trees a, h: present
	16. Aquaforestry	trees lining ponds	w: leaves forage for fish

Source: Schoene et al. (2007) in Rao et al. (2007) w: woody species, a: animals, h: herbaceous (crop) species.

most ubiquitous agroforestry systems found across landscapes in sub-Saharan Africa with about ten (10) practices scattered across different agro-ecological zones of the region. There are few silvi-pastoral and agro-silvi-pastoral practices in sub-Saharan Africa when compared to agro-silvicultural practices. This may be due to the simplicity and ease to manage agro-silvicultural practices when compared to the complexities associated with especially the agro-silvi-pastoral system. The multifarious agroforestry practices in sub-Saharan Africa portray the importance of these practices to smallholder farmers especially in the context of an increasingly variable and changing climate.

Agroforestry and agricultural sustainability enhancement in the context of climate change

Following Pretty (2007), the concept of agricultural sustainability today revolves around developing agricultural techniques and practices that have positive effects on the environment, easily available and effective to farmers, improves food productivity and positively impacts environmental goods and services. Sustainability in agricultural systems therefore embodies many concepts like resilience and sustenance, as well as other broader economic, social and environmental issues. The four (04) key principles of agricultural sustainability according to Pretty (2007) are; to integrate into food production processes, biological and ecological processes such as competition, parasitism, nutrient cycling, predation, nitrogen fixation, soil regeneration and allelopathy; to ensure that non-renewable inputs that are a menace to the environment or to the health of farmers and consumers are minimized; to make proper use of human capital by beefing up self-reliance and substituting costly external inputs through the putting into use of farmers' indigenous knowledge; and to solve common agricultural and natural resource problems, such as pest, watershed, irrigation, forest and credit management by making productive use of people's collective capacities to work together.

Catacutan et al. (2017) concludes that agroforestry practices fit perfectly within these principles of agricultural sustainability because they contribute immensely to addressing several sustainability issues through the provision of ecosystem services like biological diversity conservation, provision of wood and non-timber products, maintenance of ecosystem integrity, soil and water quality improvement, terrestrial carbon storage and multifarious socio-economic benefits. According to the World Bank (2004), about 1.2 billion rural persons around the world currently practice agroforestry on their farms and in their communities, and depend upon its products, and most of these people are smallholder farmers living in village communities in sub-Saharan Africa.

Climate change in particular and other drivers in general have led to a steady decrease in soil fertility thereby seriously destabilizing the practice of sustainable agriculture in sub-Saharan Africa (Young, 1989; Garrity et al., 2006; Oke and Odebiyi, 2007). Soil degradation especially topsoil erosion has worsened in recent years and is probably to be further worsened by prolong removal of crop residues and surface litter (Muchena et al., 2005). Discussions on food security in sub-Saharan Africa today have been tilted towards sustainable agroforestry practices owing to the shortage of mineral fertilizers, the inability of smallholder farmers to purchase the available mineral fertilizers and the poor performance of existing agricultural policies (Mbow et al., 2013a).

Agroforestry has enormous potentials to enhance the fertility of the soil (Catacutan et al., 2017). This is basically due to the fact that the leguminous trees integrated in agroforestry-based farming systems contribute to biological nitrogen fixation and an amelioration of soil organic matter. The role of green mulch from leguminous trees to the enhancement of soil fertility for associated crops in agroforestry systems in the tropics has been evaluated by many studies (Garnett et al., 2013). These studies have found in most cases that the integration of trees on farms enrich the soil with nutrients and organic matter and facilitate tighter nutrient cycling, as well as enhancing soil structural properties than monoculture systems (Mbow et al., 2013b). Waliyar et al. (2003) and Garrity et al. (2010) found that the integration of trees in farmlands helps with the recovery of nutrients, the conservation of soil moisture and the improvement of soil organic matter through the tapping of water from deeper soil horizons and preventing the leaching of nutrients.

Bayala et al. (2008) on their part found that trees integrated in croplands improved the structural stability of the soil, enhanced water infiltration through tree roots and increased the number of soil pores which improved water storage. Lott et al. (2009) demonstrated that, macro pores in the soil channel excess surface water flow and allow air and moisture to move into the soil speedily thereby reducing the risk of soil erosion; meanwhile tree roots and trunks reduce surface flow of water and sediment by acting as physical barriers. Mueller et al. (2012) found that, trees in croplands greatly influenced the addition of nutrients associated crops through the interception of rainfall, by way of throughfall (rainwater falling through tree canopies) and stemflow (rainwater falling down branches and stems). Molua (2006) stated in clear terms that agroforestry has huge potentials to reduce the yield gap, but this is largely dependent on the biophysical and human context under which it is practiced, hence he proposes a slate of improved agroforestry techniques such as soil improving trees, trees that grow very fast for fuel wood, indigenous fruit trees that provide added nutrition and income, and trees that provide medicinal plant products. This explains why Rice (2008); and Oke and Odebiyi (2007) emphasized on the absolute necessity to differentiate between simple agroforestry practices (like alley cropping, intercropping, life fences, and hedgerows) and complex agroforestry practices that function more or less like natural forest ecosystems but are still integrated into agricultural management systems (like multipurpose hedgerows and Aquaforestry).

Dosskey (2001) conducted a study which demonstrated that it is possible to reduce pollution from crops and grazed pastures through agroforestry. Following this study, tree strips located close to rivers, streams or lakes reduces water pollution from farmlands in five major ways: reducing surface runoff from fields; filtering surface runoff; filtering groundwater runoff; reducing bank erosion; and filtering stream water. According to Lott et al. (2009), trees in croplands have deeper roots which captures leached out nutrients from the crop rooting zone, reducing pollution and enhancing the efficiency of nutrient use. Lott et al. (2009) demonstrate that a permanent tree component helps to capture nutrients and store for use during the next planting season which is not the case with monocultures where the soil remains bare after harvest. According to Borin et al. (2009), buffer strips greatly reduce pollution from run-off, with reductions of between 70 to 90% for suspended solids, 60 to 98% for phosphorus and 70 to 95% for nitrogen. Borin et al. (2009) equally demonstrate that runoff can be reduced and infiltration increased if riparian buffers and other agroforestry practices are implemented by smallholder farmers.

Following a study conducted by Jose (2009), agroforestry practices contribute to the preservation of biodiversity owing to their naturally higher diversity of components than monocultures of crops and livestock which usually have a single component (crops only, livestock only or trees only). Jose (2009), further demonstrates that biodiversity can be preserved through agroforestry in five major ways: preserving the germplasm of threatened species; reducing the rates of transformation of natural habitat and reduce resource use pressure; habitat for species that can tolerate some degree of perturbation; providing connectivity through corridors created between habitat remnants and the conservation of threatened floral and faunal species; conserving biodiversity by providing ecosystem services like water recharge and erosion control, preventing the degradation and loss of habitats.

Schoeneberger and Ruark (2003), Du-Toit et al. (2004), McNeely and Schroth (2006), Harvey and Gonzalez-Villalobos (2007) and Bhagwat et al. (2008) have all demonstrated that, agroforestry plays a major role in conserving biodiversity. These studies show that agroforestry based farming systems integrate plant and animal species that are (in some cases) as rich and diverse as natural forests, but composed of mostly non-forest species.

Lal (2004), Verchot et al. (2007), Schoeneberger (2009), Nair et al. (2009), Catacutan et al. (2017), CGIAR (2017) and Sanz et al*. (*2017) have found that agroforestry practices in smallholder farming systems contribute to climate change mitigation and adaptation. Following Jose (2009), there has been an increase in research over the last two decades looking at the potential of agroforestry as a practice to tackle the nefarious effects of climate change. Research shows that agroforestry owing to the incorporation of trees and shrubs, increases the quantity of carbon sequestered compared to monocultures of crops or animals (Sanz et al., 2017). Following Schroeder (1994), a great amount of carbon is stored by woody perennials in above ground biomass as well as contributing to belowground carbon sequestration in soils. Nair et al. (2009) found that agroforestry systems store an estimated average of 21 and 50 Mg C ha^{-1} of carbon in sub-humid and humid zones, respectively. According to Dixon (1995), over fifty (50) years, agroforestry systems can contribute to sequester 1.9 Pg of carbon, following a worldwide estimate of 1023 million ha of agroforestry. Watson et al. (2000) on their part found that 585 to 1274 x 10^{6} ha of suitable land could be used for the establishment of agroforestry systems at the global scale contributing to storing 12 to 228 Mg C ha^{-1}. Thus, it is estimated that 630 million ha of unproductive croplands and grasslands could potentially sequester 586,000 Mg C yr^{-1} by 2040 should agroforestry systems take the place of these unproductive croplands and grasslands.

According to Oke and Odebiyi (2007), agroforestry systems constitute the third largest carbon sink in Africa after primary forests and long term fallows. Compared to monoculture systems, agroforestry systems contribute to greater abatement of greenhouse gases especially CO_2, N_2O and CH_4 (Mutuo et al., 2005). Albrecht and Kandji (2003) found that N_2O emissions are reduced drastically in agroforestry systems owing to a reduction in the application of supplementary nitrogen as inorganic nitrogen recycled from leaf litter and made available to associated crops. Thevathasan and Gordon (2004) ran models demonstrated that, the release of nitrates is reduced by an estimated 50% when compared to a monoculture based system. Models estimate that nitrates leaving a tree-based intercropping system can be reduced by 50% compared to a monoculture system. Agroforestry is therefore a multifunctional land-use system that contributes to climate change mitigation and adaptation simultaneously. There are few existing options that can do this, thus there is need to document, promote and encourage the adoption and implementation of sustainable agroforestry practices especially amongst smallholder farmers.

Studies have equally demonstrated that agroforestry-based farming systems provide various socio-economic benefits which go a long way to aid in adaptation to climate change and enhance the sustainability of smallholder farming systems (Smith, 2010). In the economic sphere, agroforestry practices enhance financial benefits through the diversity of local products and services they provide; advance the skills of the rural population and increases employment opportunities; and reduces reliance on fossil fuels for energy. Socially, agroforestry practices play cultural, aesthetic and recreational roles. Though the social aspect of agroforestry is often overlooked, its importance to the local population and the public cannot be underrated (Smith, 2010).

The World Agroforestry Centre (ICRAF) has conducted studies which show that agroforestry systems can contribute to the attainment of between six to seven Sustainable Development Goals (SDGs) (especially in the case of the rural poor and smallholder farmers in sub-Saharan Africa) which are: combating hunger, poverty, disease, illiteracy, environmental degradation, climate change and discrimination against women. ICRAF has demonstrated that agroforestry can contribute to the eradication of hunger through its ability to improve soil fertility and enhance the regeneration of land, thereby improving crop productivity and food security. Agroforestry can further contribute to poverty alleviation through the marketing of the numerous products and services obtained from agroforestry systems which improves the incomes of smallholder farmers.

Agroforestry can equally improve the health and nutrition of the rural poor through the utilization of medicinal plants, food crops, fruits and animal products found in agroforestry based systems. Agroforestry also contributes to reduce environmental degradation through the conservation of biodiversity *ex-situ* and the protection of watersheds. Combating climate change and its nefarious effects is also possible through agroforestry as it contributes to climate change mitigation through carbon sequestration especially by the tree component in the system.

Lastly, agroforestry contributes to the empowering of women thereby fostering gender parity. This is because agroforestry is mostly practiced by women in rural areas which give them the possibility to make income and be independent. With the "food-fuel-biodiversity" palaver continuing to be a thorn in the flesh of many development stakeholders, agro-ecosystem based farming systems like agroforestry become a necessity (Mbow et al., 2012; Fobissie et al., 2014). Little wonder, Leakey (2010) calls for the uptake of multifunctional landuse systems (like agroforestry) which simultaneously meet fuel, food, environmental and biodiversity protection needs as well as resilience enhancement to climate change. Smith (2010) conducted a study, which showed that there is a great desire by the research community and policy makers to find and promote agricultural systems that proffer environmental and ecosystem services, with agroforestry identified as one of the few existing practices today.

It was within this framework that, this study sought to look at the place of agroforestry in enhancing agricultural sustainability under changing climate conditions, especially its role in climate change mitigation and resilience enhancement in smallholder farming systems.

Agroforestry and agricultural productivity improvement under changing climate conditions

Agricultural productivity is generally seen as a measure of the amount of agricultural output produced for a given amount of input. Under changing climate conditions especially in the case of sub-Saharan Africa, the productivity benefits accruing from agroforestry-based farming systems are quite marveling. In studies conducted on agroforestry systems by Garity et al. (2006), Jackson et al. (2000) and Catacutan et al. (2017), there is general unanimity that a higher level of productivity occurs in agroforestry systems than in monoculture systems owing to the complementary relationship that exists between trees and crops, as the deep tap roots of trees capture and supply nutrients to crops that crops on their own would not capture. This fits squarely with the ecological theory of niche differentiation according to which resources are captured from different parts of the environment by different species. In a study carried out by Smith (2010), it was observed that crops are unable to absorb soil nutrients, water and leached nutrients from deep underground soil horizons hence the tree component on croplands helps to capture these nutrients and water, making it available at the level of the crop's rhizosphere. Garrity et al. (2006) found that, the complementarity that exists between trees and crops in an agroforestry system increase nutrient capture as well as crop yields compared to monoculture systems, owing to better nutrient cycling through leaf fall and fine root decay in the agroforestry system. A study conducted by Leakey (2010) found that agroforestry systems are endowed with a wide array of products and services such as food, fuelwood, timber, gums and resins, thatching and hedging materials, gardening materials, medicinal products, crafts products and recreation. Mead and Willey (1980) came up with a ratio for comparing productivity in agroforestry and monoculture systems, known as the Land Equivalent Ratio (LER). Following Mead and Willey (1980), "the LER is calculated as the ratio of the area needed under monoculture to the area of agroforestry at the same management level to obtain a particular yield". As stated by Dupraz and Newman (1997), "an LER of 1 indicates that there is no yield advantage of agroforestry compared to monoculture, while an LER of 1.1 indicates a 10% yield advantage that is under monocultures, 10% more land would be needed to match yields from agroforestry". Dupraz and Newman (1997), however found that the LER has a drawback which is the fact that, it does not take into consideration the services that agroforestry systems provide like air quality regulation, climate buffering, flood control, water quality regulation, and pest and disease control. This goes to show that, should all these services be taken into consideration when computing for the LER, agroforestry's productivity will far exceed that of monocultures.

A study conducted by Jose et al. (2004) demonstrated that agroforestry systems play a key role in microclimate buffering, especially its tree component. Following this study, trees on croplands play a positive role in inducing crop growth and animal welfare owing to their ability to buffer microclimatic elements like temperature, wind speed, and water vapour present in the atmosphere. Tamang et al. (2010) found that trees on croplands helped to reduce wind speed by up to 30 times the height of the trees on the leeward side, preventing crop destruction and increasing crop productivity. Tamang et al. (2010) further demonstrate that wind speed reduction by the tree component in agroforestry systems helps crops to grow faster, protects crops from windblown soil, controls soil moisture content and protects the soil from erosion, thereby leading to an increase in productivity. Brandle et al. (2004) conducted a study which demonstrated that higher air and soil temperature on the leeward side of trees found in agroforestry systems, helps to extend the growing season, as crops germinate earlier and grow faster at the start of the season. They equally discovered that, agroforestry systems bolster animal welfare as the multifunctional role of trees provides animals with resources like shelter from the rain and wind, shade from the sun, different foraging materials, and hideouts from predators. The trees can also benefit from the interaction with animals in a silvi-pastoral agroforestry system, as the excrements of the animals contribute to fertilize the trees and thus enhancing growth compared to a treeless rangeland (Ponder et al., 2005). This mutually beneficial relationship contributes to enhance the productivity of the system.

According to Schroth et al. (2000), agroforestry systems contribute to a reduction in pest problems owing the higher level of diversity and complexity present in agroforestry systems compared to monoculture systems. An earlier study had been conducted by Vandermeer (1989), showing that pest problems are attenuated in an agroforestry system due to several factors: pests find it difficult to discover plants due to a variable distribution of host plants; some associated economically valuable species are protected from attack because a plant species which is very attractive to pests can act as “trap-crop”; some plant species are repellant to pests which helps to deter the pests from attacking other palatable plant species in the vicinity; the spread of pests is limited owing to increased inter-specific competition between pest and non-pest species. Following Young (1989), Stamps and Linit (1998) and Schmidt and Tscharntke (2005), agroforestry systems if well managed enhances pest control owing to its ability to provide sources of adult parasitoid food like flowers and sites for oviposition, resting and mating as well as more structural and microclimatic diversity, more biomass, diverse pollen sources, nectar, and stable refuge for pests.

Wilkins (2008) conducted a study which showed that agroforestry systems help smallholder farmers to reduce the use of inorganic inputs. Following this study, it was found that the tree-crop interaction in agroforestry systems increases ecosystem efficiency through improved nutrient recycling thereby reducing the necessity for external inputs. The study further stated that a landuse system is ecologically efficient if, there is a greater efficiency and sustainability of the resources used in agricultural production. This efficiency is attained when a higher level of agricultural production is obtained using fewer resources while ensuring environmental protection. According to BCPC (2004), agroforestry possesses five key attributes which make it an ecologically efficient farming system: efficient use of resources especially renewable resources; no pollution both internally and externally; foreseeable output; ecological processes are aided through the conservation of biodiversity; ability to quickly respond to changes in the socio-economic and biophysical environment. The study shows that compared to monoculture systems, improved agroforestry systems can meet all five of the above mentioned criteria, thus enhancing the economic base and increasing farm profitability. Owing to the deeply entrenched poverty amongst smallholder farmers in sub-Saharan Africa, agroforestry systems are often managed conventionally with little or no additional inputs. This therefore permits agroforestry systems to realize their full potential as a sustainable and low-input system.

Young (1989) conducted a study which demonstrated that agroforestry systems favour the proliferation of soil micro and macro organisms owing to the differences in litter quality between the tree and crop components in an agroforestry system. The study further showed that soil micro and macro organisms carry out numerous soils biological processes leading to sustained productivity in agroforestry systems. Garrity et al. (2006) equally found that differences in the quality and quantity of litter in agroforestry systems leads to greater microbial diversity, increased enzyme activity and greater stability in agroforestry systems compared to monoculture systems. According to Schädler et al. (2010), Arbuscular mycorrhizal (AM) fungi present in most agroforestry systems, enhances crop yields while reducing the need for chemical fertilizer input. This is done through the facilitation of plant nutrient uptake and growth, soil aggregation and soil stability and the rate of litter decomposition. The foregoing discussion goes a long way to show that agroforestry is a good candidate for agricultural productivity enhancement under the prevailing changing climate conditions.

Trade-offs between sustainability and crop yields in agroforestry systems

In the food-focused smallholder farming systems in sub-Saharan Africa, trade-offs emerge between agricultural sustainability and improved crop yields (Figure 1a and b). With food demand expected to double in the next 50 years owing to population explosion, food production will become an issue and natural resources will be skinned terribly unless sustainability concerns are taken into consideration (Tilman et al., 2002). Studies show that agroforestry systems through the ecosystem services provide, contribute to agricultural sustainability enhancement than their monoculture counterparts (Elmqvist et al., 2011; Vaast and Somarriba, 2014).

However, studies also demonstrate that monoculture systems improve agricultural yields at the expense of other ecosystem services owing to limited diversity and limited competition between the components on the farm compared to agroforestry systems (Gockowski and Sonwa, 2010; Tondoh et al., 2015).

Under the current changing climate conditions in sub-Saharan Africa, agroforestry practices are therefore the best option for smallholder farmers as evidenced by the numerous ecosystem services they provide, which

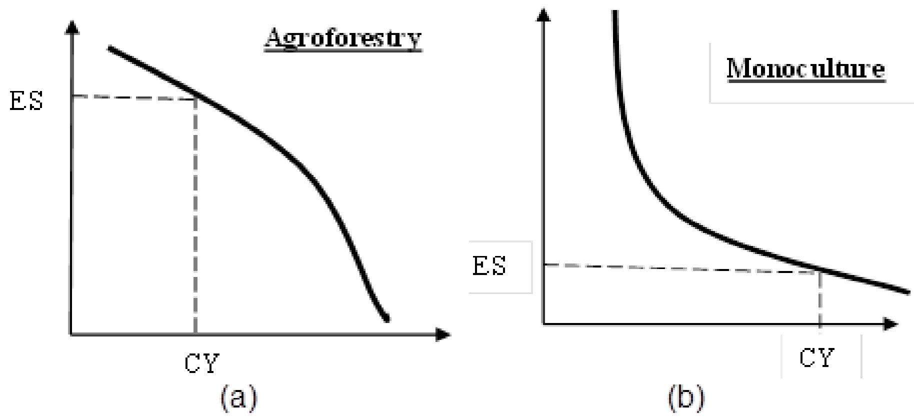

Figure 1. (a) Agroforestry and (b) Monoculture practices (ES = Ecosystem Services, CY = Crop Yields). Source: Adapted from Elmqvist et al. (2011).

contribute to enhance the resilience of smallholder farming systems. Monoculture systems are only able to enhance crop yields, but provide few or no ecosystem services, and under the prevailing changing climate conditions, monoculture systems are unsustainable (Tondoh et al., 2015).

Conclusion

This review paper found that sustainable agroforestry practices could contribute to the simultaneous attainment of the twin goals of agricultural sustainability and improved agricultural productivity in the context of climate change in sub-Saharan Africa. More attention therefore needs to be tilted towards agroforestry especially during international environmental conferences and forums owing to the social, economic and ecological benefits of this practice. Promoting agroforestry into the mainstream however necessitates three key tools: research, dissemination of information, and favourable policies.

Scientific research in the domain of agroforestry is still very limited and mainly global, thus the need for more locally based research in order to better decipher the realities on the ground (for local problems imperatively need local solutions). Awareness raising on the benefits of agroforestry amongst smallholder farmers is essential to trigger intensification as well as adoption and implementation. Favourable policies equally need to be implemented in order to incentivize smallholder farmers to take up agroforestry.

Factoring in the above it is imperative that locally based scientific research on agroforestry be conducted in sub-Saharan Africa adopting the participatory approach in order to understand farmers' problems and propose proper solutions. Additionally, research on agroforestry should be conducted to assess how to quantify and assign costs to the various ecosystem services provided by agroforestry-based farming systems, in order to pave the way for payments of ecosystem services to smallholder farmers practicing agroforestry.

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CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Lenght Reseach

Evaluation of improved potato (*Solanum tuberosum* L.) varieties for some quality attributes at Shebench Woreda of Bench-Maji Zone, Southwestern Ethiopia

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In Ethiopia, potato sub-sector is expanding, with more value added products, such as potato chips, mainly due to increasing demands associated with growth of population and urbanization. Processing industry is very dependent on the quality parameters of tuber to satisfy the increasing demand of customers. Thus, this experiment was conducted with the objective to evaluate the quality of some improved potato varieties at Shebench district of Bench-Maji Zone. The study comprised of nine improved potato varieties laid out in randomized complete block design (RCBD) with three replications. The tuber size distribution and proximate quality data were collected and analyzed by using SAS Version 9.2 statistical software. The results of the study revealed that all of the variables considered were significantly (P<0.01) affected by varieties except pH. Accordingly, considering tuber size distribution, the highest percentage of medium tuber was observed for Gudanie (77.4) followed by Belete (72.18). Whereas the highest percentage of large tuber was observed for variety Belete (17.35) followed by Shenkola (14.03). On the other hand, the least percentage of small tuber size was observed for variety Belete (10.47) followed by Gudanie (13.59). With regard to physicochemical qualities, the highest value of dry mater content (21.67%), specific gravity (1.08) and starch content (14.69%) were observed for Gudanie variety whereas Degemegn (3.28%) and Gudanie (3.27%) varieties showed the highest protein contents. Therefore, considering majority of the tested marketable and processing quality attributes, variety Gudanie can be considered as superior and recommended for the study area. In addition to this, growers in the study area can also use variety Belete for its good marketable tubers and varieties Gera, Gorebela and Chala for their acceptable processing quality.

Key words: Potato, variety, quality, gudanie.

INTRODUCTION

Potato, *Solanum tuberosum*, is the most cultivated not cereal crop in the world, ranking fourth after rice, wheat and corn (FAO Statistics, 2012). It represents an important component of human diet, because tubers are able to supply several nutrients, such as essential amino acids, vitamins (as vitamin C) and minerals (Melito et al.,

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2017). Between 1991 and 2007, the potato production in the world increased by almost 21%, interestingly, a massive increase of harvested tubers was shown by developing countries with approximately 94% (FAO, 2008). In Ethiopia, its production was estimated to be 0.92 million tons from an area of 0.07 million hectares by 1.2 million smallholder farmers (CSA, 2016/2017).

Nowadays, one of the most important aspects of potato production is tuber quality, that includes biological traits (e.g. proteins, carbohydrates, and minerals), sensorial traits (e.g. flavour, texture), and industrial traits (e.g. tuber shape, cold sweetening, starch quality) (Carputo et al., 2005). According to Rytel et al. (2013), the quality of potato tuber and their chemical composition are influenced by genetic factors, soil fertility, weather conditions and chemical treatments that are applied.

These days, the utilization of potatoes is shifting away from table consumption to processed products such as French fries, mashed and canned potatoes. Although the direct consumption of potato represents an important part of the market, more than 50% of tuber yield is used by processing firms (Carputo et al., 2005). Mainly in developed countries, approximately 60% of potatoes are consumed in a processed form; it is caused by the changing of consumers' lifestyle that prefer for greater convenience (Kirkman, 2007; Storey, 2007). In Ethiopia, majority of potatoes produced are used for preparation of different kinds of traditional foods. Recently, however, small-scale potato processors are flourishing in cities and big towns. These require a supply of raw materials with specific internal attributes and regular tuber size (e.g. for the production of French fries and chips, tubers must have a high specific gravity). So far many improved potato cultivars have been developed and widely used for commercial purpose all over the country. In developing these varieties, much emphasis was given to productivity per unit area and late blight reaction while less emphasis was given to quality. Moreover, information on the performance of varieties in relation to their tuber quality at Shebench woreda of Bench-Maji zone was not known due to lack of research in the area. For quality potato tuber production in the area, it is essential to evaluate the fitness of the released cultivars in terms of quality under the agro-ecological condition of the area and to incorporate quality as a yardstick in variety selection procedure for growers in the area. Hence, this study was initiated to evaluate quality of some released potato varieties in Shebench wereda of Bench-Maji zone.

MATERIAL AND METHODS

Description of the study area

The experiment was conducted at Ziagin Farmers Training Center (FTC) of She-Bench district, during 2015/2016-2016/2017 main cropping season. Geographically, the study area is located at 60° 52"N – 70`N, 35° 21``E with an altitude of 1950 m.a.s.l. The site has a bimodal rainfall distribution and receives mean annual rainfall ranging from 1801 to 2000 mm with mean minimum and maximum temperatures of 15.1 to 25°C, respectively. The area is considerably characterized by mid and high land and with high length of growing period (Masresha and Solomon, 2015).

Experimental materials and design

For this study, 9 potato varieties released by different research centers for different agro-ecologies of Ethiopia were used. Descriptions of the varieties are shown in Table 1. The experiment was laid out in a randomized complete block design with three replications. Each plot was 3 m × 3 m = 9 m^2 wide consisting of four rows, which accommodated 10 plants per row and thus 40 plants per plot. The spacing between plots and block were 0.5 and 1 m, respectively. Well-sprouted potato seed tubers of each variety were planted by hand in furrows at a depth of about 15 cm and at a spacing of 75 cm between rows and 30 cm between plants. According to EARO (2004) recommendation, 110 kg N ha^{-1} fertilizer in the form of Urea (in split: half at planting and the rest during flowering) and 90 kg of P2O5 ha^{-1} fertilizer in the form of side dressing at the time of planting (DAP) was applied. Management practices such as weeding; cultivation and ridging was practiced as per the recommendation (Gebremedihin et al., 2008). Harvest was under taken by hand when the leaves of 50% of the plants in the plot turned yellowish.

Data collection and analysis

Data on tuber size distribution and physiochemical quality analysis were recorded for individual response variables from the two harvestable middle rows of each plot.

Tuber size categories

Tubers from two central rows were graded into three groups considering size of tubers: <35 mm (small), 35 - 55 mm (medium) and >55 mm (large) (Hassanpanah et al., 2009; Abbas et al., 2012).

Tuber dry matter content (%)

Tubers from randomly chosen five plants per plot was washed, chopped and mixed. 200 g of sample was taken and pre-dried at a temperature of 60°C for 15 h and further dried for 3 h at 105°C in a drying oven (Zelalem et al., 2009). Finally, dry matter content was calculated as:

Dry matter content (%) = (Dry weight /Fresh weight) × 100

Specific gravity and starch contents (%)

They were computed from the recorded dry matter content. Consequently, the equation from Kleinkopf et al. (1987) of dry matter (%) = -214.9206 + 218.1852 × (specific gravity) and the equation from Von Schéele et al. (1937) of starch (%) = 17.565 + 199.07 × (Specific gravity – 1.0988) were used to convert the dry matter value of varieties in this study to specific gravity and starch content, respectively.

Tuber pH

Five potato tubers were peeled and homogenized in a juice extractor (Model 31JE 35 New Hartford Connecticut 06057 USA). The pH then directly measured using HI 9025 microcomputer pH

Table 1. Descriptions of potato varieties used for the study.

S/N	Variety	Released year	Breeder/Maintainer	Recommended altitude (m.a.s.l.)
1	Belete	2010	Holeta Research Centre	1600-2800
2	Gudenie	2006	Holeta Research Centre	1600-2800
3	Marachere	2005	Awassa Research Centre	1700-2700
4	Gera	2003	Sheno Research Centre	2700-3200
5	Gorrebella	2002	Sheno Research Centre	2700-3200
6	Jalenie	2002	Holeta Research Centre	1600-2800
7	Chala	2004	Haramaya University	1700-2000
8	Shenkola	2005	AwARC/SARI	-
9	Degemegn	2002	HARC/EIAR	-

meter and the test was performed in three replications according to Pardo et al. (2000).

Crude protein content

Potato tubers were sorted, washed, peeled, sliced and dried using an oven drying method. Dried samples were finely ground using a mortar and pestle to prepare the flour and then crude protein content was determined by micro-Kjeldahl method (digester F30100184, SN 111051, VELP Scientifica; distiller F30200191, SN 111526, Europe) of nitrogen analysis (% protein = %N × 6.25) by taking about 1.0 g potato flour (AOAC, 1994) using urea as a control in the analysis.

Data analysis

The raw data were subjected to analysis of variance (ANOVA) following the standard procedure given by Montgomery (2013). After fitting ANOVA model for those significant response variables, a mean separation was carried out using LSD method at 5% level of significance. All the statistical analyses were carried out using SAS-9.2 statistical soft ware package (SAS institute Inc, 2008).

RESULTS AND DISCUSSION

Results of ANOVA of eight quality characters for 9 improved Irish potato varieties are shown in Table 2. Accordingly, all the quality characters considered showed significant ($P<0.01$) difference among the tested varieties except pH which showed non-significant ($p > 0.05$).

Tuber size categories

Percentage of small sized tuber (%)

There was highly significant ($P< 0.01$) variation among the tested varieties with respect to small size tuber number in percentage (Table 2). The result revealed that significantly, the highest percentage of small tubers (34.35) was obtained from variety Maracharre, whereas the lowest and statistically similar values were recorded from Belete (10.47) and Gudanie (13.59) varieties (Table 3). These results are in confirmation with the findings of Bilate and Mululalem (2016) who reported that the highest and significantly different small sized tuber number per hill was recorded from Marrachare variety. The highest percentage of small size tubers observed in this experiment may be due to higher vigor of plants coupled with delayed maturity as reported by Sharma and Singh (2009).

Percentage of medium sized tuber (%)

Percentage of medium sized tuber was highly and significantly ($P< 0.01$) influenced by the tested varieties (Table 2). The highest percentage of medium sized potato tuber (77.44) was recorded from Gudanie variety followed by Belete (72.8) but the lowest percentage (60.68) was obtained from Maracharre variety (Table 3). This result is in agreement with the findings of Bilate and Mululalem (2016) and Habtamu et al. (2016) who observed highly significant variation among potato varieties with regard to percentage of medium sized potato tuber. Higher value observed for this variable might be due to rapid plant emergence and better plant growth as described by Kumar and Ezekiel (2006) and Patel et al. (2008).

Percentage of large sized tuber (%)

Percentage of large sized tuber was found to be highly and significantly ($P<0.01$) influenced by varieties (Table 2). Belete (17.35) produced significantly highest percentage of large sized tuber, while Jalenie (1.68) produced significantly the lowest percentage of large sized tuber (Table 3). This variation observed for percentage of large sized tuber could be genetically controlled. This result is similar to the finding of Habtamu et al. (2016) who confirmed that significantly highest number of large size tubers in percentage was calculated for Belete variety grown in eastern Ethiopia. Bilate and Mululalem (2016) also reported that large sized tuber

Table 2. Mean square values on some quality response variables of Potato (*Solanum tuberosum* L.).

Source of variation	DF	Tuber size categories (%)			Dry matter content (%)	Specific gravity (g/cm^3)	pH	Protein content (%)	Starch content (%)
		Small tuber (%)	Medium tuber (%)	Large tuber (%)					
Variety	8	213.02**	70.44**	83.44**	11.98**	0.00025**	0.026^{ns}	1.39**	9.97**
Block	2	3.27	6.13	2.24	0.78	0.000018	0.036	0.05	0.65
Error	16	0.73	1.57	1.99	0.45	0.0000099	0.03	0.06	0.38
Total	26	-	-	-	-	-	-	-	-
CV (%)	-	3.61	1.84	16.99	3.62	0. 29	1.77	9.12	5.17

In the column mean square values showed that **=highly significant at 5% level of probability, ns=non-significant at 5% level of probability, CV= coefficient of variation, DF=degree of freedom.

Table 3. Mean values of small, medium and large tuber percentage of improved potato varieties.

Variety	Tuber size category		
	Small tuber (%)	Medium tuber (%)	Large tuber (%)
Jalenie	30.06^{C}	68.26^{CD}	1.68^{E}
Belete	10.47^{E}	72.18^{B}	17.35^{A}
Degemegn	20.80^{D}	67.85 ^{CD}	11.35^{C}
Chala	29.95^{C}	66.39^{DE}	3.66^{DE}
Shenkola	20.42^{D}	65.54^{EF}	14.043^{B}
Gorebela	32.19^{B}	64.09 ^{F}	3.72^{DE}
Gera	21.11^{D}	69.91^{C}	8.99^{C}
Gudanie	13.59^{E}	77.443^{A}	8.97^{C}
Maracharre	34.35^{A}	60.68^{G}	4.97^{D}
$LSD_{0.05}$	1.48	2.17	2.44
CV (%)	3.61	1.84	17

Means followed by different letters in the same column are significantly different at 5% level of probability.

number per hill was significantly influenced by varieties. In general, the observed significant variations among the varieties for tuber size distribution may be attributed to inherent potential of the varieties.

Tuber dry matter content and specific gravity

Dry matter content and specific gravity of the potato tubers were very highly and significantly ($P < 0.01$) influenced by varieties (Table 2). Variety Gudanie produced the highest percentage of dry matter (21.67%), closely followed by Chala, Gera and Gorebela, which showed the same dry matter content (20%). Whereas the lowest value was recorded from Maracharre and Jalanie with 15.83% dry matter content. Similarly, the highest specific gravity was obtained for Gudanie (1.084) variety, followed by Gera, Gorebela and Chala, which showed the same value (1.080), and the lowest value (1.06) was observed for Jalanie and Maracharre varieties (Table 4). This variation in tuber dry matter content and specific gravity may be attributed to inherent genetic differences among the potato varieties in the production of dry matter (total solids) contents of tubers. This result is in confirmation with the report of Tekalign and Hammes (2005) who observed significant variation among cultivars with respect to total dry matter production.

Dry matter contents and specific gravity are important parameters of the potato tubers quality. According to Rommens et al. (2010) tubers with high specific gravity and dry matter generally give higher yields of French fries or chips of low oil absorption and better texture and are more economical to process. Processing of potato tuber into different products require tubers with dry matter contents greater or equal to 20% and specific gravity of greater or equal to 1.08 (Lefort et al., 2003; Abebe et al., 2013).

High dry matter has a direct effect on chips and French fries yield as the weight of the processed product depends directly on the amount of dry matter present per quantitative weight of fresh potatoes. Therefore, based on specific gravity and dry matter content selection criteria, from the tested varieties Gudanie, Chala, Gorebela and Gera meet these requirements and observed to be suitable for processing.

Table 4. Mean value of dry weight, specific gravity, starch content and crude protein content as affected by potato varieties.

Variety	Dry matter content (%)	Specific gravity (g/cm^3)	Starch content (%)	Crude protein content (%)
Jalenie	15.83^D	1.06^D	9.36^D	3.17^{AB}
Belete	17.50^C	1.07^C	10.89^C	3.14^{AB}
Degemegn	18.33^C	1.07^C	11.65^C	3.28^A
Chala	20.00^B	1.08^B	13.17^B	1.82^D
Shenkola	18.33^C	1.07^C	11.65^C	2.56^C
Gorebela	20.00^B	1.08^B	13.17^B	1.65^D
Gera	20.00^B	1.08^B	13.17^B	2.77^{BC}
Gudanie	21.67^A	1.084^A	14.69^A	3.27^A
Maracharre	15.83^D	1.06^D	9.36^D	1.82^D
$LSD_{0.05}$	1.1674	0.0055	1.065	0.4119
CV (%)	3.62	0. 29	5.17	9.12

Means followed by different letters in the same column are significantly different at 5% level of probability.

Total starch content (%)

There was highly significant (P<0.01) variation among the tested varieties with respect to total starch content (%) (Table2). Accordingly, Gudanie had significantly the highest total starch content (14.69) than the other varieties. This is followed by Chala, Gera and Gorebela which showed the same value (13.17%) and the lowest total starch content was observed for Maracharre and Jalanie (9.36%) (Table 4). The results are in line with that of Tsegaye (2014) who reported that the total starch contents of potato tubers are significantly influenced by potato genotypes. The significant differences in the tuber total starch contents among the potato varieties in this study could be attributed to varietal differences as suggested by Storey and Davies (1992) who reported that concentration and desired functional properties of starch could be achieved by the selection of potato cultivar. Potato varieties with a starch content of 13% and above are the most preferred for processed products (Kirkman, 2007). Thus, from the tested varieties, Gudanie, Chala, Gera and Gorebela had total starch content of 13% and above indicating that they are fit for processing.

Crude protein contents (%, dry matter basis)

Crude protein contents was significantly (P<0.01) affected by the varieties (Table 2). Variety Degemegn (3.28%) and Gudanie (3.27%) are statistically similar and were found to have the highest total crude protein contents as compared to the rest of the varieties (Table 4). The lowest crude protein contents were observed for the variety Gorebela (1.65%) and Chala (1.82%). This variation in the protein contents of the potato varieties in this study may have occurred due to differences in the varieties. The crude protein (N × 6.25) represents in tubers approximately 2% of a fresh weight that creates approximately 10% of dry matter, however, the crude protein content ranges significantly in dependence on genotype and growing conditions (Bártová, 2009).

Conclusion

The result of the current study revealed that potato varieties significantly affected all the tested quality attributes of potato tuber. According to this study result, with regard to tuber size distribution, Gudanie and Belete varieties were superior in percentage of medium sized tuber in decreasing order, whereas Belete and Shenkola in decreasing order showed high percentage of large sized tuber. On the other hand, the least percentage of small tuber size was observed for variety Belete followed by Gudanie. The highest value of dry mater content (21.67%), specific gravity (1.08) and starch content (14.69%) was observed for Gudanie variety. In addition to this, Gera, Gorebela and Chala varieties have also showed the acceptable range for processed products. In terms of protein content, Degemegn (3.28%) and Gudanie (3.27%) depicted significantly the highest value followed by Jallenie (3.17%) and Belete (3.14%). Therefore, it can be concluded from this study that for the majority of potato tuber quality attributes, variety Gudanie performed best in producing attractive and marketable tubers with superior processing quality. In addition to this, variety Belete can also be selected for its good marketable tubers whereas Gera, Gorebela and Chala varieties can also be grown for their acceptable processing quality.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Involving small holder farmers in the agricultural land use planning process using Analytic Hierarchy Process in rice farming systems of Kilombero Valley, Tanzania

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Despite the truth that the agricultural land use planning exercises have so far covered small and fragmented part of the African continent, the involvement of farmers who are among the direct beneficiaries of the outputs have been limited. This work demonstrates the contributions of farmers on the land use planning process for rice production in Kilombero Valley, Tanzania. Analytic hierarchic process (AHP) was used to assign scores of comparative importance of attributes for a suitable land for rice production. Scoring was done by three groups: farmers, extension staff, and joint group comprising both farmers and extension staff. Joint group scores were considered more refined as they were generated by discussions and consensus between the two groups. Results showed that the three groups sequentially ranked the attributes the same. However, the attributes actual scores were different. The farmers' scores were consistently close to the joint group's scores compared to the extension staff group. The closeness suggests superiority and consistence of farmers' perceptions of importance of the identified attributes used for this land use planning exercise. Thus, this study recommends more involvement of farmers in agricultural land use planning process for better and sustainable land use planning outputs.

Key words: Kilombero Valley, rice, land use planning, Tanzania, Analytic Hierarchic Process.

INTRODUCTION

Involving beneficiaries in the planning process is a way of increasing productivity and sustainability of resource utilization (Birendra et al., 2014; Pendred et al., 2016). Open and adequate involvement of beneficiaries minimize conflicts, provide in-built controls and incentives for decisions implementations, and provide policy alternatives that are more acceptable to the community (Wright, 1997; Herath, 2004). African small holder farmers have been at a receiving end of many decisions regarding land management practices. Often, this results

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to poor policy formulations, land resource use conflicts, poor crop and livestock productivity and increased land degradations (Turner et al., 2000; Mulder and Brent, 2006; Agbarevo, 2013).

Participatory land use planning has been suggested as a methodology toward sustainable land uses (FAO, 2004, 2005; Venema et al., 2009; GIZ, 2011). Despite the fact that the land use planning exercises have so far covered small and fragmented parts of the African continent, limited involvement of the direct beneficiaries has been common (Owei et al., 2010). Often, the people commissioned to do land use planning exercises use expert knowledge and tools which do not sufficiently involve farmers such as modern soil survey techniques, laboratory analyses, remote sensing, geographical information system (GIS), artificial intelligence, and other computer based models and programs (Malczewski, 2004; García et al., 2014). The land use planning processes come up with reports highlighting limitations, potentials and likely management strategies for sustainability of the current or proposed land use types (FAO, 1976, 2004, 2005; Collins et al., 2001; Kuria et al., 2011; Kihoro et al., 2013; Massawe, 2015). Participation of the current and potential land users in the process makes them own the process and outcomes of the work, thus enhances implementation of the best practices suggested by the reports.

Land resources are increasingly becoming scarce due to increased population, land degradation and climate change (Mueller et al., 2010; Elaalem et al., 2011). Sustainable use of the land is a critical factor in improving food production, especially in sub Saharan Africa where poverty and food shortages are currently more experienced, and population growth is faster than the rest of the world. The African population is projected to rise from 1.2 billion in 2015 to 2.4 billion in 2050 (You et al., 2014). This, therefore, necessitates prioritization of interventions which would sustainably tackle land degradation problems and sustainably increase food production, especially in areas that has great agricultural production potential due to availability of water resources and relatively fertile soils like the Kilombero Valley in Tanzania.

The Kilombero Valley covers an area of about 11,600 km^2 (Kato, 2007). It presents great potential for intensification of crop production, particularly low land rice production due to extensive network of seasonal and permanent rivers, and alluvial young soils. Like other parts of the country, the government of Tanzania has employed extension officers who offer technical support to the farmers to increase productivity. The working approach is predominantly putting the farmers; especially the small holders as receivers, assuming the extension officers know better and are the sources of solutions. This work is intending to demonstrate how small holder rice farmers in Kilombero can team up with the extension officers in land use planning process using a multi-stakeholders approach. Farming of rice, the third most important food crop in Tanzania (Wilson and Lewis, 2015) is characterized by many small holder farmers cultivating 0.2 to 4 ha of land (Massawe and Amuri, 2012; Tanzania Investment Center, 2013), with over 74% of production being under rain fed system (Wilson and Lewis, 2015). The average yields are low ranging from 1.0 to 1.5 t ha^{-1} (Bucheyeki et al., 2011), mainly due to poor agronomic practices.

Several attributes are used as inputs in the analysis to decide if a piece of land is suitable for a particular land use type (Marinoni and Hoppe, 2006; García et al., 2014, Massawe, 2015). The process considers not only the inherent capacity of a land unit to support a specific land use type sustainably, but also the socio-economic and environmental costs (Kuria et al., 2011; Samanta et al., 2011; Elsheikh et al., 2013). Thus, a decision about the best land use alternative is a result of a comparison of one or more alternatives with respect to one or more criteria that are considered relevant for the decision. Dealing with many criteria in making decision requires multi-criteria decision making (MCDM) approaches (Xu and Yang, 2001). The MCDM processes include use of scoring methods where, a score is used to express the decision maker's preference in numerical value. The Analytical Hierarchy Process (AHP) method (Saaty, 1988) is among the most popular scoring methods (Xu and Yang, 2001; Marinoni and Hoppe, 2006; Saaty, 2008; Elaalem et al., 2011; García et al., 2014). AHP can deal with inconsistent judgments by providing a measure of inconsistency. The method can also be integrated into other analytical applications such as GIS to provide greater flexibility and accuracy (Marinoni and Hoppe, 2006; Ahmed et al., 2007; Perveen et al., 2008; Kihoro et al., 2013).

This work demonstrates the contributions of small holder farmers when working with government extension staff on the land use planning process for rice production in Kilombero Valley, Tanzania. A multi-criteria approach is used while employing AHP method.

METHODS

The study area

The study was conducted in Kilombero Valley, Tanzania (Figure 1). The valley is part of Rufiji Basin, and collects water from the Great Rift Valley Escarpment and the Mahenge Mountains (Figure 2). The study site is occupying the area lying between 9064697 and 9089031 m northing and 175422 and 197033 m easting (UTM zone 37 south). It covers land of about 300 km^2 within Mngeta Mchombe and Mbingu areas of Kilombero district.

The Kilombero Valley is crisscrossed by numerous permanent and seasonal rivers which contribute to the Kilombero River (Bonarius, 1975). The valley has annual rainfall ranging between 1000 and 1800 mm, with areas closer to the escarpment and Mahenge highlands getting higher rainfalls. The mean daily maximum and minimum temperature varies from 22 to 28°C, while the relative humidity is between 70 and 90%. Major part of the

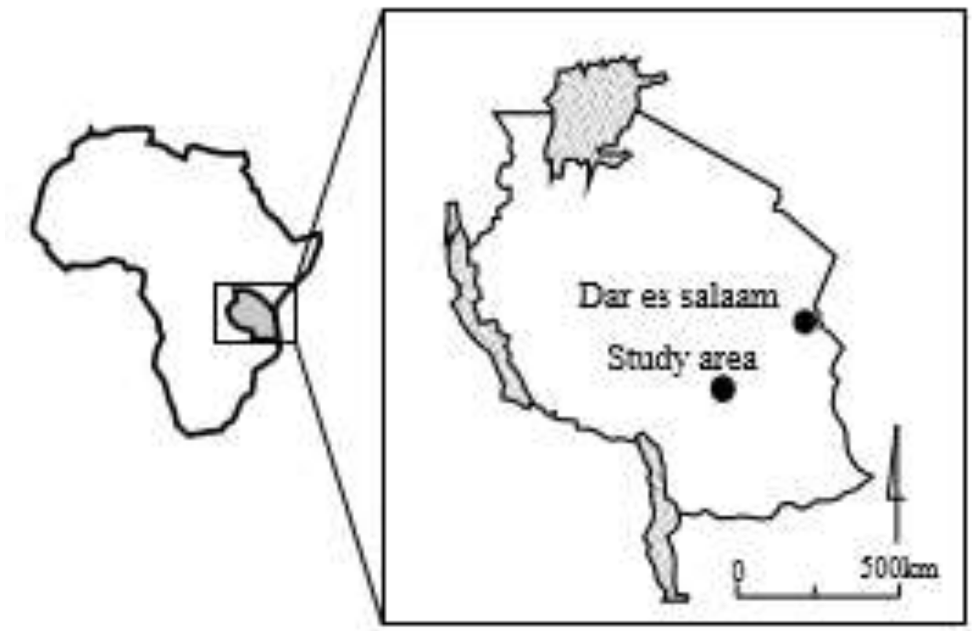

Figure 1. Location of the Kilombero Valley, Tanzania.
Source: Adopted from Kato (2007).

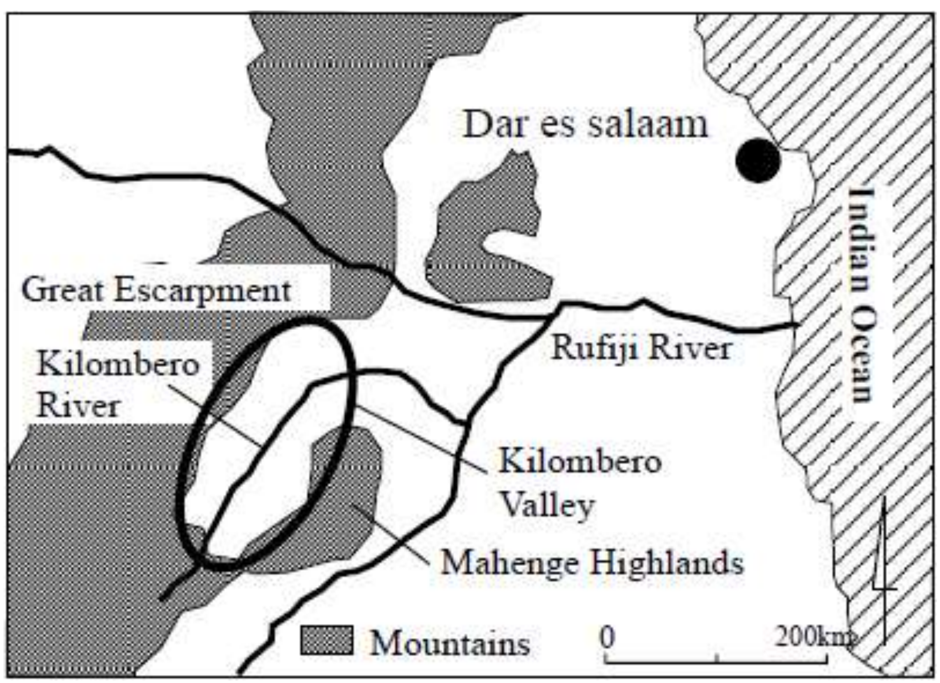

Figure 2. The Kilombero Valley.
Source: Adopted from Kato (2007).

study area is used for agriculture, mainly small holder's lowland rice production. Natural vegetation is dominantly tall grasses, mainly elephant grass (*Penisetum purpureum*), guinea grass (*Panicum maximum*), *Hyparrhenia* species and reed (*Phragmites mauritianus*) which cover protected areas close to the centre of the valley. The soils of the area are generally young alluvial soils.

Identification of the multi-criteria evaluation attributes

The attributes to be considered for the multi-criteria land evaluation for rice production suitability were identified through a combination of literature search and focused group discussions. Four lead farmers and five extension staff from three wards (Mchombe, Mngeta and Mbingu) covering the study area were used in the discussion. The lead farmers were identified with help from respective ward leaders and extension staff based on a set of criteria which included: active participation in farm activities (farm ownership and engagement in rice production), evidence of relatively higher productivity emanating from improved agronomic practices and adoption of extension services compared to other farmers, active participation in previous trainings offered by different facilitators with focus on agricultural production, and active participation in farmers groups activities including leadership roles.

The following attributes were identified as important for rice production, hence were included in the multi-criteria suitability analysis for rice production:

(1) Soil physical properties: These included physical attributes of the soil that have influence on flooded rice production, water infiltration rates, surface runoffs, workability, rooting, and water holding capacity (Landon, 1991; Lal and Shukla, 2004).
(2) Soil chemical properties: These included attributes such as levels of soil pH, soil organic matter, soil micronutrients and macronutrients (Havlin et al., 2005; Brady and Weil, 2010).
(3) Accessibility: This referred to the roads/paths network. For this criterion, reference was made on how easily people can reach their farms (Marinoni and Hoppe, 2006).
(4) Distance to market: This criterion referred to distance from the farms to village centres or sub towns where buyers normally put buying posts (García et al., 2014)
(5) Surface water resources: This criterion referred to the network of rivers and streams. Distances to rivers and streams are related to amount and duration of floods which are crucial for lowland rice production (Bonarius, 1975).
(6) Terrain: This referred to the shape and steepness of the slope gradient of the land (Gallant and Wilson, 2000).

Attributes scoring

The Analytical Hierarchy Process (AHP) method (Saaty, 1988) was used to give scores to the identified attributes. Lead farmers and extension staff were used for this exercise. Firstly, each group performed their own scoring. Secondly, a joint group comprising farmers and extension staff performed a joint scoring of the attributes. Hence, three sets of scoring were done.

In the process of scoring the criteria (attributes), a pairwise preference matrix was prepared. The verbal terms of the fundamental Saaty's scale (1-9) (Saaty and Vargas, 1991) were used to assess the preference between two compared criteria at each instance in the matrix and to translate the verbal judgement to quantitative information (Table 1).

Each one of the comparison matrices assumed the form:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

where a_{ij} represents the pairwise comparison rating for attribute *i* and attribute *j*. The matrix has reciprocal property, thus if $a_{ij} = x$, then $a_{ji} = 1/x$ where $x \neq 0$.

The comparison (preference) matrices were used as inputs in BPMSG AHP online priority calculator (Goepel, 2014). The outputs from the calculations were the consistence ratios (CR), the Principal Eigen values and weights of the attributes.

The matrices were solved using the eigenvector method to derive the priority vectors and the maximum eigenvalue. The eigenvector method utilizes Equation 2.

$$\sum_{n}^{j=1} a_{ij}\, w_j = \lambda_{max} w_{ij}\,,\ \forall i a_{ij} (a_{ij} = \frac{1}{a_{ij}}\ and\ a_{ij} > 0) \quad (2)$$

where *i* and *j* represent coordinate positions in the matrix and the corresponding preference ranking on the Saaty scale and λ_{max} represents the maximum eigenvalue. The second half of the equation shows the matrix is reciprocal and non-negative. The equation generates the weight/priority vector w_i, of each attribute. The weights for all attributes must add up to 1 (Equation 3).

$$\sum_{i=w}^{n} w_i = 0 \quad (3)$$

The weights were then used to rank the attributes from most important to least important. A consistency ratio (CR) was calculated to determine whether or not the scoring groups had been consistent with their scoring (Equation 4). Revisions of the preference matrices were done when the CR was above 10%.

$$CR = \frac{CI}{RI} \quad (4)$$

where *CR* is the consistency ratio, *CI* is the consistency index, and *RI* is the random consistency index. The consistency index can be represented as:

$$CI = \frac{(\lambda_{max} - n)}{n-1} \quad (5)$$

where *n* is the number of performance indicators and λmax is the maximum eigenvalue.

Attribute scores and ranking were generated for each of the three groups. The rankings were compared for each group, and the calculated attributes scores were compared using percentage differences between the farmers, extension staff, and joint groups.

RESULTS AND DISCUSSION

AHP criteria scores by extension staff group

The preference matrix of the attributes prepared by Extension Staff group is shown in Table 2. The highest preferences were recorded in comparisons of surface water resources and soil chemical properties against distance to markets. According to the verbal scale definitions (Table 1), the group has sufficient evidence that availability of water and soil fertility status are more important than distance to market for rice production at the highest possible order of affirmation. Most of the farmers sell some or most of the harvested rice immediately after harvesting to pay debts and cover the harvesting and transportation costs (Ngailo et al., 2016). Buyers set buying posts within the fields, and village centres, while some go to the farmer’s specific fields

Table 1. Fundamental Saaty's scale for comparative judgments (Saaty and Vargas, 1991).

Intensity of importance	Definition (verbal scale)	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong importance	An activity is favoured very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals	If activity *i* has one of the above numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

Table 2. Extension staff group's preference matrix on factors important for rice production land use type.

Criteria	Soil physical properties	Soil chemical properties	Accessibility	Distance to market	Surface water	Terrain
Soil physical properties	1.00	0.33	5.00	7.00	0.20	3.00
Soil chemical properties	3.00	1.00	7.00	9.00	0.50	9.00
Accessibility	0.20	0.14	1.00	2.00	0.17	0.33
Distance to markets	0.14	0.11	0.50	1.00	0.11	0.25
Surface water resources	5.00	2.00	6.00	9.00	1.00	7.00
Terrain	0.33	0.11	3.00	4.00	0.14	1.00

Table 3. Criteria weights and ranks derived from extension staff's preference matrix.

Criteria	Weight	Rank
Surface water resources	0.414	1
Soil chemical properties	0.316	2
Soil physical properties	0.139	3
Terrain	0.066	4
Accessibility	0.039	5
Distance to markets	0.025	6

waiting to collect the fresh harvests. In their FAO (2015) report on the rice value chain in Tanzania, Wilson and Lewis (2015) describe the rice value chain as being dominated by a large numbers of small-scale producers, an unknown (but undoubtedly immense) number of middlemen who operate across every link, and a similarly unknown number of small processors. This might be the reason for the lowest preference the distance to market attribute got when compared with surface water resources and soil chemical properties. However, it should be noted that costs of transportation and harvesting increase with distance from the village centres where majority of the buyers set their buying posts.

The criteria weights calculated from the matrix and their respective rankings are shown in Table 3. Results show that surface water resources criterion was given higher importance for rice land use type in the study area by the extension staff compared to other identified criteria. It scored 41.4%, followed by soil chemical properties (31.6%) and soil physical properties (13.9%). Distance to market and accessibility of the farms were given the lowest two priorities by scoring 2.5 and 3.9%, respectively.

Given the major land use type being lowland rice production, it is not surprising to see availability of water being ranked the highest by this group. With rain fed

Table 4. Criteria weights and ranks derived from farmers' decision matrix as compared to extension staff group weights.

Criteria	Weight (by farmers)	Weight (by extension staff)	Rank
Surface water resources	0.419	0.414	1
Soil chemical properties	0.245	0.316	2
Soil physical properties	0.200	0.139	3
Terrain	0.076	0.066	4
Accessibility	0.033	0.039	5
Distance to markets	0.026	0.025	6

system being the dominant (Wilson and Lewis, 2015), it is also not surprising to see topography (terrain) ranked just below the soil properties. The production system banks on water loging resulting from seasonal rains and to a large extent, the overflows of the rivers which receive water from the Mahenge highland and the plateau which direct the water to the valley through numerous rivers and channels down the rift valley wall extending a distance of over 100 km west of the valley.

AHP criteria scores by lead farmers group

The criteria weights derived from the farmers' matrix are shown in Table 4. The order of ranking of the criteria from the most to the least important was similar to that of extension staff's group (Tables 3 and 4). However, there were differences in actual weights given to the criteria by each group, indicating differences in perceptions about the importance of each criterion on rice productivity and sustainability between the extension officers group and the farmers group. This is not new when comparing experts and common users of land resources. Overlaps may appear among criteria between the groups of the stakeholders, and the criteria may be perceived having the same importance by both groups. However, the difference can be seen in terms of hierarchical order of those factors and their respective priority values. In a study of community users' and experts' perspective on community forestry in Nepal using AHP (Birendra et al., 2014), both groups believed that community forest management was generally a positive strategy for forest management. However, the level of magnitude of scores given by the two groups differed. Community users combined positive priority value was found to be 76%, while that of the experts was found to be 69%. Groups consisting of people with similar expertise and working on the field but in different setting have also been found to have different opinions. For example, in a resilience-based approach for comparing expert preferences across two large-scale coastal management programs in Masan Bay, USA and Puget Sound, Korea study; the technical experts in the two regions showed several significant differences in their preferences for management objectives (Ryu et al., 2011).

The extension staff and the farmers groups appeared to give almost similar magnitude of weights to the surface water resources which is also the highest ranked criteria. Extension staff gave it a weight of 41.4%, while farmers gave it 41.9%. Close magnitude of importance was also given on terrain and distance to markets (Table 4). This indicates farmers and extension staff had more or less similar perceptions on importance of some of the criteria identified for low land rice production.

The two soil based parameters: soil physical properties and soil chemical properties received different magnitudes of importance by the two groups. The extension staff gave soil chemical properties importance score of 31.6%. To farmers, the criterion was less important and they gave it a 24.5% score. The importance of soil physical properties scoring by farmers did not differ much with soil chemical properties as compared to the perception of the extension staff on the two parameters (Table 4). To extension staff, the two soil properties received much different weights, where soil chemical properties were ranked higher than soil physical properties. Understandably, soil physical properties such as soil texture and soil depth can be more important factors in deciding on agricultural land use because they are not easily modifiable. Soil chemical properties can be modified in relatively shorter times by application of agricultural inputs such as fertilizers and lime (Brady and Weil, 2010)

The magnitudes and directions of differences in perceptions per each criterion for the two groups as indicated by differences in the criteria weights shown in Figure 3. The extension staff group perception of the importance of soil physical properties on rice production was lower by 30.5% compared to that of the farmers group. Their opinion about the importance of soil chemical properties was higher by 29% compared to the farmers' while that for accessibility was also higher by 18.2%. The extensions staffs perception of importance was lower than the farmers' perception on terrain by 13.2%. Farmers and extension staffs appear to agree on the magnitude of the importance of surface water resources and distance to market, as extension staffs scoring of the criteria was only 1.3 and 3.3%, respectively

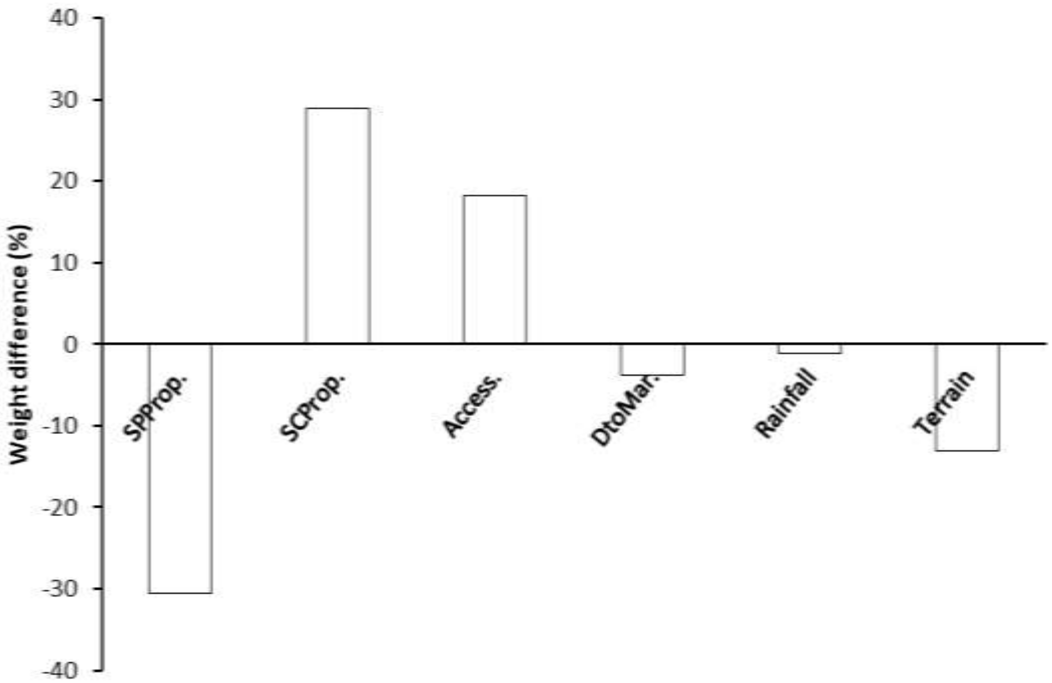

Figure 3. Extension staff's and farmers' differences in perception of importance of criteria identified for allocating the land for rice production in Kilombero Valley. At value 0, there was no difference in perception between the farmers and extension staff on the importance of that attribute for rice production. Negative values imply extension staff gave lower importance to the attribute than farmers by that value. Positive values imply extension staff gave higher importance to the attribute than the farmers by that value. SPProp. = Soil physical properties; SCProp. = Soil chemical properties; Access. = Accessibility; DtoMar. = Distance to markets; Rainfall = Surface water resources; Terrain = Terrain.

below the farmers scoring.

There were no clear explanation on what lead to the differences in perceptions between farmers and extension officers. Despite comparatively low level of formal education of the farmers to that of extension staff, they appeared to quickly and comfortably grasp the whole AHP exercise and relate it to their farming activities. This was confirmed by the low inconsistency results from their first preference matrix before revision (CR = 11.5%). Other studies of similar nature have also recorded higher consistence by the beneficiary consisting of less formally educated group. For example, in an AHP study which looked at developing and prioritizing performance indicators for Maria Island Marine Nature Reserve in Australia involving groups of managers, fishers, and researchers were the most consistent group (Pendred et al., 2016).

Both extension staffs and farmers participate in rice production by owning farms. However, the farmers participate directly in the farming practices by leading the family labour force, and working with hired labour. The extension staffs have lesser time to do the day to day management of their farms compared to farmers because of the employment commitments. This may lead to less exposure of extension staff to real challenges facing the farmers. In a study by Amalu (1998), he noted that several among qualified scientists are knowledgeable in pure basic research but grossly inexperienced in applied or adaptive research methodologies. This can be true also when it comes to extension services where extension staff might lack hands-on experience in farming activities.

AHP criteria scores by the joint group for rice production land use type

The first decision matrix from the joint group showed high inconsistency (CR = 23.5%). The high inconsistency indicates the difficulty the joint group had in reaching consensus during preparation of the preferential matrix. A revised matrix with CR = 7.9 was later generated by the joint group. The calculated criteria weights and ranks based on the revised decision matrix shown in Table 5, together with scores from individual farmers and extension staff groups' scores for comparison purpose.

The results of criteria ranking by the joint group were similar to those ranked by extension staff and farmers groups separately. This, again, shows groups general agreement on importance of one criterion over the other.

Table 5. Weights and ranks of criteria from extension staff's, farmers', and joint group.

Criteria	Extension staff group		Farmers group		Joint group	
	Weight	Rank	Weight	Rank	Weight	Rank
Surface water resources	0.414	1	0.419	1	0.462	1
Soil chemical properties	0.316	2	0.245	2	0.234	2
Soil physical properties	0.139	3	0.2	3	0.19	3
Terrain	0.066	4	0.076	4	0.052	4
Accessibility	0.039	5	0.033	5	0.036	5
Distance to markets	0.025	6	0.026	6	0.025	6

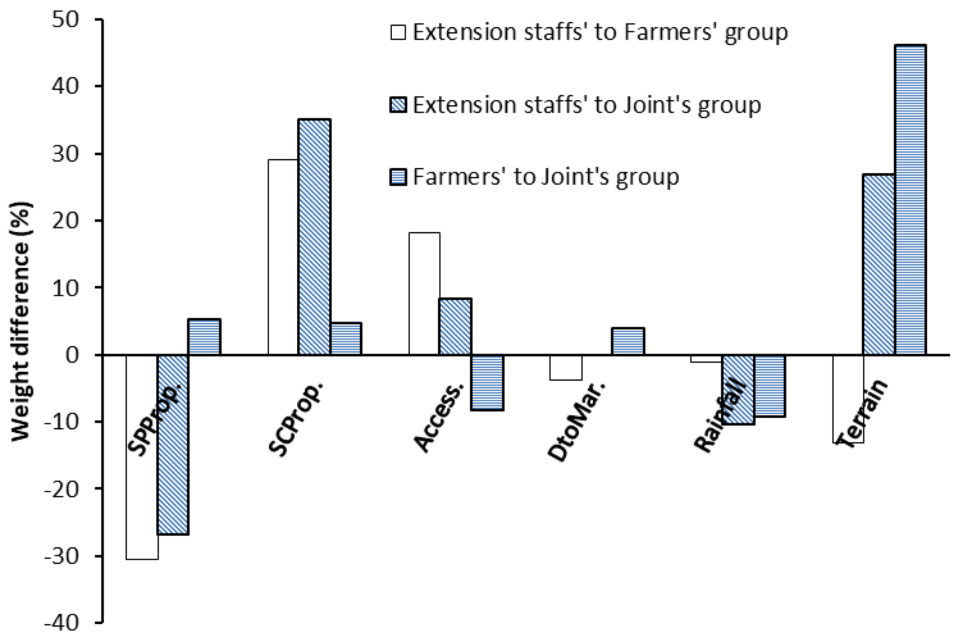

Figure 4. Extension staff's, farmers', and joint group's differences in perception of importance of criteria identified for allocating the land for rice production in Kilombero Valley. At value 0, there was no difference in perception between the groups on the importance of that attribute for rice production. Negative values imply the group gave lower importance to the attribute than the one it is compared with. Positive values imply the group gave lower importance to the attribute than the one it is compared with. SPProp. = Soil physical properties; SCProp. = Soil chemical properties; Access. = Accessibility; DtoMar. = Distance to market; Rainfall = Surface water resources; Terrain = Terrain.

However, there were differences on weights given for each criterion, differing from both the farmers and the extension staff groups.

Percentage differences in criteria weights between the joint group and the former two groups are depicted in Figure 4. The farmers' group prioritization of soil physical properties criteria was higher by 5% while that of extension staff was lower by 26.8% compared to the joint group prioritization of the same criterion. On the soil chemical properties criterion, farmers' scoring was higher by 4.7% while that of the extension staffs was higher by 35% over the joint group's scoring. It can be observed that the farmers' group scores for both physical and chemical soil properties were very close to the joint group's scores as compared to those of the extension staff. On the importance of accessibility, farmers' criteria were lower by 8.3% while those of extension staff were higher by 8.3%. The extension staffs' perception of the importance of distance to market criteria was the same as that scored by the joint group, while that of farmers group was up by 4%. There was no much difference between the farmers and extension staff differences against the joint group on the groups' priorities given to the surface water resources criteria. The farmers' weight was lower by 9.3% while that of extension staff was lower by 10.4%. On terrain, the joint groups' results suggest that the farmers group emphasized the importance of terrain by 46.2% while the extension staff was 26.9%.

From these results, it is observed that famers' weights were generally very close to the joint group's weights except for the terrain criterion (Table 5 and Figure 4). The differences between farmers' weights and joint group's weights are less than 10% for five out of six criteria, while only two criteria have their differences below 10% for the extension staff's weightings. This suggests that the farmers' were more consistent on assigning scores to the criteria compared to the extension staff. The farmers' consistence might be attributed to the hands-on experience they have in rice production, or un-preparedness of the extension staff.

The high inconsistence demonstrated in the side of the extension staff suggests the need to involve farmers in decision making process for better and sustainable land use planning. While studying farmers' perception of effectiveness of agricultural extension delivery in Cross-River State, Nigeria, Agbarevo (2013) found that extension delivery scored poor performance especially with farming system research and farmers training programmes partly due to being inadequately prepared for face to face dialogue with farmers. Another explanation could be giving up by extension staff group, since farmers have more stakes on the exercise. Despite the measure of inconsistence during the decision making using AHP scoring method, it is difficult to assess how group consensus was reached. Group interests may influence the final decision. For example, in a study conducted in Australia to incorporate community objectives in improved wetland management using AHP, it was observed that the conservation group predominantly preferred option where no investment is made and the wetland is maintained in its pristine condition, the business group predominantly preferred option where maximum investment can be made, while the recreation group predominantly preferred option where some investment is also made (Herath, 2004).

These results may lead to refocusing of decision making process for projects and programmes involving small holder farmers in Africa, where the top down approach has been common and the experts, including extension staff assume superiority in knowledge (Beynon et al., 1998; World Bank, 2007; Agbarevo, 2013). The process can also be used in policy formulation.

While this study has employed AHP method in land use planning for rice production, the strength of the tool can be applied in other decision making processes requiring involvement of all stakeholders. The tool has been used elsewhere in issues requiring stakeholders participation in decision making processes in public administration, environmental management, sustainability and energy issues, and agricultural policies (Duke and Aull-Hyde, 2002; Oddershede et al., 2007; Xu et al., 2012; Chávez et al., 2012; Kurka, 2013; Kukrety et al., 2013). Despite the flexibility of the AHP and that it can be adapted to different needs and contexts such as in ranking, choices, resource allocation, prioritization and conflict resolutions; the evaluation and analysis in AHP can become complicated when the number of the options and criteria are becoming higher (Bharwan et al., 2013). Also, it should be noted that the success of the AHP method depends on correct structuring of the decision problem, how the pair wise comparisons are carried out, and provision of credible answers by the respondents.

Conclusion

This work involved farmers in a land use planning process whereby six attributes identified as important for rice production were scored and ranked using AHP. Farmers and extension staff agreed on overall importance of each identified criteria by ranking them the same, but differed on the scores of some of the attributes. Farmers' scores of the attributes were consistent and made a better representation of the rice growing situation in Kilombero Valley, such as not putting overemphasis on soil chemical properties, which can be addressed by application of appropriate fertilizer or lime, over the soil physical properties, which cannot be easily rectified. This study demonstrated the ability of the farmers to influence the land use planning process in a positive way since they know their areas better by working on it. Involving the land users in such exercises will contribute towards sustainable land uses and improved agricultural production. Similar process can be adopted to get participation of all stakeholders in policy formulations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Boosting self-sufficiency in maize crop production in Osisioma Ngwa Local Government with internet of things (IOT)-climate messaging: A model

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The cultivation of maize round the year is a great challenge to both subsistence and mechanized farmers in Abia State owing to the changes in climatic conditions especially precipitation, relative humidity, and temperature during the two traditional seasons, which affect the growth and yield of the cereal crop. This paper is the first of a two-part study aimed to evolving an internet-based remote monitoring and messaging system for farmers in the Umueze-Umuchi communities and other connected areas in Osisioma Ngwa Local Government of Abia State to enable monitoring of vital climatic conditions that are much likely to affect their maize farms during the dry season. This study is descriptive and presents succinct information on maize cultivation in the communities with recourse to topography, relief and drainage, climate, soil and vegetation of the area. Data were collected through observation and interview of selected farmers. The vital atmospheric conditions required for maize farming such as temperature, vapour pressure, and relative humidity were noted to vary during the seasons: rainy and dry seasons, respectively. Data from farmers showed that maize cultivation begins in early march following early rainfall and actively ends around June when the volume of precipitation is at its peak. No maize cultivation is done during the dry season beginning from early November owing to low precipitation regardless of the presence of the Aba River across these communities. Consequent upon the findings, the authors are led to examining the option of all year-round maize cultivation aided by an internet of things (IoT)-enabled climate monitoring system in order to boost maize production in the aforementioned communities. It is submitted that the use of the monitoring device will enable the farmer know when to complement the adverse climatic conditions during the dry season thereby enhancing maize cultivation round the year.

Key words: Osisioma Ngwa, Abia State, maize farming, internet of things (IoT), food production, climate monitoring system.

INTRODUCTION

Research has shown that Africa faces great challenges in the production of cereal crops of which Maize is the largest (Macauley and Ramadjita, 2015). This is against the backdrop that maize forms the highest percentage of calorie intake in the national diet of 22 countries of the world, sixteen of which are domiciled in Africa (Blein, 2013). According to a United Nations report, Maize accounts for almost 50% of the calories and protein

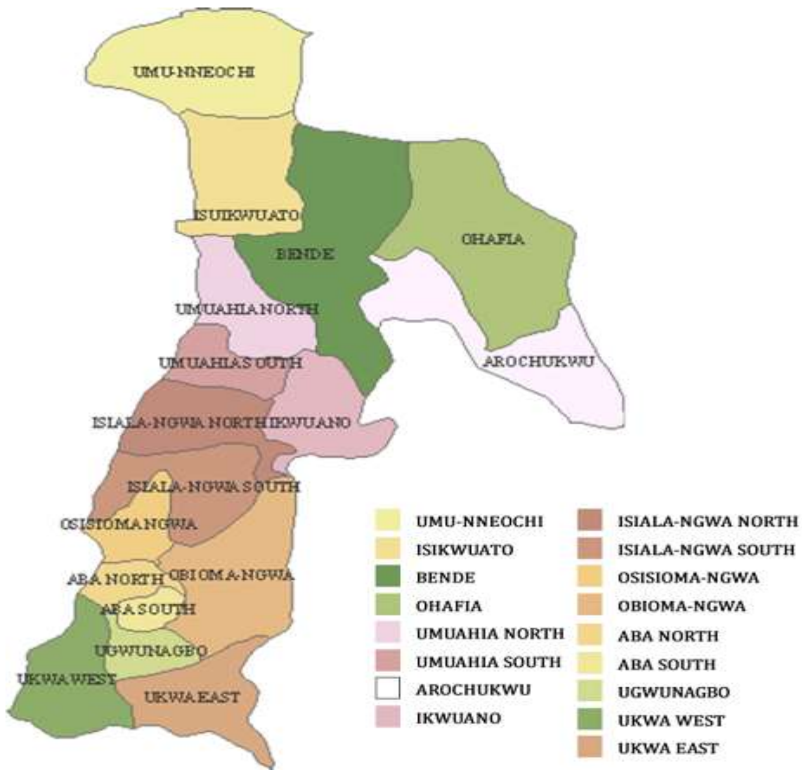

Figure 1. Map of Abia State.

consumed in Eastern and Southern Africa, and 20% of the calories and protein consumed in West Africa. It is estimated that about 208 million people in sub-Saharan Africa depend on maize for food security and economic wellbeing. Maize is adjudged the most important cereal crop (Badmus and Ariyo, 2011) in the world after wheat and rice with regard to cultivation areas and total production (Osagie and Eka, 1998; Purseglove, 1972). Maize occupies more than 33 million hectares of sub-Saharan Africa's estimated 200 million hectares of cultivated land. Considering the low average maize grain yields that are still pervasive in farmers' fields, meeting the projected increase demand for maize grain in Africa presents a challenge. In Nigeria, maize cultivation is predominant across the North-Central, South-East, South-West, and South-South states. It is estimated that 48.3% of all households in Nigeria (NBS, 2016) cultivate maize crop.

Concise geography of Abia State

Abia State is one of the prominent South-Eastern States in Nigeria. The state whose capital is Umuahia, was carved out from Imo State in 1991. It is geographically located on approximately latitude 5°25′N and longitude 7°30′E. Abia "God's own State" as it is fondly called, is popular for Commerce, Industry and Agriculture. The state, which has 17 local council areas (Figure 1), occupies a land area of 5,834 km^2 (ABSG, 2015). The state is bounded on the West by Imo State, on the North by Enugu and Anambra States, respectively, on north-east by Ebonyi State, on the East by Cross River State, on the south-east by Akwa Ibom State, and on the South by Rivers State (Figure 2). Its commercial nerve centre is Aba located south of the state. Aba is prominent for its strategic location as well as its industrial and commercial potentials with notable industries involved in textile manufacturing, footwear and leather production, pharmaceuticals, soap, plastics, cement, and cosmetics (Hoiberg, 2010). Aba is also the largest town in the state and situated on a plain with Aba River Valley lying on its eastern side. Aba is about 60 km south of Umuahia, the state capital, and is generally accessible to all the south-eastern states by road. Notwithstanding the industrial potentials of the state, the manufacturing sector accounts

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Figure 2. Abia State and its boundaries.

for 2% of the gross domestic product (GDP). Agriculture is the most prominent sector in the state and accounts for about 70% of the state's economic activity.

Overview of maize cultivation in Osisioma Ngwa Area of Abia State

Like in other parts of Abia State, maize is the predominant cereal crop cultivated in Osisioma Ngwa area. The reason behind this is not farfetched. Maize is enjoyed by majority of the local population in various flavours such as: roasted maize, boiled maize, maize cake, pap (known in the local parlance as akamu), maize flour, etc. During the middle of the year, maize in combination with the local African pear provides a wonderful meal for majority of the local dwellers. In addition, maize seeds are used as raw materials for the production of starch and other compounds by chemical and pharmaceutical industries within Aba and beyond. Maize cultivation commences in early march at the onset of the rainy season. Planting of maize by farmers continues until mid-June and stops around early July when the volume of rainfall is at its peak. Thus, the plant is not really favoured by continuous heavy precipitation.

General conditions for maize cultivation

Relative humidity, temperature, and precipitation are basic climatic elements that are important to crop cultivation in the tropics in addition to good arable soil. Consequent upon the foregoing, crop production and yield may be largely affected by any or all of these factors especially when the required amount for plant growth is either not met or exceeded. The climatic conditions for maize cultivation are well documented (Agbossou et al., 2012; Bert et al., 2006; Fakorede and Opeke, 1985; Oluwaranti et al., 2015; van Eijnatten, 1965). The maturity period of the maize crop ranges from 3 to 4 months. Sub-optimal atmospheric conditions beginning from late June affect maize productivity. The general conditions necessary for maize cultivation are briefly discussed herein.

Maize grows well at temperatures between 18 and 27°C during the day and around 14°C during the night. The most important factor in the growth of maize seedlings is the frost-free days usually 140 days during its growth cycle. The growing maize plant is very susceptible to frost hence its commonplace in temperate climates. There is a relationship between temperature and relative humidity. Relative humidity (RH) is expressed as a ratio of the actual water vapour content to the saturated water vapour content at a given temperature and pressure. RH is often given in percentage. RH is known to increase at low temperatures hence the mean maximum RH is usually recorded in the early morning whereas mean low values are recorded during the early noon hours. As in other crops, RH influences the growth of leaves, pollination, photosynthesis, etc. The growth of maize is seriously affected by very high and very low humidity. At low RH,

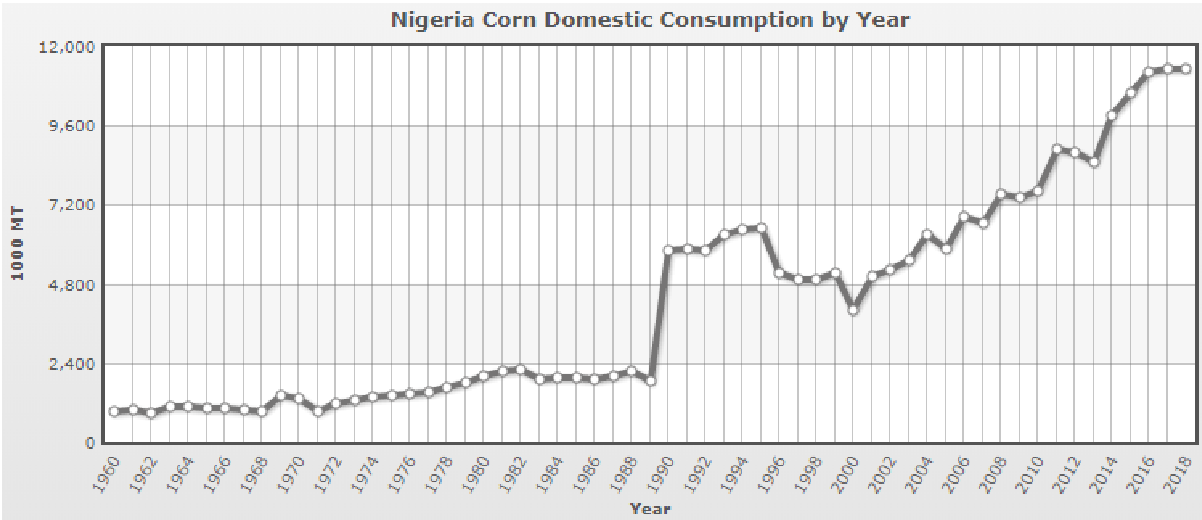


Figure 3. Domestic maize/corn consumption rate in Nigeria.
Source: indexmundi.com, 2018.

transpiration increases which results in water deficits and consequently the stomatal pores close up preventing the admittance of carbon IV oxide necessary for photosynthesis. A high RH on the other hand reduces evapotranspiration, increases heat load of plants, activates closure of stomatal pores, decreases Carbon IV oxide uptake, etc. Thus, for optimal maize growth, a moderately high RH of about 60 to 70% is required.

The maize plant thrives well under climates with annual precipitation ranging between 600 and 1100 mm, as well as in warm climates with precipitation of about 400 mm. Precipitation decreases the water stress levels. As numerous researchers have shown, water stress is an important factor to be considered prior to cultivation having regard to irrigation and the particular soil as well as on different species and the different origins of the species, and ultimately has been found to be of great importance while identifying the species that are most resistant to drought (Cetin, 2013; Sevik and Cetin, 2015; Yigit et al., 2016a, 2016b; Cetin, 2017; Guney et al., 2016a; Guney et al., 2016b; Sevik et al., 2017; Guney et al., 2017).

Like precipitation, humidity is a very important factor the growth of plants as it determines the rate of transpiration or water loss through the stomatal aperture. In other words, humidity regulates the rate at which photosynthesis takes place, tissue temperatures, water potentials, and concentrations of calcium in certain tissues, tissue osmosis, and vapour uptake (Tibbitts, 1979).

With respect to soil, maize grows in a wide range of soils, ranging from podzolic soils in temperate climates to rich loamy soils of the tropics. The deep, rich black soils with abundant nitrogen is often adjudged the most suitable soil for maize cultivation. The plain regions are most suitable for maize cultivation. Cultivation is best on fertile loamy soils located on relatively flat well-drained surfaces. Maize is also cultivated on undulating lands as well as on lower slopes of the hills.

Unlike other food crops, maize cultivation does not require huge capital as it does not require much mechanization. The most important economic factor to maize production is well-drained arable land. Labour requirements are not significant save in medium to large scale production. Labour may also be reduced by the use of appropriate machinery.

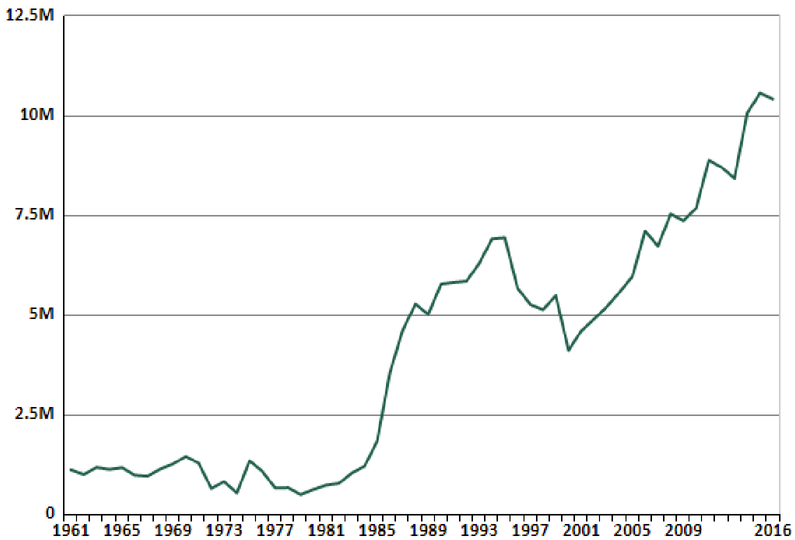
Trends in maize production and consumption in Nigeria

Research has shown that consumption rate of maize is higher that production rate in Nigeria (Indexmundi, 2018; Knoema, 2018). In 2016, maize production for Nigeria was 10.4 million tonnes (Indexmundi, 2018) whereas in the same year 11.2 million metric tonnes were reported consumed (Knoema, 2018).

Figures 3 to 4 show the consumption and production rate of maize in Nigeria. It is evident that as the population grows, the rate of consumption increases.

Statement of the problem

Maize like any other plant cultivated in the tropical and temperate climates is affected by climatic conditions. In addition to good soil, atmospheric conditions such as precipitation, relative humidity, temperature, sunlight are important to the growth of the maize plant. Due to the existence of two different seasons in a year in Abia State, maize is termed a seasonal crop which cultivation is considered feasible during the beginning of the rainy



Date	Value	Change, %
2016	10,414,012	-1.40 %
2015	10,562,050	5.00 %
2014	10,058,968	19.43 %
2013	8,422,670	-3.13 %
2012	8,694,900	-2.07 %
2011	8,878,456	15.65 %
2010	7,676,850	4.33 %
2009	7,358,260	-2.22 %
2008	7,525,000	11.91 %
2007	6,724,000	-5.30 %
2006	7,100,000	19.19 %
2005	5,957,000	

Figure 4. Domestic maize production from 2005 to 2016.
Source: Knoema (2018).

season. The seasonal maize farming may be connected to the shortfall in the production of the food crop as reported by Knoema (2018) wherein it is stated notwithstanding the continuous rise in maize production in Nigeria from 1967 to date, there is still a shortfall in the production of the maize vis-a-vis the consumption rate. To this end, it is submitted that the continued cultivation of the maize in both dry and rainy seasons may help remedy the shortfall thus improving food availability and ultimately help combat hunger. A workaround to the seasonal problem may require continuous measurement and monitoring of the basic atmospheric conditions especially in the dry season to enable farmers know when and what kind of human intervention to adopt as it affects the protection of their maize farms. Intervention in this context may imply the use of artificial means to remedy the natural climatic conditions. A typical example is irrigation of a maize farm to improve relative humidity and soil water. It is widely reported that soil water increases the relative humidity (Doerr et al., 2002; Leelamanie, 2010).

Aim and objectives of the study

The aim of this paper is to propel the idea of all year-round maize production in Abia State having regard to its importance as a staple food for over 90% of the local population as well as for livestock production. The objectives of this paper are:

(1) To briefly review the factors necessary for maize growth and yield in the local communities in the Osisioma Ngwa Local Government Areas of Abia State with emphasis on those communities that are in proximity to natural water bodies.
(2) To review the effects of relative humidity, precipitation, and temperature on the all year round cultivation of maize in Umueze and Umuchichi communities in Abia State.
(3) To examine the scientific relationships between Relative humidity and Temperature as they affect maize farms during rainy and dry seasons in these communities.
(4) To discuss the usefulness of IoT-based community-wide climate messaging system among farmers as it affects the all year-round cultivation of maize in the local communities.
(5) To propose a model that when implemented will enable many farmers within the communities share a single messaging system that would enable them engage in maize cultivation regardless of the traditional cultivation season.

METHODOLOGY

Location of study

This study is conducted around the Umueze and Umuchichi communities, respectively in the Osisioma Ngwa Local Government Area (Figure 5) located in the Southern district of Abia State. These two congruous communities are strategically located in that they are less than 7 km from Aba the commercial nerve centre of Abia State. The communities are accessible through Aba-Owerri road and Okpu-Umuobo road (an exit point from Aba-Owerri road around the Umungasi axis) respectively. In addition to sharing common boundaries, they also share common Relief, Drainage, Climate, and Vegetation. Of significant importance to these two communities is the Aba River, which flows through both communities with its

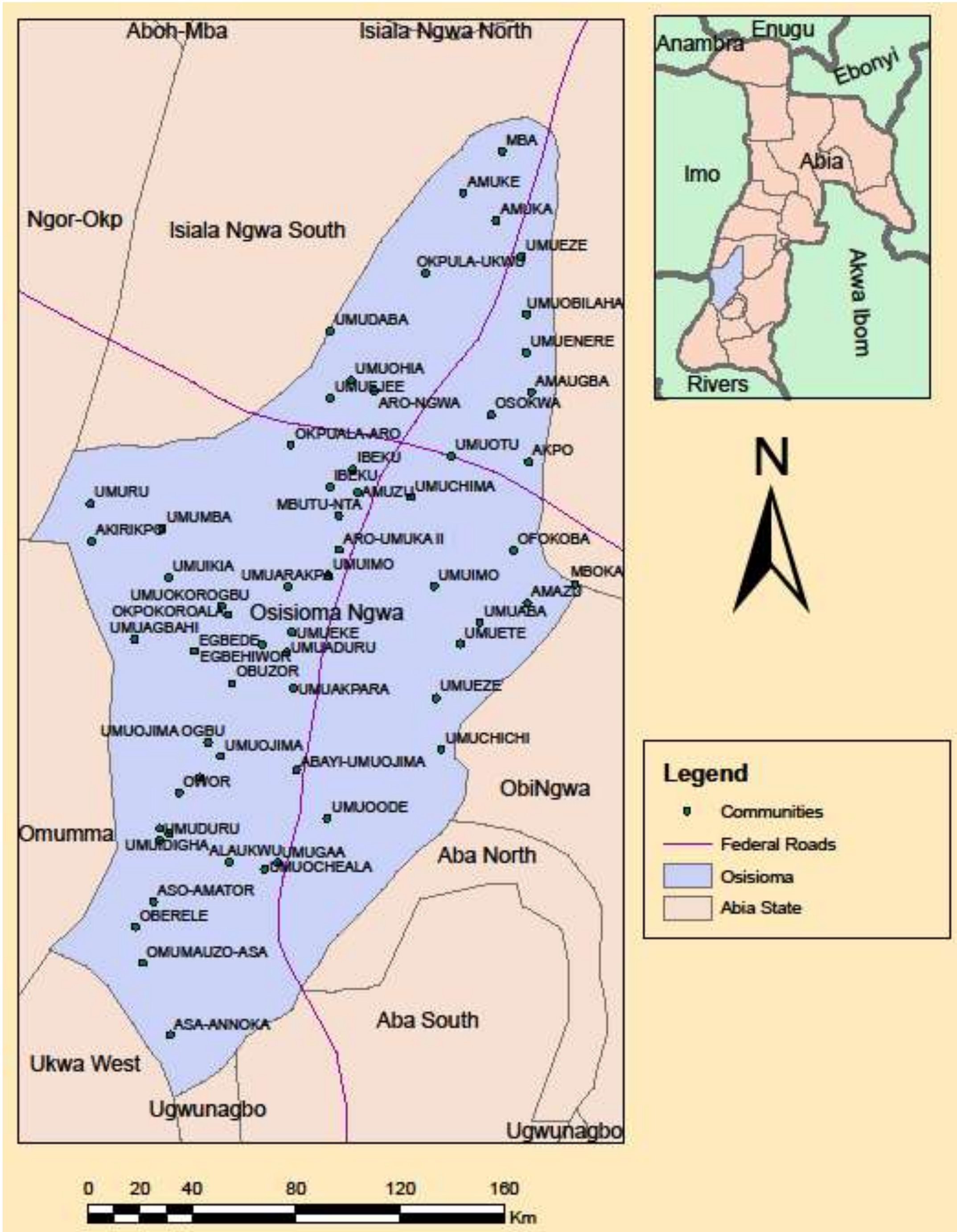


Figure 5. Map of Osisioma Ngwa Local Area of Abia State.
Source: Nwagbara and Okwuonu (2016).

headwaters at Urata in Okpu-umuobo a neighbouring community lying northwest to both communities.

Study population

The population sample is drawn from farmers in the two communities. The sample consists of 100 maize farmers who have actively participated in maize farming from 2014 to 2018.

Materials

The materials used include: Handheld GPS device (HN-5000A), Tecno 10-inch 4G Smart Tablet running Android 7.0 with GPS coordinate, and My elevation apps installed; HP ProBook 6470b

Figure 6. Extech 445580 Compact Digital Hygro-Thermometer pen.

Notebook running Grass GIS 7.4 and Google Earth, Interview Schedules, Extech 445580 Compact Digital Hygro-Thermometer pen for humidity and temperature measuring equipment (Figure 6).

Method of data collection

The methods of data collection employed were observation and interview. A series of observations were made in the month of March on 25 cleared and cultivated farmlands located around Umueze and Umuchichi spanning through an area of 20 km^2 during the beginning of the early rains. The second survey was conducted in the month of June during the time of harvest of ripe maize grains, and the third set of surveys were made during the month of August on uncultivated farmlands spanning an area of 10 km^2 in the same communities. The essence of the first set of observations was to document physical setting of the communities and the maize growing patterns during the onset of the early rains. The second series of surveys were meant to ascertain the usual time of harvest of maize in the said communities whereas the third survey was aimed at establishing the rate of maize cultivation at the end of the first maize harvest. Data on actual geographical locations, vegetation, temperature, and relative humidity were also collected during the survey on the farmlands. To complement data gathered through the survey, interview was used to document the farming history especially as it affects the cultivation of maize in the communities. Other information collected include: seasonal preferences, soil fertility and labour requirements, climatic conditions, logistics, harvest, economies of scale, sale of harvested crops, consumption and preservation.

RESULTS AND DISCUSSION

Relief and drainage of the area

Osisioma Ngwa Local Area is located between latitudes and 5°19’32”N and longitudes 7°15’49” and 7°25’23”E and has a land area of about 198 km^2 and an estimated population of 250,000 inhabitants. Umueze also called Ayaba Umueze is located around latitude 5°8’52”N and longitude 7° 21’32.3”E. Umuchichi is located on latitude 5°8’48.3”N and longitude 7°21’33.468”E.

The two communities are characterized by a variety of landforms though flat and tablelands are more prominent though Umuchichi has marked lowlands and gentle slopes especially at the areas around the Aba River (Figure 7). The major road traversing Umuchichi is Okpu-umuobo road which has its entry point from Aba-Owerri road around the Umungasi axis. Its elevation varies from 39 to 50 m above sea level as against Umueze which enjoys a relative table land with elevation varying between 68 and 74 m above sea level. Both communities receive inflows from the Aba River, which flows through the principal commercial city of Aba.

Climate

Generally, the climatic condition in the communities like every other area in Abia State round the year is classified in terms of seasons. There are two seasons in one year, namely: the rainy (wet) season and the dry season. The rainy season starts in early March and often terminates around late October. About a week of rain-free period is often experienced around the month of August and popularly called the ‘August break’. The onset of the rainy season is marked by heavy thunderstorms. There is also a slight decrease in the total rainfall from 2200 to 2000 mm across the two communities from March towards late October. The relative humidity is relatively high throughout the year, reaching its peak during the rainy

Figure 7. Section of Umuchichi village and Aba River.

season with mean values above 90%. At the commencement of the early rains in March, there is the usual notion of liveliness among potential farmers. The foregoing often heralds the clearing of farmlands and commencement of farming. Traditionally, farmlands are not cultivated continually but left to fallow after harvest for at least 12 months before the next cultivation.

With adequate rainfall during the rainy season and the fertile arable land, the farmlands in the communities flourish with notable food crops such as yams, maize, cassava, rice, plantains, potatoes, *etc*., as well as cash crops especially the oil palm. Also notable is the constant temperature round the year with an annual minimum temperature of 21.2°C and an annual mean maximum temperature of 31.9°C.

The dry season begins in middle to late November each year and ends by early March of the following year. The average period of the dry season is 4 months. The hottest dry period is between January and March with a mean temperature of at least 27°C.

Soil and vegetation

The common soils in the communities are the ferralitic and alluvial soils. The ferralitic soils are less predominant whereas the alluvial soils are predominant along the low terrace of the areas supplied by the streams from Aba River in both communities. Due to heavy annual precipitation, the soils are prone to leaching. The communities are somewhat exposed to ecological problems of sheet and gully erosion. Like other areas in southern Nigeria, the tropical rainforest vegetation is predominant. Numerous species are prevalent in the rainforest vegetation of both communities but the most predominant trees are the oil palm, which is also the most prominent cash crop in the state.

Maize farming culture in the communities

Mono-cropping is not traditional practice in the communities hence maize is often cultivated with other crops like Melon, Cassava, Yam, etc., on loamy soils. The planting period is usually during the onset of the early rains in March. Cultivation is preceded by bush clearing and burning. Artificial fertilizers are commonplace as majority of the soils are prone to leaching hence a significant reduction in the soil nutrients required for crops to thrive.

Figures 8 to 9 show a cross-section of maize farms in both communities in early May. It is interesting to note that the growth of maize on both environments is very similar owing to similar climatic conditions.

Harvest of mature maize grains starts around early June and ends around July. Late planting of maize is seldom practiced in the communities for want of rainfall regardless of the available water sources in the communities. In other words, at the end of the first maize (Corn) harvest, the supply of fresh corn dwindles greatly and ends by late July. Thus there is a gap of about 9 months before the commencement of another season of maize cultivation.

Individual involvement in maize farming

The survey conducted shows that the farmers in both communities are distributed among the young and the old. Out of the 100 farmers surveyed, 50 had the primary school certificate (First School Leaving Certificate), 30 persons attended secondary school whereas 5 have

Figure 8. Maize farm in early May at Umuchichi community.

Figure 9. Maize farm in early May at Umueze community.

advanced qualifications, while 15 have vocational training in areas other than agriculture. Though the highest numbers of farmers involved in maize farming are those whose education is at primary level having accounted for 50% of the entire sample population, however, all the participants agreed that Education and Technology are important vehicles for modernizing agricultural practices in the communities. Table 1 shows the statistical distribution of the interviewees having regard to their educational backgrounds. The age distribution of the farmers is shown in Table 2. Maize farmers between the age of 50 and 59 are most prominent having accounted for 26% of Maize farmers in both communities. As regards the gender, maize cultivation is predominant among the female folks especially the married ones in both communities (Table 3). There is also what appears to be somewhat among the farmers in the communities generally, that is, maize farming is perceived as a peculiar farming practice of women whereas men farmers are more interested in tuber crops especially yam. Table 4 shows the distribution of farmers with respect to seasonal maize cultivation. All the farmers cultivate maize during the rainy season. No farmer carries any maize farming during the dry season.

Relevance of climatic conditions to maize cultivation in the communities

All the farmers agree that maize farming is actually regulated naturally by such elements as precipitation, sunshine, temperature, *etc.* It is widely believed by the locals that maize can only thrive during the early rains. The belief appears to be the ground underlying the traditional practice of not cultivating maize during the dry season. Sunshine is almost regarded as a constant climatic element in the communities hence is not considered as a challenge to maize farming. However, it

Table 1. Educational distribution of maize farmers in both communities.

Level of education	Population by community		Total
	Umuchichi	Umueze	
Tertiary/Advanced	2	3	5
Vocational	5	10	15
Secondary School	14	16	30
Primary	28	22	50
None	0	0	0
Total			100

Table 2. Age distribution of maize farmers in both communities.

Age	Population by community		Total
	Umuchichi	Umueze	
70-79	2	3	5
60-69	7	15	22
50-59	9	17	26
40-49	14	6	20
30-39	4	11	15
18-29	5	7	12
Total			100

Table 3. Gender distribution of maize farmers in both communities.

Age	Population by community		Total
	Umuchichi	Umueze	
Male	20	15	35
Female	40	25	65
Total			26

Table 4. Maize cultivation pattern in both communities.

Season	Population by community		Total
	Umuchichi	Umueze	
Rainy	50	50	100
Dry	0	0	0
Total			100

is important to note that such an assumption is rebuttable, as there exists a connection between the amount of radiation and temperature. High temperatures during the dry season often cause an increase in evaporation of water from the soil surface leading to loss of soil water as well as soil nutrients. Consequently, plant growth is affected by soil temperature especially as it concerns water and nutrient uptake and root growth. A reduction in temperature often results to a decrease in water and nutrient uptake at a constant moisture content. Transport of minerals and nutrients from the root to the shoot and vice versa is reduced at low temperatures. The relevance of relative humidity to growth of maize has been discussed previously.

Maize cultivation during the dry season in the communities

Notwithstanding the presence of the Aba River and its

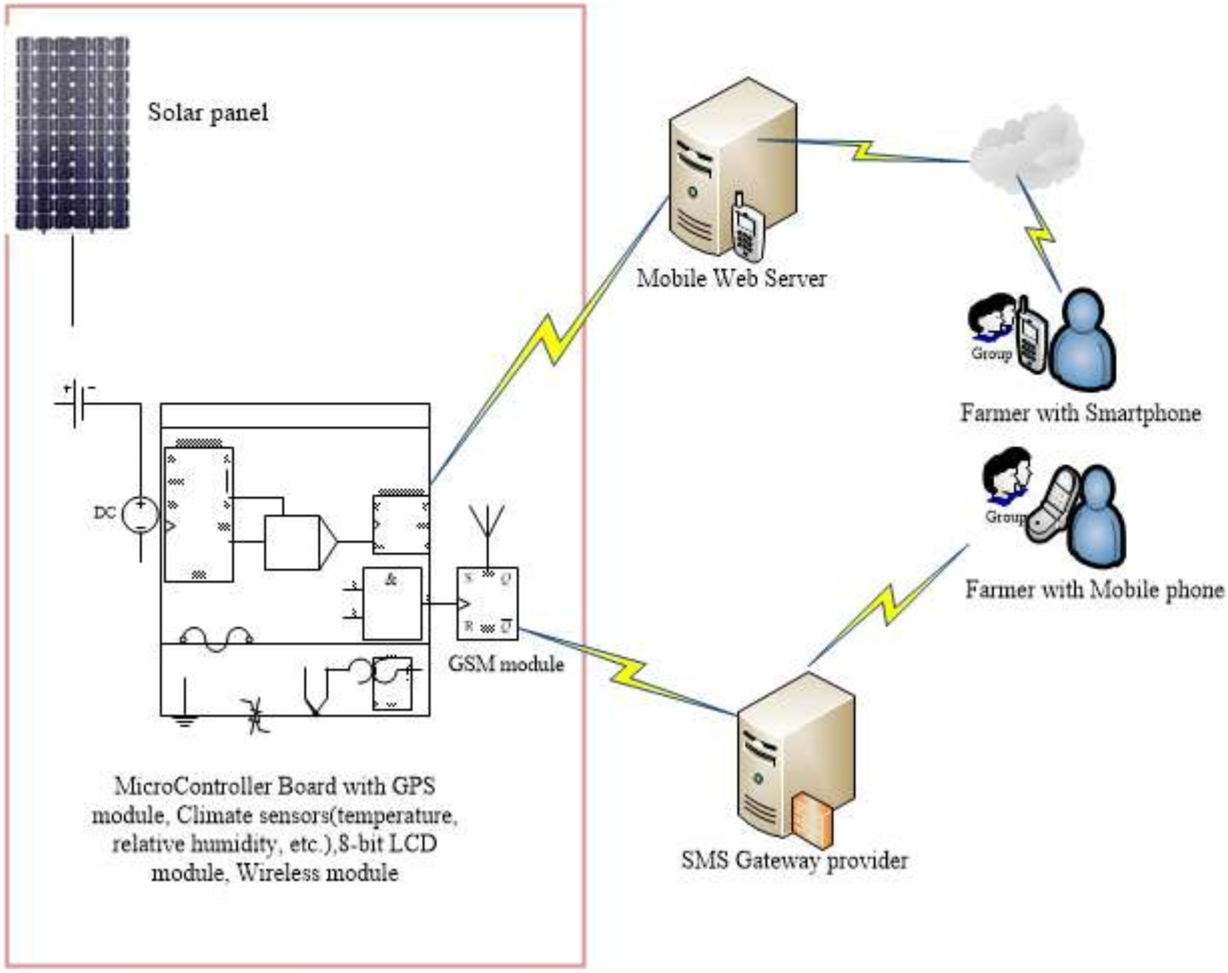


Figure 10. Schematic model of the proposed system.

tributaries within the communities, the cultivation of maize during the dry season is not a practice in the communities owing to the general conception that labour and seedlings expended on such activities will be a waste.

Proposing a remote monitoring and messaging system for maize farmers

All farmers drawn in the sample understood the importance of humidity and temperature among other climatic conditions in the cultivation and growth of maize. The farmers agreed that cost-effective control and messaging systems would be helpful in monitoring the status of their farms not only during the rainy season but also during other times. They also agreed that such a technology should be able to notify farmers through short messaging service regarding the status of the climatic conditions especially when the conditions are tending towards the extreme.

Having regard to the understanding of the farmers, we proposed a group internet-based remote messaging system option. The model of the proposed system is as shown in Figure 10. The function of the remote messaging system is to automatically measure the temperature and relative humidity within an area spanning across interconnected maize maize farmlands over a short period, compare it with reference values and alert the concerned farmers who are registered on the system, through a short messaging service over the internet. Farmers with smartphones can also monitor on real-time the status of the climatic conditions. Penultimate, the essence of the messaging to the farmer when extreme limits of temperature and humidity is recorded is to afford the farmers to take action as to the application of measures to ensure that the growth of the crops are not hampered. Another importance of such an arrangement is to reduce the wastage of resources whereby farmers visit their farms on a daily basis for physical assessment of the situation. In addition, with such notifications, a farmer who is far away from the locality can engage a second party to carry out some tasks such as sprinkler irrigation where such is necessary.

Assumptions on the proposed system

In proposing an internet-based group remote messaging system for farmers, basic assumptions have been made based on the field measurements and data collected from the farmers. The assumptions were:

(1) The spread of sunshine across the concerned communities is constant over the year and that there is no significant difference in the distribution from one community to another.
(2) The precipitation levels across the communities are similar
(3) The average temperatures across the communities over a year is the same
(4) A single microcontroller-based IOT device deployed in a given location within the referenced communities can effectively and efficiently serve many farmers who have farmlands within the communities.
(5) 95% of the sampled farmers own at least a mobile phone

With regard to the aforementioned assumptions, it would take less effort to enrol many farmers into one multi-user device thus reducing the cost of implementation of the system. And as the number of users increase the expenditure per farmer as to the cost of acquisition and maintenance of the messaging device falls.

Conclusion

The centerpiece of this paper is to design an automated solution that can help boost maize production in the local communities in *Osisioma Ngwa* Area of Abia State. From the data gathered through field measurements and farmers' submissions, this study discovered farmers value a system that can provide real-time information on the climatic conditions of their farmlands having regard that maize cultivation is affected by a good number of climatic factors such as temperature, relative humidity, precipitation amongst others. It was noted that due to the farmers' familiarity with the traditional farming period notably at the commencement of the early rains, no attempt is made carrying out cultivation during the dry season regardless of the surrounding streams. The study unveiled the gap which is traced to the deficit in the knowledge of the farmers. Consequently, this study concludes that:

(1) Vital information regarding the state of climatic conditions are necessary for the participation of local farmers in all round the year maize farming;
(2) Any cost-effective system that could provide farmers with necessary information as to improving their farming practice would be beneficial
(3) Since mobile phones are ubiquitous across the local communities, a microcontroller-controlled IoT-based system with mobile messaging capability can assist farmers within a given geographical area with same climatic conditions such as temperature, relative humidity, sunshine, *etc.*
(4) With one such device that can serve numerous farmers in a community, the cost of deployment will fall and farmers will benefit more as the number of farmers' subscription into the system increases.
(5) Every potential maize farmer within the communities can be motivated to engage in all round the year maize farming is he is assured of being duly informed on what to do to his farm even during the dry season.
(6) The resultant effect of such a novel invention is that many farmers would participate in maize farming thus boosting the production of sufficient maize cereal for local consumption as well as for sale or even exports thus curtailing the menace of hunger and food scarcity across Abia State in particular and Nigeria at large.

FUTURE WORK

This study has laid appropriate foundation for the construction of a multi-user IoT-based climate messaging system. It is our firm understanding that the groundwork was concluded in this paper leaving out the actual implementation of the proposed system. In our next paper, we shall address the design and implementation of this proposed novel technology to enable farmers have access to real time information to boost their farming culture. The necessary factors such as cost-effectiveness, ease of use, service quality, location coverage, and choice of technology for implementation of the system.

CONFLICT OF INTERESTS

The authors have not declared a conflict of interests.

ABBREVIATIONS

ABSG, Abia State Government; **GDP,** gross domestic product; **IoT,** internet of things; **NBS,** National Bureau of Statistics; **RH,** relative humidity; **UN,** united nations.

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Genetic variability of common bean (*Phaseolus vulgaris* L.) genotypes under sole and maize-bean cropping systems in Bako, Western Oromia, Ethiopia

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Knowledge of the sources and magnitude of variability among genotypes plays a pivotal role in any crop improvement program to maximize gains from selection. This experiment was conducted at Bako Agricultural Research Center in 2011 cropping season with the objective of studying and estimating the extent of genetic variability in common bean genotypes under sole and mixed cropping systems. Meanwhile, the wider range of variability observed from the mean of various quantitative traits. The genotypes that varied by cropping system depicted the presence of high level of variability. The highest genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) values were recorded for hundred grain weight (29.56 and 35.46 g), biological yield (27.22 and 31.37) and grain yield (26.60 and 31.54 q/ha), whereas the lowest GCV and PCV values were recorded for days to maturity of sole common bean genotypes. Phenotypic variance in both sole and mixed cropping systems was higher than that of genotypic variances. This implies that, considerable contribution of environmental factors to the phenotypic expression of the genotypes. High broad sense heritability as observed under both sole and intercropping systems indicated that, genetic improvement can be obtained through further selection programme. Important agronomic traits: pods per plant, seeds per pod and branches per plant had positive and significant correlation with grain yield in most cases. Path coefficient analysis at genotypic level indicated that all traits except plant height, seeds per pod and hundred grain weights exerted their positive direct effect on grain yield. Hence, the current study identified the presence of wide variability between those common bean genotypes which can be used for further breeding program and selection can be made using those traits associated to yield.

Key words: Genotypic variance, heritability, intercropping, phenotypic variance, quantitative traits, sole cropping.

INTRODUCTION

Genetic diversity in crop plants arises as a consequence of evolutionary processes (mutations, selections, migration and random genetic drift) and the influence of man through selection and domestication (Allard, 1960).

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Genetic variability has been considered as an important factor which is also an essential prerequisite for crop improvement program for obtaining high yielding progenies (Tiwari and Lavanya, 2012). In this regard, variability is the occurrence of differences among individuals due to differences in their genetic composition and/or the environment in which they are raised. This variability within or among populations can be genotypic, phenotypic or the interaction of these two factors (Falconer and Mackay, 1996). According to Welsh (1990) and Sharma (1998), genetic variability is due to genetic differences among individuals within a population, is the core of plant breeding.

Genetic variation is, therefore, the basis for crop improvement and plant breeders use this variation to direct and control evolutionary process by developing new varieties. This therefore has an immense importance to the breeder.

Heritability is important to plant breeders primarily as a measure of the value of selection for particular character in various types of progenies and as an index of transmissibility. Falconer and Mackay (1996) defined heritability as the heritable portion of phenotypic variance and is a good index of transmission of characters from parents to offspring. It is a property not only of a character being studied but also of a population being sampled, of the environmental circumstance to which the individuals are subjected, and the way in which the phenotype is measured (Dabholkar, 1992; Falconer and Mackay, 1996).

Heritability in broad sense estimates the ratio of total genetic variance, including additive, dominance, and epistatic variance, to the phenotypic variance whereas heritability in the narrow sense estimates only the additive portion of the total phenotypic variance and it expresses the extent to which phenotypes are determined by the genes transmitted from parents (Raiz and Chowdhry, 2003). Allard (1960) indicated that the heritability values for quantitative traits are low mainly due to their sensitivity to environment factors. Estimate of narrow sense heritability is not possible; thus, by estimating broad sense heritability along with genetic gain is usually more useful in selecting the best individual (Johnson et al., 1955).

Genetic advance measures the difference between genotypic values of generation obtained from the selected population over the mean value of the base population. Therefore, the utility of estimates of heritability is increased when heritability and genetic advance are used in conjunction with selection differential, the amount that the mean of the selected lines exceeds the mean of the entire group (Johnson et al., 1955). Heritability estimates and genetic advance should always be considered simultaneously, because high heritability will not be always associated with high genetic advance (Amin et al., 1992). Economic characters like grain yield are polygenic in nature and are often influenced by the environment and thus have low heritability (Raiz and Chowdhry, 2003). If environmental variability is small in relation to genotypic differences, selection will be efficient and the selected trait will be transmitted to its progeny (Briggs and Knowles, 1967).

Furthermore, understanding of the genetic association of breeding materials could help to maintain genetic diversity and sustain long term selection gain. Correlation analysis suggested observations on rhizome yield and other such that the magnitude of genotypic correlation was morphological traits. The mean value of these is higher as compared to their corresponding plants computed and used for statistical phenotypic correlations indicating the inherent analysis. Analysis of variance to test the significant relationship among the characters studied (Prajapati et al., 2014). Hence, any breeding program aiming at increasing yield should consider association between yield and its attributes through estimation of genotypic and phenotypic correlation, which help a great deal in formulating selection indices to aid in selection programs. Knowing the variability existing in a crop is necessary to formulate and accelerate conventional breeding program. Therefore, the present study was initiated to assess the extent and pattern of phenotypic and genotypic variability of different common bean genotypes of the area.

MATERIALS AND METHODS

The study area

The experiment was conducted at Bako Agricultural Research Center (BARC) in 2011 cropping season. BARC is found in East Wellega zone, Oromia Regional State of Ethiopia. The center is located on 9° 6' N and 37° 09' E latitude and longitude, respectively. It is also characterized by sub-humid agro-ecology with an altitude of 1650 m.a.s.l and has a unimodal rainfall pattern and an annual rainfall of 1425.3 mm/annum. The rainy season extends from April to November, but maximum rainfall of 295.2, 224.0 and 294.6 mm was received during the growing months in June, July and August, respectively (Figure 1).

The minimum, maximum and average air temperature of the center was 13.5, 27.3 and 20.4°C, respectively. Soil type of the study area is Alfisols, which is clay in texture and acidic in reaction (Negassa, 2001).

Experimental materials

Twenty-four common bean genotypes including one local variety which was frequently used by the farmers of the area were used as a planting material. These common bean genotypes were obtained from Melkassa Agricultural Research Center (MARC) and selected from the regional variety trials which were conducted at BARC during the 2009/2010 cropping season. The selection was made based on *per se* performance and adaptability of bean genotypes under sole cropping condition around Bako area (Table 1).

The hybrid maize variety used in this study was BH-540 which is the most popular maize variety around Bako and similar agro-ecologies of East Wellega and it has medium plant height and grouped within the medium maturing hybrid varieties.

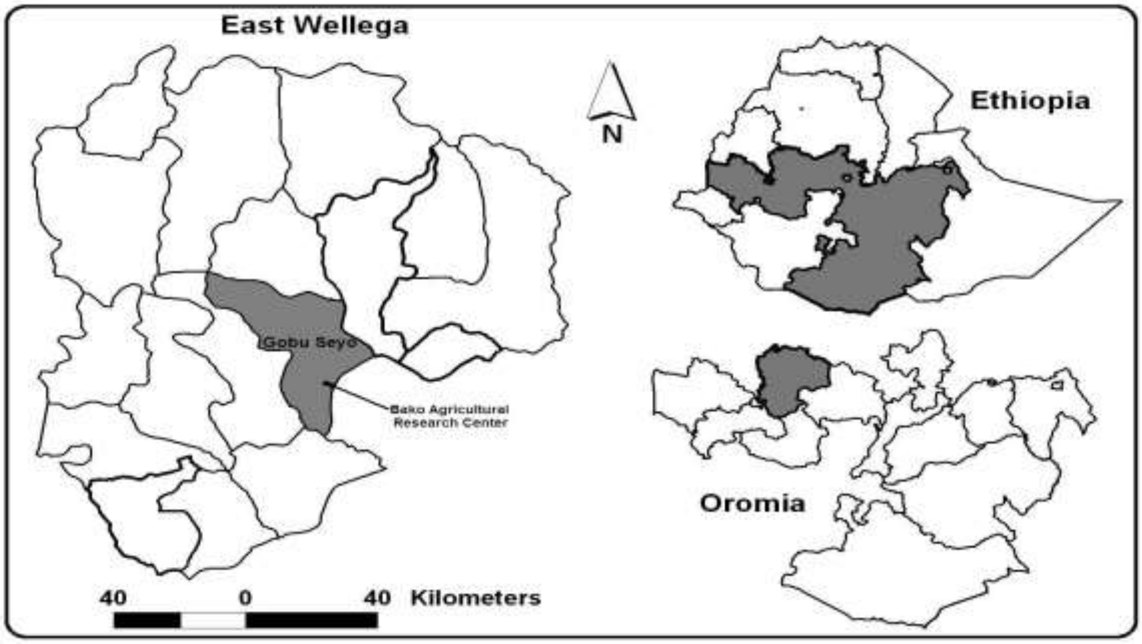

Figure 1. Study district in East Wellega Zone of Oromia, Ethiopia.

Table 1. List of common bean genotypes used.

Genotype	Genotype
SEN–4L	FEB–147 X EAP–4
SEN–46	ECAB–06–01
SEN–53	557–FIN–1
ICTAJU–95–56	DB–190–84–1
TB–94–02	UBR(92)25–13–1
AN–92=12123	BAT–1198 XBAT–1248
ICTAJU–95–1–07	MEXICO235 X PAN–182
AN–9123342	SK–93846
ICTAJU–95–28	MEXICO–23 X BAT–338–1C–10
FEB–190	BAT–1198 X BAT–1248–6
ROBA X FEB–147	BAT–448 X PAN–182–2
ATENDABA X EAP–4	Local check (Burree)

Experimental design and field management

The experiment comprised two separate activities, that is, sole common bean component and bean-maize intercropping which were used for compatibility study of common bean genotypes. Both experiments were laid out in 5×5 triple lattice designs with three replications. The sole common beans involved a total of twenty-five genotypes including one standard and local check and the bean-maize intercropping consisted of twenty-four genotypes and one maize plot grown without common bean as sole cropping. Each of the sole bean plots comprised four rows spaced at the distance of 0.40 m with 5.1 m length, and the space between individual plants within a row was 0.10 m. On the other hand, intercropped plot consisted of four rows of 5.1 m length and sown between 0.75 m spaced maize rows. Common bean genotypes were under sown after twenty-one days at their optimum planting densities alike to that of sole cropping and later reduced to 50% of the plant population. Fertilizers were applied in the form of Urea and DAP with the rates of 18/46 kg ha^{-1} N/P_2O_5 and 100/100 kg ha^{-1} N/P_2O_5 for sole common bean and maize-bean intercropping plots, respectively. All the DAP fertilizer was applied at planting while urea was applied at two rates, half at planting and the remaining half side-dressed at knee height stage of maize.

Data collection

Data for all traits of beans and maize were collected from ten randomly selected plants of the two central rows for both sole and intercropped experiments. Grain yields of the two crops were adjusted to 10 and 12.5% moisture level for bean and maize, respectively.

Date of emergence, days of flowering, days of maturity, plant height, number of pods per plant, number of seeds per pod, pod length, grain yield, number of plants per plot, 100 grain weight, biological yield and number of primary branches were data collected for bean crop whereas the number of ears per plant, ear length, thousand kernel weight and grain yield were data collected for maize crop.

Data analysis

Analysis of variance (ANOVA)

ANOVA for sole common bean was computed using Statistical Analysis System (SAS) computer software using SAS syntax for simple lattice design (SAS, 2004). Comparisons of the relative efficiency of lattice design to RCBD were done after data analysis due to the flexibility of lattice design (Cochran and Cox, 1957). The mean values and rank orders were calculated for each genotype. In addition, correlation coefficients were computed between each pair of the traits.

Estimation of components of variation

The genetic and phenotypic variability among genotypes and coefficient of variation of each trait under the study were calculated for common bean genotypes planted under sole and intercropping condition using the formula adopted by Johnson et al. (1955).

Genotypic variance $\sigma^2_g = \frac{(MSg - MSe)}{r}$

Phenotypic variance $\sigma^2_p = \sigma^2_g + \sigma^2_e$

Environmental variance $(\sigma^2_e) = MS_e$

where σ^2_g = genotypic variance, σ^2_p = phenotypic variance, (σ^2_e) = environmental variance, MS_g = Mean square due to genotypes/accessions, MS_e = Error mean square, and r = number of replications.

The coefficients of variations at phenotypic and genotypic level were estimated using:

$$GCV = \frac{\sigma_g}{x} \times 100$$

$$PCV = \frac{\sigma_p}{x} \times 100$$

$$ECV = \frac{\sigma_e}{x} \times 100$$

where σ_p= Phenotypic standard deviation, $(\sigma_g + \sigma_e)$ σ_g = Genotypic standard deviation, σ_e = Environmental standard deviation, and X = Grand mean for the characteristic x; PCV, GCV, and ECV = Phenotypic, genotypic and environmental coefficient of variation, respectively.

Estimate of heritability

Heritability (h^2) in broad sense for all characters was computed using the formula suggested by Allard (1960).

$$h^2 = \frac{\sigma^2 g}{\sigma^2 p} X100$$

$$\sigma^2 p = \sigma^2 e + \sigma^2 g$$

where $\sigma^2 g$ = genotypic variance, $\sigma^2 p$ = phenotypic variance, and $\sigma^2 e$ = error variance.

Estimation of expected genetic advance

Genetic advance as percent of the mean (GA) for each character were computed using the formula by Allard (1960).

$$A = K \times \sigma p \times h^2$$

$$GAM = \frac{GA}{\overline{x}} \times 100$$

where K = selection differential (2.056 at 5% selection intensity), $\sigma\rho$ =Phenotypic standard deviation, h^2 =Heritability and $\overline{X}$ = Grand mean.

Estimation of phenotypic and genotypic correlations

Phenotypic and genotypic correlations between yield and yield related traits were estimated using the method described by Miller et al. (1958).

Phenotypic correlation coefficient:

$$rp_{xy} = \frac{\sigma_{pxy}}{\sqrt{\sigma^2_{gx} \times \sigma^2_{gy}}}$$

Genotypic correlation coefficient

$$rg_{xy} = \frac{\sigma_{gxy}}{\sqrt{\sigma^2_{gx} \times \sigma^2_{gy}}}$$

where rp_{xy} = phenotypic correlation coefficient between character x and y, rg_{xy} = genotypic correlation coefficients between character x and y, σ^2_{px} = phenotypic variance for character x, σ^2_{gy} = genotypic variance for character y, σ^2_{gx} = genotypic variance for character x, and σ^2_{py} = Genotypic variance for character y.

Table 2. Average mean values and percent reduction of grain yield of common bean genotypes grown as sole and intercropping, 2011.

Genotype	2011		RANK	% Reduction
	Sole	Mix	Sole	
SEN-4L	37.81	3.96	8	89.53
SEN-46	35.18	4.42	11	87.44
SEN-53	23.23	2.70	18	88.38
ICTAJU-95-56	30.13	2.61	15	91.34
TB-94-02	27.08	3.77	16	86.08
AN-92=12123	35.54	3.86	9	89.14
ICTAJU-95-1-07	20.16	1.74	21	91.37
AN-9123342	34.89	2.47	10	92.92
ICTAJU-95-28	6.81	3.37	24	50.51
FEB-190	36.92	2.13	7	94.23
ROBA X FEB-147	39.84	3.13	3	92.14
ATENDABA X EAP-4	34.67	3.09	14	91.09
FEB-147 X EAP-4	36.29	5.13	5	85.86
ECAB-O6-01	40.71	3.04	4	92.53
557-FIN-1	36.22	3.29	13	90.92
DB-190-84-1	39.29	3.80	6	90.33
UBR(92)25-13-1	39.06	8.51	2	78.21
BAT-1198 XBAT-1248	16.12	2.68	22	83.37
MEXICO235 X PAN-182	32.29	7.51	12	76.74
SK-93846	45.88	3.33	1	92.74
MEXICO-23 X BAT-338-1C-10	21.73	1.86	20	91.44
BAT-1198 X BAT-1248-6	22.81	3.21	19	85.93
BAT-448 X PAN-182-2	24.42	2.89	17	88.17
Local check	10.26	1.19	23	89.53

BYIE=Biological yield (g), BRPL=branch per plant, DF= days to flower, DM=days to maturity, HGW= hundred grain weight (g), HI= harvest index (%), PH=plant height (cm), POPL=pod per plant, PLEN=pod length (cm), SEPO=seed per pod, YLD=grain yield (Qt ha^{-1})

Path coefficient analysis

The direct and indirect effects of the independent traits on grain yield per plot were estimated by formula described by Dewey and Lu (1959) and, it was analysed using the formula developed by Singh and Chaudhary (2004).

$$rij = pij + \sum r_{ik} p_{kj}$$

where rij = Mutual association between the independent character (i) and dependent character (j) as measured by the correlation coefficient. pij = Component of direct effects of the independent character (i) and dependent (j) as measured by the path coefficient, and $\sum r_{ik} p_{kj}$ = Summation of components of indirect effect of a given independent character (i) on the given dependent character (j) via all other independent character (k).

RESULTS AND DISCUSSION

ANOVA for sole and intercropped common bean genotypes

ANOVA indicated that highly significant differences (*P≤0.01*) between cropping systems for plant height, pods per plant, seeds per pod, pod length, biological yield, and harvest index, branches per plant and grain yield and highly significant differences (*P≤0.01*) were observed among genotypes for all traits except for pod length (Table 2).

Genotype × cropping system interaction effect was highly significant *(P≤0.01)* for all traits except for days to flowering, seeds per pod and hundred grain weights. This indicates that the performances of the bean were not consistent across the cropping systems.

Most of the genotypes responded differently under various cropping systems. This could be mainly due to the difference in the genetic makeup of the genotype and the environment on which the genotypes were grown. In general, the significant difference observed among the

Table 3. Analysis of variance for yield and yield related traits of common bean varieties under sole and intercropping condition at Bako (2011).

Source	Df	50%DF	DM	PH	POPL	SEPO	POLEN	HGW	BYIE	HI	BRPL	YLD
REP	2	93.44	48.38	317.26	11.96	0.39	0.92	30.14	258.43	20.54	2.65	6.82
Cropping system (A)	1	52.90^{ns}	3.86^{ns}	11665.13**	5119.17**	12.43**	11.20**	31.21^{ns}	1159063.93**	562.93**	359.90**	25.903.13**
Error A	2	134.25	29.55	129.76	12.87	0.27	0.42	83.96	139433.34	7.21	5.48	28.02
Genotype (B)	23	31.91**	316.88**	3533.66**	60.80**	2.84**	4.53^{ns}	292.72**	171413.06**	312.2**	5.80**	177.37**
A x B	23	11.59^{ns}	73.88**	777.74**	36.45**	0.43^{ns}	0.60**	29.34^{ns}	111254.25**	158.23**	4.42**	136.98**
Error B	46	10.65	16.42	135.16	7.78	0.16	0.35	15.47	41531.20	50.66	1.16	22.06
R2	-	0.85	0.90	0.97	0.95	0.90	0.92	0.90	0.91	0.90	0.91	0.97
CV	-	6.86	5.50	12.61	22.05	8.66	6.36	19.73	30.10	13.43	16.25	27.55
LSD	-	3.15	5.55	10.15	3.16	0.56	0.63	5.18	251.89	6.72	1.42	5.41
Relative reduction*	-	–3.3	–0.7	22.9	64.9	9.0	7.2	7.6	56.5	14.7	34.0	88.5

*Percent relative reduction due to intercropping ($1-V_{mixed}/V_{sole}$), negative values indicate an increase under intercropping in that particular trait; V_{mixed} and V_{sole} , indicate trait mean values under intercropping and sole cropping condition, respectively. BYIE= biological yield (g), BRPL= branch per plant, DF= Days to flower, DM=days to maturity, HGW= hundred grain weight (g), HI= Harvest index (%), PH=plant height (cm), POPL=pod per plant, PLEN=pod length (cm), SEPO= Seed per pod, YLD =Grain Yield (Qt ha^{-1}), * *, * and ns = Highly significant at ($P \leq 0.05$), significant and non-significant, respectively.

genotypes in the two cropping systems indicated that there is an apparent phenotypic and genotypic variation among the genotypes and which could be exploited in breeding program (Table 3).

Components of variation for sole and intercropped bean genotypes

As per the analysis for intercropped beans shown in Table 4, the highest genotypic and phenotypic coefficient of variations were recorded for plant height (50.22 and 52.8), grain yield (45.04 and 51.40), hundred grain weight (33.23 and 40.85) and pod per plant (32.13 and 37.0), respectively, whereas the lowest genotypic and phenotypic coefficient of variation was recorded for the days to maturity (6.65 and 8.84). Similarly, when the two cropping systems are compared based on the GCV and PCV values of respective traits, the highest GCV and PCV values were exhibited for similar traits, that is, hundred grain weight, grain yield and pod per plant, for both sole and intercropping conditions. Moreover, the GCV and PCV values for plant height for both sole cropping and intercropping were considered as the highest value. Generally, the PCV values were greater than the GCV values in both cropping systems which indicated the influence of environmental factor greater than genotypic factor. In addition, the PCV values exhibited for most of the traits under inter cropping condition were greater than the PCV values exhibited under sole cropping condition except for days to maturity and branch per plant. Pooja et al. (2015), also indicated that, PCV values were higher than GCV values, which indicate the effect of environment on the expression of characters. Characters showed considerable difference between PCV and GCV values, to be number of pods per plant and number of ovules per pod. It indicates more environment influenced variation rather than due to genotype, so these traits may be misleading in selection procedure. Similar to the PCV values, the GCV values recorded for most of the quantitative traits under intercropping condition were greater than the PCV values recorded under sole cropping condition except for days to maturity, pod length, biological yield and branch per plant. The greater difference in PCV and GCV value of the traits and the variability of genotypes under sole and intercropping condition for most of the traits implicated that the presence of phenotypic and genotypic variation between genotypes and these variations were more pronounced under intercropping than the sole cropping Kassaye (2006) reported that the highest values of PCV and GCV were recorded for most of the traits and the lowest PCV and GCV values were recorded for days to maturity. Similarly, Samal et al. (1995) also examined the performance, variability and correlation and co-heritability estimates in Rajmash and found out that all the traits except branches per plant and pod length exhibited wide range of variability. He also reported that the phenotypic and genotypic

Table 4. Values for components of variation and range for sole and intercropped bean at Bako (2011).

Trait	GVs	GVMi	PVs	PVMi	EVs	EVMi	GCVs	GCVMi	PCVs	PCVMi	Range Mi
DM	57.65	33.51	67.36	59.36	9.71	25.85	8.78	6.65	9.49	8.84	71.0-104.33
PH	291.05	914.68	423.92	1010.90	132.87	96.22	21.84	50.22	26.35	52.80	26.33-156.33
POPL	13.90	4.18	26.12	6.34	12.22	2.16	20.59	32.13	28.23	39.58	2.73-8.53
SEPO	0.42	0.60	0.59	0.81	0.17	0.21	11.13	14.68	13.21	17.03	2.8-6.27
PLEN	0.87	0.57	1.11	0.99	0.25	0.42	10.41	9.07	11.80	11.98	6.8-10.47
HGW	52.44	54.02	73.04	66.87	20.60	12.85	30.24	33.23	35.69	36.97	13.67-49.67
BYIE	49581.26	7678.14	102181.74	20282.30	52600.48	12604.16	22.70	20.52	32.58	33.35	233.3-900.0
HI	78.84	35.72	96.62	90.47	17.78	54.75	19.58	14.55	21.68	23.15	21.87-60.67
BRPL	1.81	0.66	3.58	1.06	1.77	0.40	14.91	13.66	20.95	17.29	3.93-7.33
YLD	62.56	2.47	90.97	3.21	28.41	0.75	26.10	45.04	31.48	51.40	1.19-8.52

BYIE=Biological yield (g), BRPL=branch per plant, DF= days to flower, DM=days to maturity, HGW=hundred grain weight (g), HI=harvest index (%), PH=plant height (cm), POPL=pod per plant, PLEN=pod length (cm), SEPO= seed per pod, YLD =grain yield (Qt ha^{-1}), GVs, PVs, EVS, GCVs, and PCVs =genotypic variance, phenotypic variance, environmental variance, genotypic coefficient of variation and phenotypic coefficient of variation for sole cropping, respectively. GVMi, PVMi, EVMi, GCVMi and PCVMi =genotypic variance, phenotypic variance, environmental variance, genotypic coefficient of variation and phenotypic coefficient of variation for intercropping, respectively.

Table 5. Heritability, genetic advance as percent mean, mean and coefficient of variation of eleven traits for sole and intercropped bean.

Trait	Heritability		Genetic advance		GA as percent of mean		Grand mean		CV (%)	
	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed	Sole	Mixed
DM	85.59	56.45	14.44	8.94	16.70	10.26	86.51	87.11	3.60	7.16
PH	68.66	90.48	29.06	59.14	37.20	98.21	78.13	60.22	14.75	17.30
POPL	53.21	65.91	5.59	3.41	30.89	53.63	18.10	6.36	19.30	21.55
SEPO	71.02	74.31	1.12	1.37	19.29	26.02	5.80	5.28	7.10	8.63
PLEN	77.86	57.36	1.69	1.17	18.88	14.12	8.94	8.30	5.50	7.81
HGW	71.79	80.78	12.62	13.58	52.68	61.40	23.95	22.11	18.95	16.20
BYIE	48.52	37.85	318.90	110.84	32.50	25.95	981.13	427.08	23.40	21.50
HI	65.29	42.83	39.99	26.74	45.89	35.97	87.14	74.33	20.14	21.26
BRPL	50.61	62.39	1.97	1.32	21.80	22.17	9.03	5.96	14.70	10.6
YLD	68.77	76.79	13.49	2.82	44.51	81.15	30.30	3.48	17.59	24.76

BYIE=Biological yield, BRPL=branch per plant, DM=days to maturity, HGW=hundred grain weight, HI=harvest index, PH=plant height, POPL=pod per plant, PLEN=pod length, SEPO=seed per pod, YLD=yield quintal per hectare, CV(%)=coefficient of variation for mixture.

variances were maximum for yield per plant and minimum for branches per plant.

Heritability in broad sense and genetic advance of common bean under sole and intercropping condition

Heritability estimates for all traits varied from 50.6 branches per plant to 85.6% for days to maturity for the sole cropping. Most of the traits recorded the highest percentage of heritability, which included days to maturity (85.59), pod length (77.86), hundred grain weight (71.79), seed per pod (71.02), grain yield (68.77), plant height (68.66) and harvest index (65.29) (Table 5). The lowest heritability value was recorded for days to flowering (30.19) indicating that selection may be difficult to improve this character due to the masking effect of environment on the genotypic effect. Some of the traits that have higher heritability estimate also have high to moderate GCV and PCV values which indicated that improvement of these characters could easily be achieved because of close association between genotype and phenotype.

Likewise, the heritability estimates for intercropped bean genotypes revealed that the highest heritability estimate was recorded for plant height (90.48) followed by hundred grain weight (80.78) and grain yield (76.79) and the least heritability estimate was recorded for biological yield (37.85) and harvest index (42.83) under bean intercropping condition. Most of the traits under this cropping system exhibited the highest heritability, GCV

Table 6. Genotypic correlation among traits in common bean under sole cropping systems (the upper most of the table) and maize-bean intercropping (below diagonal) when analysed separately.

Correlation	DF	DM	PH	POPL	SEPO	PLEN	HGW	BYIE	HI	BRPL	YLD
DF		0.669**	0.501*	-0.128	0.319	0.328	-0.385	-0.113	-0.125	-0.122	-0.020
DM	0.59		0.706**	0.376	0.397	-0.372	-0.549**	0.289	-0.156	-0.086	0.197
PH	0.593**	0.895*		-0.087	0.326	0.038	-0.127	0.194	-0.080	-0.469*	0.094
POPL	0.460*	0.767**	0.759**		0.341	-0.556**	-0.536**	0.179	0.217	0.740**	0.549**
SEPO	0.339	0.428*	0.192	0.266		-0.271	-0.486*	0.426*	0.390	0.064	0.543**
PLEN	0.177	0.014	0.147	-0.251	-0.159		0.696**	-0.311	0.101	-0.309	-0.131
HGW	0.210	-0.089	0.129	-0.127	-0.730**	0.637**		-0.468*	0.309	-0.266	-0.142
BYIE	0.139	0.368	0.366	0.397	0.063	0.171	0.210		-0.139	-0.052	0.444*
HI	-0.005	0.584**	0.693**	0.588**	0.300	-0.008	-0.063	0.306		0.297	0.72**
BRPL	0.043	0.317	0.356	0.353	-0.227	0.083	0.288	0.559**	0.304		0.414*
YLD	0.029	0.831**	0.906**	0.829**	0.221	0.100	0.088	0.589**	0.795**	0.419	

BYIE=Biological yield (gm), BRPL=branch per plant, DF=days to flower, DM=days to maturity, HGW=hundred grain weight (g), HI=harvest index (%), PH=plant height (cm), POPL=pod per plant, PLEN=pod length (cm), SEPO= Seed per pod, YLD =Grain Yield (Qt ha^{-1}),

and PCV estimates that could be used during selection through these characters because of the better association between the genotype and phenotype. The higher genetic advances were recorded for biological yield (110.8 and 318.9) followed by plant height (59.14 and 37.2) and the least was recorded by branch per plant (1.32) and seed per pod (1.2) for sole and intercropped beans, respectively. Whereas, the highest genetic advance as a percent of mean were recorded for plant height (98.21), grain yield (81.15), hundred grain weight (61.4) and pod per plant (53.6) according to their order of importance. Generally, 98, 81, 61, and 53% of improvement can be made in selection through these characters for intercropped beans.

In agreement with the present study, Alemineh (2009) indicated that, heritability of the different traits measured under drought stressed and non-stress condition. Days to 50% flowering showed the lowest (31.74%) heritability under non-stressed whereas chlorophyll content had the lowest heritability under stressed treatments. Kassaye (2006) also reported high heritability estimate coupled with high genetic advance as percent of mean for 100-seed weight, plant height and number of nodes on the main stem.

Mesele (1997) also indicated that almost all the characters studied showed higher heritability percentage for pods per plant, pod length, seeds per plant and yield per plant than other characters. According to Sintayehu (1997), higher heritability estimate was recorded for 100-seed weight and moderately higher heritability estimates for pod length, yield per plant and days to maturity.

Most of yield and yield related traits in both cropping systems show the largest heritability estimates which enable the breeders to improve bean genotypes through better heritable traits. Similarly, the genetic advance as a percent mean also implicated that greater possibility of genotype improvement which could be made through these characters.

Association of characters

Genotypic correlation coefficient for intercropped beans in comparison with sole cropping

Seed yield is a complex trait whose production is influenced by its component traits directly or indirectly. Breeder is certainly interested in investigating the extent and type of association of such traits for they contribute valuable information in breeding for yield. The correlation coefficient result for bean intercropping, below diagonal of the Table 6, indicated that grain yield was found to be positively and significantly correlated with days to maturity (rg=0.83**), plant height (rg=0. 91**), pod per plant (rg=0.83**), biological yield (rg=0.59**) and harvest index (rg=0.80**). Similarly, days to maturity with plant height (r=0. 89**), pod per plant with days to maturity (rg=0.77**) and plant height (rg=0. 76**), hundred grain weight with pod length (rg=0.64**), harvest index with days to maturity (rg=0.58**), plant height (rg=0.69**) and pod per plant (rg=0.59**) and branch per plant with biological yield (rg=0.56**) positively and significantly correlated.

There was also positive and significant correlation observed between pods per plant and days to maturity and days to flowering, and between seeds per pod and days to maturity. In contrast to this result there was negative and highly significant correlation observed between seeds per pod and hundred grain weight (rg = -0.73**). Grain yield exhibited positive and highly significant genotypic correlation with harvest index (rg=0.71** and rg=0.80**), pod per plant (rg=0.55** and rg=0.83**) and biological yield (rg=0.44** and rg=0.59**) under both sole and intercropping condition, respectively.

Table 7. Combined analysis of correlation coefficient among traits in common bean sole and intercropping condition.

Trait	DF	DM	PH	POPL	SEPO	PLEN	HGW	BYIE	HI	BRPL	YLD
DFMIX	**0.409***	0.448*	0.372	-0.007	0.149	0.224	-0.175	0.196	-0.204	-0.114	0.020
DMMIX	0.612**	**0.662****	0.646**	0.134	0.474*	0.077	-0.212	0.306	0.234	-0.173	0.424*
PHMIX	0.561**	0.554**	**0.675****	0.015	0.312	0.297	0.112	0.079	0.323	-0.293	0.338
POPLMIX	0.501*	0.623**	0.454*	**0.349**	0.318	-0.104	-0.151	0.092	0.361	0.125	0.393
SEPOMIX	0.356	0.509*	0.388	0.252	**0.761****	-0.401	-0.748**	0.527**	-0.065	0.038	0.227
PLENMIX	-0.013	-0.245	0.238	-0.725**	-0.308	**0.776****	0.451*	-0.248	-0.362	-0.554**	-0.527**
HGWMIX	-0.211	-0.433*	-0.116	-0.597**	-0.643**	0.809**	**0.822****	-0.398	-0.035	-0.319	-0.322
BYIEMIX	-0.322	-0.100	0.067	-0.141	0.165	0.323	0.267	**0.319**	0.388	0.030	0.410
HIMIX	0.248	0.348	0.621**	-0.070	0.331	0.096	0.085	0.075	**0.467***	-0.250	0.333
BRPLMIX	0.020	-0.095	0.051	0.045	-0.134	0.224	0.302	0.028	0.271	**0.140**	0.286
YLDMIX	0.369	0.482*	0.649	-0.007	0.321	0.241	0.133	0.078	0.442*	-0.193	**0.391**

BYIE=Biological yield (g), BRPL=branch per plant, DF=days to flower, DM=days to maturity, HGW=hundred grain weight (g), HI=harvest index (%), PH=plant height (cm), POPL=pod per plant, PLEN=pod length (cm), SEPO=seed per pod, YLD=grain yield (Qt ha^{-1}), DFMIX=days to flower in mixture, DMMIX= days to maturity in mixture, PHMIX=plant height in mixture, POPLMIX=pod per plant in mixture, SEPOMIX=seed per pod in mixture, PLENMIX=pod length in mixture, HGWMIX=hundred grain weight in mixture, BYIEMIX=biological yield in mixture, HIMIX= harvest index in mixture, BRPLMIX=branch per plant in mixture, YLDMIX=grain yield in mixture.

The comparison of variables between sole and bean maize cropping systems and the association of some of the characters is shown in Table 7. The result indicated that, among the tested variables, days to maturity (rg=0.66**), plant height (rg=0.68**), seed per pod (rg=0.76**), pod length (rg=0.78**), and hundred grain weight (rg=0.82**) showed positive and highly significant correlation between the two cropping systems.

Similarly, days to 50% flowering (rg=0.41*) and harvest index (rg=0.14*) showed positive and significant correlation between sole and intercropping. The result of the present study agreed with the report of Santalla et al. (2001) who indicated that significant and high correlations of bean yields between sole cropping and intercropping with maize.

According to Woagyehu (2008), grain yield of common bean genotypes under sole cropping has shown a positive correlation with yield under intercropping (rg=0.55). Similarly, he stated that, positive correlation between grain yield between the two-cropping system. Some of yield and yield related traits, that is, branch per plant, biological yield, pods per plant and grain yield revealed insignificant correlation between the sole and inter cropping conditions. It is worth mentioning that there was no negative association between variables of the two cropping systems.

Similarly, Mesele (1997) indicated the relationship between seed yield and number of pods per plant was highly significant at phenotypic and genotypic level. He also reported that yield per plant was highly and significantly correlated with number of seeds per plant both at phenotypic and genotypic levels.

Most of the traits showed highly significant variation between the two cropping systems revealing the insignificant correlation between sole and intercropping. Therefore, as per the combined analysis of variance, there was an apparent variation between genotypes, cropping system and genotype × cropping system interaction.

However, the correlation coefficient can be affected by the test genotypes and environments at which the genotypes are raised, correlations among the quantitative traits are very important for selecting genotypes and/or populations having multiple associated characters.

Direct and indirect effects of characters on grain yield at genotypic level for sole cropped common bean

Every component character can exert a direct and indirect effect on grain yield. Path coefficient analysis offered a much more realistic interpretation of the factors involved. The use of this technique requires a cause and effect situation among the variables. Based on the effects exerted by characters on the grain yield, one can consider that the possibility of improving the crop through these characters.

The direct and indirect effects of various traits on seed yield per plant among genotypes are shown in Table 8. Among the eleven characters studied, ten quantitative traits assumed to be the causal factors exerted their direct or indirect effects on grain yield. Of these traits, all exerted their positive direct effects on grain yield except seed per pod and hundred grain weight. Harvest index (0.96) and biological yield (0.62) recorded the highest direct effect on grain yield and followed by days to maturity, branch per plant, days to 50% flowering and pod length.

This indicated that, selection of high yielding genotypes

Table 8. Genotypic path analysis (direct and indirect effect) of ten quantitative traits studied for sole cropping.

	DF	DM	PH	POPL	SEPO	PLEN	HGW	BYIE	HI	BRPL	rg
DF	**0.191**	0.173	0.130	0.085	0.085	-0.040	-0.097	0.023	0.075	-0.024	-0.020
DM	0.128	**0.259**	0.083	0.046	0.049	-0.047	-0.063	0.037	-0.038	-0.005	0.197
PH	0.096	0.182	**0.117**	0.001	0.003	0.000	-0.001	0.002	-0.003	-0.004	0.094
PL	0.063	0.102	-0.009	**0.007**	-0.107	0.162	0.153	0.059	0.076	-0.210	0.549
EPO	0.063	0.107	0.035	0.004	**-0.278**	-0.072	-0.113	0.084	0.045	0.033	0.468
LEN	-0.029	0.103	0.002	0.006	0.112	**0.175**	-0.052	0.025	0.005	0.026	-0.131
GW	0.072	-0.140	-0.015	-0.005	0.175	0.133	**-0.680**	-0.311	0.166	-0.220	-0.142
BYIE	-0.017	0.081	0.023	0.002	-0.131	-0.065	0.035	**0.615**	-0.113	0.007	0.444
HI	0.056	-0.084	-0.032	0.003	-0.070	0.014	-0.019	-0.073	**0.957**	0.078	0.718
RPL	-0.018	-0.011	-0.052	0.008	-0.052	-0.067	0.025	0.004	0.357	**0.207**	0.4414

U=0.2132. BYIE= biological yield (g), BRPL= branch per plant, DF= Days to flower, DM=days to maturity, HGW=hundred grain weight (g), HI= Harvest index (%), PH=plant height (cm), POPL=pod per plant, PLEN=pod length (cm), SEPO=Seed per pod, YLD=Grain Yield (Qt ha^{-1}), rg=genotypic correlation, U=Residual.

either separately or in combination of these traits would result in increasing grain yield. Harvest index through number of branches per plant (0.36), seed per pod through hundred grain weight (0.18) and days to maturity through plant height (018) recorded the highest positive indirect effect on grain yield.

Even though pod per plant showed significant genotypic correlation with grain yield (*rg*=0.55**), it exerted very low positive direct effect value on grain yield. On the other hand, all quantitative traits except pod per plant, hundred grain weight and harvest index and branch per plant exerted their positive indirect effect on grain yield *via* plant height. Conversely, seed per pod (-0.28) and hundred grain weight (-0.07) recorded their negative direct effects on grain yield. But this negative direct effect of the traits is compensated by the indirect effect exhibited by these traits as they interact each other, that is, seed per pod through hundred grain weight (0.175) exerted moderate to higher indirect effect on grain yield as compared to other quantitative traits.

Incongruent to the present study, Sintayehu (1997) reported 100-seed weight, had the highest direct effect on grain yield followed by pod per plant and number of seeds per pod. Similarly, Mesele (1997) also noted that seed per plant had the highest degree of favorable influence on seed yield followed by days to maturity and days to flowering exerted negative direct influence on seed yield on the other direction.

According to Kassaye (2006), days to flowering and maturity had positive direct effect on seed yield. In contrast, these phenological traits contributed their negative indirect effects through 100- seed weight.

Conclusion

Genetic variability studies provide basic information regarding the genetic properties of the population based on which breeding methods are formulated for further improvement of the crop. The present study was also aimed to investigate about the nature and extent of variability that can be attributed to characters that can be observed and realized in practical breeding.

Accordingly, in this experiment, common bean genotypes showed high significant variability for all the traits considered, that is, days to maturity, plant height, pod per plant, seed per pod, pod length, hundred grain weight, biological yield, harvest index, branch per plant and grain yield quintal per hectare, but there was no apparent variation for days to flowering. Quantitative traits that showed the maximum significant variation between genotypes were plant height, pod per plant, seed per pod, biological yield, harvest index and grain yield.

The PCV values of all of the traits considered in this study were greater than their GCV values. These results could be indication of other environmental factors played a great role on the variation observed. Whereas, the highest genetic advance as a percent of mean recorded for plant height (98.21), grain yield (81.15), hundred grain weight (61.4) and pod per plant (53.6) according to their order of importance. Generally, 98, 81, 61, and 53% of improvement can be made in selection through these characters for intercropped beans.

Based on the genotypic correlation coefficient analysis of the present study, about 70% of the traits revealed positive and significant correlation with grain yield. Among which, harvest index, pod per plant, seed per pod and biological yield showed highly significant correlation with grain yield. This correlation could be either due to pleiotropic gene action or linkage or more likely due to both phenomena. Furthermore, the qualitative traits studied for path coefficient analysis at genotypic level, most of the traits exerted their direct effect on grain yield except seed per pod and hundred grain weight.

From this study, one can conclude that, utilizing the variability of those traits which have significant and positive correlation with grain yield and those that have direct or indirect influence on the productivity of the genotypes is very much decisive.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Fungal endophytes in bananas cv Manzano affected by *Fusarium*

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Endophytes microorganisms have the potential to control vascular diseases caused by *Fusarium* spp. which does not have an effective chemical control. In this study, endophytes populations present in Manzano -apple bananas- affected by *Fusarium oxysporum* f. sp. *cubense* race 1 were studied. Endophytes were isolated in two commercial farms in Urabá-Colombia, taking leaf, pseudostem, corm and root tissues from healthy and diseased plants. Two disinfestation methods were used: conventional (2% hypochlorite + 70% Ethanol) and chlorine gas (6.25% sodium hypochlorite + 37% hydrochloric acid). 143 isolates with 11 genera were obtained from healthy plants with the following frequencies: *Fusarium* sp. (18.67%), *Nigrospora* sp. (8%), mycelia sterilia (48%), among others. Also, eight genera were found in diseased plants, *Fusarium* sp. (23.53%), *Colletotrichum* sp. (17.76%), mycelia sterilia (47.06%). All endophytic fungi are ascomycetes, except for *Pythium* sp., oomycete that was isolated only from diseased plants. *Pythium* sp. which, was isolated from healthy plants, constitutes the first reports in musaceas. According to the Simpson and Shannon-Wiener diversity indices, a higher diversity of fungi was found in healthy plants (0.282 and 1.729) than in infected ones (0.294 and 1.532); it depends on disinfection method as demonstrated here, suggesting that tissue cleaning and disinfection methodologies modulate the microbial populations obtained. This work contrasted endophytic fungi in symptomatic plants attacked by Foc R1 with healthy plants and also the genus of endophytic fungi described in this study have already been reported in previous research in *Musa,* except for the oomycete *Pythium*

Key words: Biological control, diversity, Foc, microbiota, vascular disease.

INTRODUCTION

Banana is next to rice, wheat, and maize as a food crop. Though banana is a major crop around the world in international trade, more than 85% of bananas are grown for local consumption in tropical and subtropical regions

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(Perrier et al*.,* 2011). This crop is affected by numerous diseases, but *Fusarium* wilt, formerly known as Panama disease, caused by the fungus *Fusarium oxysporum* f. sp*. cubense* (Foc), is the most destructive disease of the Musaceae family (Ploetz, 2015). It has four races, and Race 1 (R1) destroyed more than 80.000 hectares of the Gros Michel clone in Latin America in 1890 and mid-1950s, which forced the banana industry to replace this cultivar with bananas of the Cavendish subgroup resistant to R1. However, the problem of Foc R1 persists in smallholding production systems, where susceptible varieties such as Gros Michel (AAA), Manzano (Apple) (AAB), Prata (AAB) and Bluggoe-type cooking bananas (ABB) are still cultivated (Viera and Pérez-Vicente 2009; Ordoñez et al., 2015). Currently, a Foc population variant known as Race 4 Tropical (Foc R4T) is present in Asia, Oceania and Africa, but not in America. In the areas where it is present, the disease has caused extensive damage, including serious economic and productive consequences. A marginal damage cost of $2.3 billion by Foc R1 has been estimated, but there is no consolidated official data concerning RT4. However, it has been estimated that around 100.000 ha are infested globally, being the Philippines (15.500 ha), China (40.000 ha) and Jordan (80% of the production area in banana Valery) the countries with the highest loses (Ordoñez et al*.,* 2016). It is expected that damage by R4T may affect 1.6 million hectares of musaceas crops in 2040, whose production today is 36 million tons, worth 10 billion dollars (Scheerer et al., 2016).

Market conditions must change in the short and medium term due to conventional management measures are inefficient to counteract the problem (Ploez, 2015). Therefore, it is necessary to study, design and adapt control measures. One of the proposed alternatives to control is the use of endophytes, a group of microorganisms that colonize the internal tissues of plants without causing immediate negative effects. These microorganisms are linked with various beneficial interactions with their host, providing protection against a wide variety of biotic and abiotic stress factors (Porras-Alfaro and Bayman 2011; Aly et al., 2011). Microbiological composition of plants depends on multiple factors such as the host, phytosanitary status, physiological age, availability of nutrients and environmental conditions (Stone et al., 2004; Zimmerman, 2012). Studies in banana have shown the presence of endophytic microorganisms (Photita et al., 2001; Rossmann et al., 2012), and their activity spectrum can include plant growth promoters (Ting et al., 2008; Marcano et al., 2016) and Foc antagonists (Cao et al., 2005; Lian et al., 2008; Nuñez et al., 2013), among others. Endophytic fungi have been associated with plants for over 400 million years; they are ubiquitous and occur within all known plants, including a broad range of host orders, families, genera and species. Endophytic fungi mainly consist of members of the Ascomycota or their mitosporic fungi, as well as some taxa of the Basidiomycota, Zygomycota and Oomycota phyla (Sun and Guo, 2012). The aim of this study is to observe fungal endophyte populations in banana cv. Manzano, in healthy plants and plants infected with Foc R1 as an approximation to the dynamics of these organisms in pathogenesis processes, using two disinfection methods on tissues.

MATERIALS AND METHODS

Plant material

Healthy (H) banana plants cv. Manzano in a state of development of floral differentiation and phenological state 5090 of the BBCH scale (Meier, 1997) were collected in productive area in Urabá (Colombia) in the farm 'Villa Carmen' (18 years without the presence of Foc R1) (lat. 7°51'12'' N, long. 76°41'19'' W). Also, symptomatic (S) bananas plants cv. Manzano with similar developmental stages were collected in the farm 'La Isla Bonita' (12 years with the presence of Foc R1) (Lat. 7°48'08'' N, long. 76°41'25'' W). These plants had initial stages of Foc R1 symptoms consisting of chlorosis in the first three leaves. Four plants were selected in each location; roots, pseudostems, corms, 300 g sections from leave number three, and segments of each plant were collected and then immediately taken to the laboratory of Cenibanano on Carepa (Colombia).

Isolation and preservation of endophytic fungi

Under laboratory conditions, tissues were washed with tap water and cut into pieces of 0.5 cm^3. Then, samples were subjected to two sterilization methods: i) Conventional disinfection with liquid chlorine (LCD), in which each sample was immersed in 2% liquid NaOCl and then in 70% ethanol for 1 min, then it was rinsed twice with sterile distilled water for 1 min. ii) Gaseous chlorine disinfection (GCD), in which each sample was placed on filter paper and inside a hermetically sealed container. Then it was suspended for 30 min in a Cl gaseous atmosphere produced by the reaction of a mixture containing 100 mL of 6.25% NaOCl and 5 ml of 37% HCl (Marshall et al., 1999).

Tissues were placed on Petri dishes containing potato dextrose agar (PDA) + Streptomycin 150 ppm and incubated at 25°C during 8-10 days. For the incubation period, samples were observed every day, and any newly emerged fungal spot was immediately picked out using autoclaved toothpicks and transferred to another fresh PDA plate. The resulting fungal isolates were conserved in 20% glycerol in 2 ml cryovials, and stored at -20°C.

Endophytic fungi morphotypes

Fungi strains were identified based on macroscopic and microscopic features according to Barnett and Barry (1998), Hanlin (1990) and Seifert et al. (2011). Morphotypes of nonsporulating strains were determined based on macroscopic characteristics.

Diversity analyses of endophytic fungi

Using morphotypes as the unit, the number of isolates (N) was counted and the isolation frequency (IF) was calculated for each endophytic microorganism in different tissues. The species diversity was evaluated by the Shannon–Wiener index (H′) and Simpson's dominant index (λ). The indices were estimated using the EstimateS program (Version 9.1.0) (Colwell, 2013).

RESULTS AND DISCUSSION

Isolation of endophytic fungi

A total of 143 isolates of endophytic fungi were recovered (Tables 1 and 2), 45.46% from leaf, 20.28% from root, 18.18% from pseudostem and 16.08% from corm. Fourteen morphotypes of endophytic fungi, one oomycete (Chromista) and 68 sterile mycelia strains were categorized (Tables 1 and 2). It was found that 14 genera of endophytic fungi are Ascomycota (Fungi), and were identified in three classes: Sordariomycetes, Dothideomycetes, Eurotiomycetes distributed in eight orders: Hypocreales (35.7%), Sordariales and Eurotiales (14.3% each), and Pleosporales, Trichosphaeriales, Diaporthales, Capnodiales, Glomerellales (7.1% each). Additionally, 47.5% of the isolates showed sterile mycelium belongs to Ascomycota or Basidiomycota based on mycelia septation.

Prevalence of sterile mycelial fungi (Ascomycota/ Basidiomycota) in this study is the highest detected in *Musa*, with 68 strains (Figure 1). Previous reports in this genus of plants conducted by Photita et al. (2001) found 14 sterile mycelial fungi from 61 collected, and Brown et al. (1998) reported 24 strains from 100. Sun and Guo (2012) summarized that 54% of total isolates obtained in recent research on endophyte fungi did not sporulate in cultures, which suggest a considerable diversity of these fungi with sterile mycelia in plant tissues. It is consistent with finding here, in both groups of plants, healthy and diseased plants, nonsporulating strains were common (Table 1) (48 and 47.06% respectively), followed by *Fusarium, Nigrospora, Phomopsis* and *Cladosporium*, all common and reported endophytes in *Musa* (Cao et al., 2002; Photita et al., 2001; Sun and Guo, 2012; Ting et al., 2008; Zakaria and Rahman, 2011). On healthy tissues are present too *Verticillium, Curvularia, Purpureocillium, Trichoderma, Stachybotrys, Aspergillus* and *Sordaria*. On plants affected by Foc R1 *Colletotrichum, Chaetomium, Penicillium* and *Pythium* were isolated exclusively.

Common fungal morphotypes of healthy and diseased plants can be part of the usual microbiome, and within these, *Fusarium* sp. was the most frequently found morphotype in healthy (18.67%) and diseased plants (23.53%), being an endophyte widely isolated in different tissues in several banana studies (Brown et al., 1998; Photita et al., 2001; Ting et al., 2008; Zakaria and Rahman, 2011). *Nigrospora, Phomopsis* and *Cladosporium* are common to both groups of plants, and could present affinity with some tissues, such as *Phomopsis* sp. which was isolated only from foliar tissue in healthy and diseased plants under the two disinfection methods used. Similar results have been reported by Gazis and Chaverry (2010), who found that *Phomopsis* aff. *theicola* was located in leaves, while diverse genera of endophytic fungi were located in leaves and in the sapwood of wild rubber trees. Fungi belonging to the genus *Cladosporium* sp. also showed a type of affinity with roots and leaves (Photita et al., 2011; Cao et al., 2002); five isolates were found in symptomatic plants, but an individual was isolated from healthy plants in the corm, the tissue adjacent to the root. These results are in accordance with Hamayun et al. (2009) who reported the presence of *Cladosporium sphaerospermum* in soybean roots and its activity as a plant growth promoter. However, *Fusarium, Colletotrichum, Verticillium, Penicillium, Nigrospora* and *Curvularia* are reported as causal agents of crown rot in banana in different production areas (Perez et al., 2001; Kamel et al., 2016). For this reason, some endophytic fungi can be considered latent pathogens (Stone et al., 2004) under conditions such as plant senescence and biotic and abiotic stresses, but we did not probe if those endophytic isolates had pathogenic characteristics.

Verticillium, Sordaria Stachybotrys Curvularia, Aspergillus Purpureocillium, Trichoderma were obtained from healthy tissues (Table 1). Some of them were involved in biological control with active compounds against *Fusarium* on *Musa* (Brown et al., 1998; Cao et al., 2004; Nuñez et al., 2013), or in other pathosystemas such as *Stachybotrys elegans* is a fungus native to the soil, mycoparasitic properties have been widely described (Chamoun and Jabaji, 2011). *Purpureocillium* spp. is a fungus widely analyzed in the biological control of pathogens, as specified by Munawar et al. (2015), who demonstrated its biocontrol capacity in the tomato wilt complex. Others like *Sordaria* sp. have been reported as an endophyte fungus in beet (Abdelwehab et al., 2014) and conifers (Hoffman et al., 2008) but not reported in banana, so this is the first report in these plants.

On symptomatic plants, eight genera of endophytic fungi were collected (Table 1), also fungi of mycelia sterilia. Identified morphotypes included *Fusarium* (23.5%) followed by *Colletotrichum* (11.76%) and *Cladosporium* (7.53%). *Colletotrichum* sp., *Penicillium* sp., *Chaetomium* sp. and *Pythium* sp. were isolated exclusively from symptomatic plants; these genera of fungi are involved in the decomposition of tissues, a typical symptom of decay or wilting also caused by *Fusarium*, but when deep disinfection is performed, those are only on pseudostem. Rodrigues (1994) mentions that the affinity with tissues of endophytes suggests that these microorganisms have the capacity to use specific substrates or habitat, in addition to making a differential use of substrate to reduce competition among endosymbionts and prevent excessive population of endophytes in the host plant (Gamboa and Bayman, 2001; Venkatachalam et al., 2015). Presence of *Chaetomium* sp. on speudostem on infected plants suggests tissue decomposition since it is a cosmopolitan fungus and cellulose degrader (Lee and

Table 1. Morphotypes of fungal endophytes in bananas cv. apple.

Kingdom	Phylum	Class	Order	Genus/ Morphotype	Healthy			Symptomatic			Total strains
					Organ	Strains	Frequency (%)	Organ	Strains	Frequency (%)	
Fungi	Ascomycete/Basidiomycete	indeterminated	Indeterminated	Mycelia sterilia	r,c,s,l	36	48				36
Fungi	Ascomycete/Basidiomycete	indeterminated	Indeterminated	Mycelia sterilia				r.c.s.l	32	47.06	32
Fungi	Ascomycete	Sordariomycetes	Hypocreales	*Fusarium*	r,c,s,l	14	18.67	c.s.l	16	23.53	30
Fungi	Ascomycete	Sordariomycetes	Trichosphaeriales	*Nigrospora*	c,s,l	6	8	r.c	2	2.94	8
Fungi	Ascomycete	Sordariomycetes	Diaporthales	*Phomopsis*	*l*	2	2.67	*l*	1	1.47	3
Fungi	Ascomycete	Dothideomycetes	Capnodiales	*Cladosporium*	*c*	1	1.33	*r*	5	7.35	6
Fungi	Ascomycete	Sordariomycetes	Hypocreales	*Verticillium*	*r,c,l*	5	6.67		0	0	5
Fungi	Ascomycete	Dothideomycetes	Pleosporales	*Curvularia*	*r,l*	3	4		0	0	3
Fungi	Ascomycete	Sordariomycetes	Hypocreales	*Purpureocillium*	*c,l*	3	4		0	0	3
Fungi	Ascomycete	Sordariomycetes	Hypocreales	*Trichoderma*	*c,s*	2	2.67		0	0	2
Fungi	Ascomycete	Sordariomycetes	Hypocreales	*Stachybotrys*	*c*	1	1.33		0	0	1
Fungi	Ascomycete	Eurotiomycetes	Eurotiales	*Aspergillus*	*l*	1	1.33		0	0	1
Fungi	Ascomycete	Sordariomycetes	Sordariales	*Sordaria*	*l*	1	1.33		0	0	1
Fungi	Ascomycete	Sordariomycetes	Glomerellales	*Colletotrichum*		0	0	*r.s.l*	8	11.76	8
Fungi	Ascomycete	Sordariomycetes	Sordariales	*Chaetomium*		0	0	*s*	2	2.94	2
Fungi	Ascomycete	Eurotiomycetes	Eurotiales	*Penicillium*		0	0	*r*	1	1.47	1
Chromista	oomycota	Peronosporide	Peronosporales	*Pythium*		0	0	*r*	1	1.47	1
				Total		75	100		68	100	143

r: root, c: corm, s: pseudostem; L: leaf.

Table 2. Amount of endophytic morphotypes obtained by means of two disinfection methods of tissues in bananas cv. apple.

Plants	Disinfection method	Tissue				Total
		Root	Corm	pseudostem	leaf	
Healthies	L	11	11	3	19	44
	G	5	5	6	15	31
Symptomatics	L	6	4	11	19	40
	G	7	3	6	12	28
Total		29 (20.28%)	23 (16.08%)	26 (18.18%)	65 (45.46%)	143 (100%)

L: liquid chlorine disinfection
G. Gas chlorine disinfection.

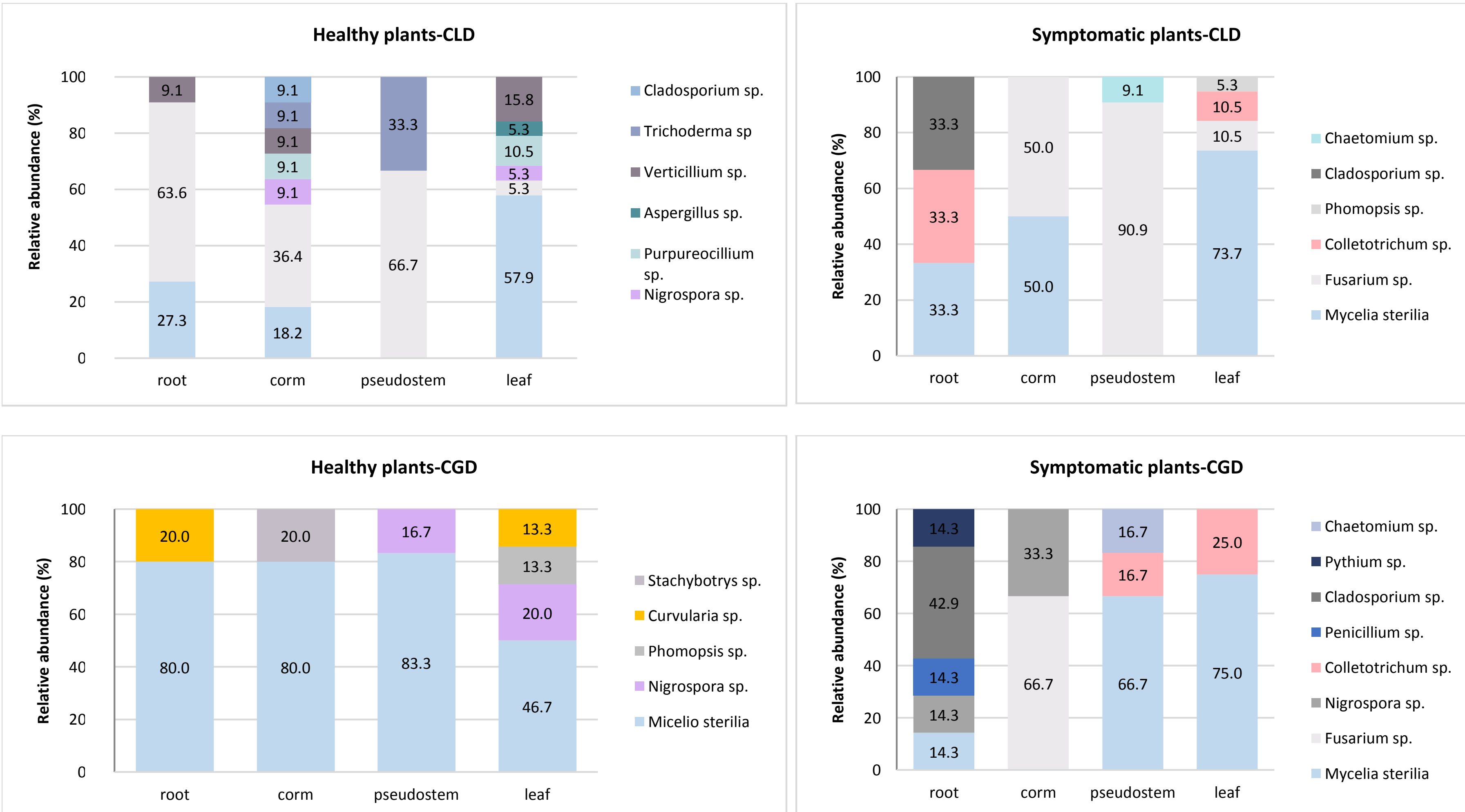

Figure 1. Richness, dominance and heterogeneity of endophytic fungi in healthy and inoculated plants of banana with F. oxysporum race 1 (CLD: Chlorine Liquid Disinfection. GCD: Chlorine Gas Disinfection).

Hanlin, 1999). Huang et al. (2015) determined that after soil disinfection of a crop affected with Foc, the presence of *Chaetomium* sp. was highlighted within the microbial community of the soil, while the population of the pathogen (Foc) decreased. It can be inferred that both genera can be common in the soil of the banana farms in the study area, and the condition of diseased plants can favor the endophytic condition of this fungus.

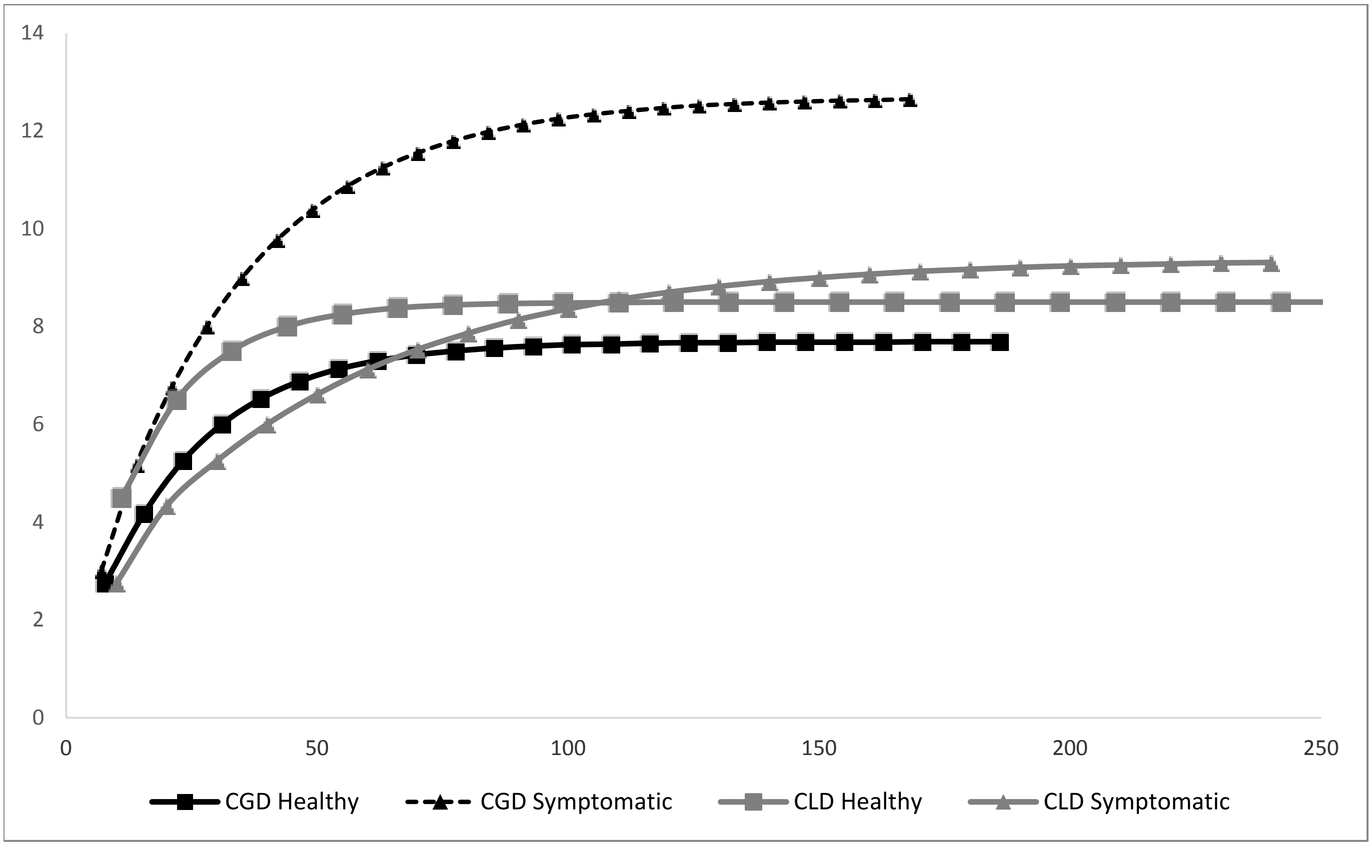

Figure 2. Rarefaction curves of endophytic fungal species for healthy and symptomatic plants under gas(CGD) and liquid (LCD) chlorine disinfection.

Pythium sp. (Oomycota: Chromista) constitutes the first report of an Oomycete in banana as endophyte on roots, obtained by means of GCD.

Previously, Oomycota had been sampled as a phylloplane inhabitant in *Musa* AAB (Urdaneta et al., 2002), but existence of *Pythium* on root tissues in banana can be explained as an opportunistic inhabitant of root rot. This genus is its direct causal agent of root rot in several crops (Manjunath et al., 2010; Gichuru et al., 2016; Charkowski, 2016). In *in vitro* banana plants, *Pythium debaryanum* has been associated with damping-off symptoms (Herrera et al., 1995). However, *Pythium* was recently reported as a microorganism that confers cross-resistance to diseases, which suggests several ecological functions in plant tissues (Yacoub et al., 2016).

Disinfection methods

In our results leaf and root tissue showed a high proportion of endophytes (Table 2, Figure 1); leaf contains the greatest diversity of endophytic fungi, but, disinfection method seems to modulate proportion of strains obtained. Leaf contains high diversity and more when in a healthy tissue, but root is as well a tissue that carries a high diversity on disease process, and again is dependent on disinfection method (Figures 1 and 2). It leads to analyze not only diversity, but also function of population inside a tissue. As was mentioned, on leaf some genuses obtained are involved in biological control activity; in contrast with some from roots from diseased plants, this community seems to be active in decomposition tissues. Context of biological stage of plants is important to analyze diversity of endophytes. It is similar with the results of Pocasangre et al. (2000).

Cultivation-dependent techniques used in this study included surface sterilization of plant tissue to eliminate superficial microorganisms (Hallmann et al., 2006). Theoretically, the sterilizing agent should kill any microbe on the plant surface without affecting the host tissue and the endophytic microorganisms. For the purposes of this study, two disinfection methods were used: the first one consisted of using gaseous chlorine (GCD), which is more efficient to remove contaminants from surfaces (Marshall et al., 1999), and the second one used conventional disinfection with liquid chlorine (LCD). The use of gaseous chlorine resulted in 30% less isolatesfrom healthy and symptomatic plants compared with the usual

Table 3. Ecological index of endophytic fungi in healthy and inoculated plants of banana with *F. oxysporum* race 1.

Comparison		Strains (n)	Richness (S)	Simpson (λ)	Shannon-Wiener (*H'*)
Plant	Healthy	75	12	0.282	1.729
	symptomatic	68	9	0.294	1.532
Gas chlorine disinfection	Healthy	31	6	0.448	1.170
	symptomatic	28	8	0.296	1.590
Liquid chlorine disinfection	Healthy	44	8	0.256	1.610
	symptomatic	40	6	0.280	1.290

disinfestation method. It is required in tissues like roots, corm and pseudostems of banana plants which have porous surfaces that can create air chambers that prevent this substance from deep cleaning them (Tables 1 and 2). As an example, *Fusarium* morphotypes were obtained from leaves in healthy plants, but when gas chlorine was used, they were not isolated from tissues. The same was observed with *Verticillium* morphotypes, which were present in leaves with superficial disinfection with liquid chlorine. In contrast, *Stachybotrys* and *Sordaria* were present on corms and leaves with deep disinfection, respectively and *Pythium* on roots in symptomatic plants when tissue was cleaned with gaseous chlorine. These findings indicate that the disinfection method leads to diversity of microorganisms that can be found by molecular or microbiological methods.

Diversity

Richness (S), dominance (λ) and heterogeneity (H´) of fungal endophyte morphotypes were calculated in healthy and diseased banana plants. Richness refers to the number of groups of genetically or functionally related individuals, in this case fungi morphotypes. In general, S of endophytic fungal morphotypes in bananas cv. Manzano was higher in healthy plants (12 morphotypes) compared with diseased plants with Foc (nine morphotypes) (Table 3). Our data suggested a high diversity of the endophytic fungal community of healthy plants in contrast to diseased plants (Table 3). Regarding S comparisons between microorganisms obtained by GCD, infected plants have more diversity or richness suggesting again that deep disinfection of tissues allows one to analyze some microorganisms as weak competitors in axenic media, but present on tissues. As discussed above, in LCD disinfestation, surfaces of healthy and diseased plants kept competitive or opportunistic strains that can survive on air chambers of tissues; those strains are more competitive in a Petri dish than any other obtained by GCD.

The Simpson diversity index (λ) is the estimated probability that two individuals randomly selected from the same habitat will be of the same species, which is a measure of dominance. This index in healthy plants was 0.282, while in diseased plants it was 0.294 (the λ index oscillates between 0 and 1, 1 being a population with 1 species). When healthy and infected plants were compared, they did not exhibit any differences, but when GCD values were observed, healthy plants tended to be less diverse.

On the other hand, the Shannon-Wiener index (H') indicates how heterogeneous or uniform the representation of the species in abundance is, considering all species, assuming that all of them are represented in a sample and that they are randomly sampled. Values range from 0 to 5. Typical values are generally between 1.5 and 3.5 in most ecological studies where 1.5 represents the lowest diversity and 3.5 the highest. This index was 1.729 in healthy plants, being slightly higher than in diseased plants, which showed a value of 1.532. The same tendencies were observed with LCD. In contrast, tissues of infected plants disinfected with GCD are more heterogeneous in terms of fungal endophyte morphotypes (Table 3).

Rarefaction curves allow comparing the number of genera between healthy and diseased plants, when finding different numbers of isolates. The results confirm that the method of disinfection is important because it allows us to understand the richness of the species in terms of their abundance in deep tissues, so that they can be considered endophytes and not superficial invaders. In the case of the evaluations between healthy and diseased plants subjected to GCD, results showed that infected plants contained more diversity of organisms, specifically in roots, but that these organisms are essentially tissue decomposers. In healthy plants, this endophytic population had other functions such as protection, and that is why although populations count numerically, it is also important to analyze their ecological significance within the tissues of the plant. This also necessarily implies that the methods of organism identification with sterile mycelium and the counting of non-cultivable ones are also two necessary and pertinent methodological components for this type of analysis

(Figure 2).

Cao et al. (2004) reported a higher number of Actinomycete morphotypes in diseased banana plants with Foc R4T in comparison to healthy plants. This fact suggests that Actinomycetes diversity increases in the presence of the pathogen. However, 50% of isolates from healthy plants showed antagonism with Foc, while only 27% of the isolates from diseased plants showed antagonistic activity. Lian et al. (2008) stated that the presence of pathogens (Foc) in banana plants triggers a cascade of reactions that leads to the synthesis of stress metabolites such as H_2O_2, phytoalexins, abscisic acid, jasmonic and salicylic acid, which can generate changes in endophytic populations. In lemon plants, a greater diversity of endophytic fungi has been found in healthy leaves compared to yellow leaves (with nutritional deficiency). This difference suggests that the yellowing of leaves can facilitate the incidence of certain endophytic fungi such as *Colletotrichum gloeosporioides* and impose growth inhibition on the other endophytes (Douanla-Meli et al., 2013), which is a similar condition to that presented in Manzano banana plants affected by Foc. Even more information is needed to understand the endophyte-host relationship, since the effects attributed to the endophytes present in healthy plants can change when host plants are grown under less favorable conditions, or even in conditions of stress triggered by the presence of pathogens or an unfavorable environment (Hardoim et al., 2015).

Conclusions

In general, healthy plants have greater diversity compared with plants infected with *Fusarium*. The attack of *Fusarium* initially concentrated in roots and, therefore, decomposer organisms was found there. Although these organisms are indicators of diversity, they are part of the necrotrophic degradation of the tissue, and for this reason, the amount of endophytic organisms found in a tissue must be analyzed in depth in the context of microbial ecology. It is necessary then, to begin to study not only the abundance but also the functionality of the microorganisms found in terms of pathogenic, symbiotic and beneficial interactions. In this work, it was demonstrated that the tissues analyzed leaf is the carrier of greater diversity of endophytic fungi, but the root from diseased plants also contains a considerable number of microorganisms associated to a decomposition of tissues. In contrast, many of the genera found in the leaf have biocontrol activity reported in literature.

As well, the type of disinfection leads to the findings of endophytes in terms of diversity. Methodology of disinfection used on tissues to obtain endophytes is crucial because it determines if surface organisms are extracted from tissues. Chlorine gas disinfection prevents air chambers of tissues on which superficial micro-organisms can be hosted, and then obtained as endophytic. In the case of *Musa* where there is prevalence of aerenchyma and irregular surfaces in some cases, the disinfection method is crucial to obtain reliable results that allow us to understand the context of the presence of a species in an endophytic community.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Performance evaluation of improved bread wheat (*Triticum aestivum* L.) varieties and production technologies in Central High Lands of Ethiopia

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The aim of this study is to evaluate the performance of five improved varieties of bread wheat and production technologies in Becho District of Oromia, Central Ethiopia. The varieties used were Sanate (T1), Mada-Walabu (T2), Hobora (T3), Hogana (T4), and Hidase as standard check (T5). The experiment was carried out in a Randomized Complete Block Design (RCBD), with six replications using six farmers' fields. Yield and yield related parameters were analyzed using SAS statistical software version 9.0. Economic analysis, preference, gender and nutrition and environmental suitability data were obtained to compare the advantages of treatments/varieties and identify the variety that performs best. All the yields and yield related components were significantly different between the varieties at 5% probability level. Sanate had the highest yield followed by Hobora and Hidase. Sanate variety had a 27% yield advantage over the standard check (Hidase) and 169.6, 143.2 and 156.6% yield advantage over the national, regional and zonal average yield of bread wheat in 2016/2017 Meher season of CSA data. Based on farmers' preference analysis, variety Sanate had the highest acceptability (96%) followed by Hobora (74%) and Hidase (65%), while Hogana variety had the lowest (24%). Economic analysis showed that Sanate variety had the highest net benefit (86,531.65 Birr/ha) followed by Hobora (71,793.96 Birr/ha) and Hidase (69,564.16 Birr/ha). Variety Hogana had the lowest net benefit of about 54,507.63 Birr/ha. Based on the rules of decision making and the integrated scoring on the bread wheat varieties, two of the tested varieties met the requirements for recommendation. Therefore, Sanate and Hobora varieties in addition to Hidase (the control) were recommended for Becho and other areas with similar agro-ecological conditions in the Central Highlands of Ethiopia.

Key words: Becho, economic analysis, environmental suitability, farmers' acceptability, gender aspect, integrated validation, protocol.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important staple food crop in Ethiopia, especially in urban areas. It provides

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about 15% of the caloric intake for the country with over 90 million population (FAO, 2015a), placing it second after maize and slightly ahead of tef, sorghum, and enset, which contribute 10 to 12% each (Minot et al., 2015). Wheat is also the fourth largest cereal crop produced by about 5 million smallholder farmers, that is, about 35% of all small farmers in the country.

Over the past two decades, both wheat production and consumption have shown increasing trends in Ethiopia. Wheat import has also grown significantly over the past decade. Yet, this substantial increase in domestic production and import has not reversed the increasing trend in wheat product prices, implying an even increased growth in wheat demand. Wheat yield in Ethiopia needs to improve further to level-up with Africa and world average yields, which were 13 and 32% higher than the average wheat yield in Ethiopia, respectively (FAO, 2015a). Beyond the contribution of agro-climatic and political factors to lower yields, technology could play a more dominant role in productivity, enable Ethiopia to enhance its yields and achieve self-sufficiency which in-turn can improve the living standard of its growing population (FAO, 2014).

After South Africa, Ethiopia is the second largest wheat producer in sub-Saharan Africa (FAO 2015b). Wheat is the principal cool-weather grain crop grown in Ethiopia. Besides the use of its grain for food, wheat residue and other by-products are also commonly used to overcome the shortage of livestock feed which is the biggest constraint to the sector in the country. The crop is grown at an altitude ranging from 1500 to 3000 m above sea level (masl), between 6 and 16°N latitude and 35 and 42°E longitude. The most suitable agro-ecological zones, however, are between the 1900 and 2700 masl (Bekele et al., 2000). The major wheat producing areas in Ethiopia are located in Arsi, Bale, Shewa, Ilubabor, Western Hareghe, Sidamo, Tigray, Northern Gonder and Gojam zones (Bekeke et al., 2000).

Despite their vast number, Ethiopian farmers in general cultivate small plots/acreage. Above half of the smallholders cultivate farms less than a hectare (EEA, 2015). The average farm size has also declined over time. Official statistics, for instance, indicate that over the past five years alone (2009/2010-2013/2014), the proportion of smallholders with farms lower than a hectare has increased by 5.2%, while those who cultivate farmland that vary from 1 and 2 ha and over 2 ha declined by 5.4 and 7.1%, respectively.

Fragmented land holding system added on the low use of agricultural inputs contributed to low productivity in the whole production system. This made Ethiopian farmers to be categorized among the lowest users of fertilizer and improved seeds in sub-Saharan Africa. The other constraint of wheat production in Ethiopia is yellow and stem rust disease which is roughly expected to occur each 7 years. All these wheat production challenges made wheat productivity in Ethiopia lower than other wheat producing countries in the world (Yami et al., 2013).

Out of the total grain crop area, 81.27% (10,219,443.46 ha) was under cereals. Teff, maize, sorghum and wheat took up 24.00% (about 3,017,914.36 ha), 16.98% (about 2,135,571.85 ha), 14.97% (1,881,970.73 ha) and 13.49% (1,696,082.59 ha) of the grain crop area, respectively. As to production, the tables paint similar picture as that of the area. Cereals contributed 87.42% (about 25,3847,23.96 t) of the grain production. Maize, teff, wheat and sorghum are made up 27.02% (7,847,174.66 t), 17.29% (5,020,440.05 t), 15.63% (4,537,852.34 t) and 16.36% (4,752,095.60 t) of the grain production, respectively (CSA, 2017).

Although small-scale farmers dominate wheat production in Ethiopia, there are some large-scale commercial farms that grow wheat. However, large commercial wheat producers account only for 3 to 5% of all wheat cultivated land (Minot et al., 2015). Production of wheat has significantly increased over the past 20 years. It has increased from 890000 metric tons (MT) in the 1991/1992 marketing year to 3.11 million MT in 2009/2010 (Bergh et al., 2012) and to 4.04 million MT in 2014/2015 (Minot et al., 2015).

In the past years, participatory demonstrations and evaluation of integrated improved wheat production technologies were implemented in the area. This innovation created an opportunity for the farmers to efficiently utilize their farmland and increase production and productivity. Especially, the use of improved varieties resistant/tolerant to wheat diseases, along with proper agronomic practices and the use of BBM (Broad Base Maker) to drain excess water from the farm field were practiced, and promising results were obtained.

Even though a lot of work has been done in this regard by different organizations, new varieties of bread wheat with different traits against disease and productivity have been released from different research centers. The objectives of this study were: (1) to assess/evaluate the performance of the newly released bread wheat varieties and production technologies in the farming system and; (2) To generate evidence on the wheat varieties and production technologies.

MATERIALS AND METHODS

Description of the study area

Bacho District is located at mid agro-ecology of South west Shewa Zone of Oromia Regional State at 8°35'0'' N latitude and 38°15' 0'' E longitude; about 80 km South West of Addis Ababa. It has an altitude range of 2,106 to 2,600 masl, with mean annual temperatures ranging from 16 to 25°C. The long term weather information revealed that the area has unimodal rainfall pattern in which the main rainy season is from May to September; its mean annual rainfall is about 1,300 mm per year. The soil of the study area is deep black vertisol, which is moderately fertile and suitable for the production of crops such as tef, wheat, chick pea lentil and other horticultural crops and forages.

Varietal/Treatment selection

The varieties were selected based on their suitability to the area, those newly released and new to the area. The varieties used for the validation activities were identified and obtained from the relevant research system of the country. The varieties were considered as treatments and the experiment was done in randomize complete block design (RCBD), with six replications. Each variety was planted on 10 m × 10 m area on individual farmers' plot and replicated with similar procedure on six farmers' field. The treatments were treated in similar manner to avoid management differences so that the varieties/treatments can express their performance and the difference in varietal performance can easily be exploited.

Site selection and land preparation

Selection of site is important for the successful implementation of activities. Selection of site and land preparation for wheat start immediately after the harvest of the preceding crops when there is residual soil moisture. The residual moisture makes us to get good friable soil structure which is very important for permeability of rain water and good emergence of seed. The preceding crops should not be the same physiologically to minimize the problem of nutrient imbalance and pest build up. Plowing should be done four to five times depending on the type of soil texture. The first plowing helps to decompose any debris in the field. The next rounds of plowing should be carried out when the first rain begins and before it comes to the saturation point. This helps to facilitate the decomposition of crop residues and prevent weed remnants. For the black soils of Becho District, drainage structures should be prepared before sowing using BBM. Sowing was carried out on the drained bed prepared at the beginning of planting when the soil was slightly "Nish". Although all improved technologies that help to improve yield were available, productivity did not improve as expected because the appropriate planting time locally called "Nish" did not coincide. Nish period is a period when the soil is relatively friable and appropriate for cultivation, like row making, using BBM and other practices which are difficult to practice when the soil is too wet. Land preparation was accomplished by using the local "Maresha". This made the soil particles to be fine.

Seed rate and planting methods

Planting was carried out with broadcasting method using BBM due to the heavy vertisol nature of the soil. Vertisol by its nature is a water logged soil, and this makes it difficult to do raw planting on it. A seeding rate of 150 kg/ha, which is common for all wheat varieties in the area, was used.

Fertilizer application

Even though the use of chemical fertilizer varies based on the soil condition and crop varieties, fertilizer application based on area specific recommendation is important. Accordingly, 100 kg/ha of NPS (19% N, 38% P_2O_5, 7% S) and 50 kg/ha of urea at planting stage and 50 kg/ha of urea at tillering stage (35-40 days) after planting were applied.

Data collection and analysis

The validation of the varieties (Sanate, Mada walabu, Hobora, Hogana, and Hidase as a standard check) was conducted on 100 m^2 of land of 6 selected farmers' fields for each variety. Data were collected based on the validation protocol developed by CASCAPE and Wageningen University and Research (de Roo et al., 2017). The validation protocol provides a practical guideline for an integrated validation of best-fit practices with 6 parameters, namely, productivity (agronomic data), profitability (economic data), acceptability (farmers' preference), gender (labor demand), nutrition and environmental sustainability (usage of chemicals). Data were collected in these parameters and the scores of each parameter were integrated to establish standardized scores for each variety; decision was passed based on the integrated score.

Data on yield were analyzed using the ANOVA and mean separation procedures of the SAS statistical software. The remaining data on the other parameters were summarized descriptively using average, sum, percentage, frequency, etc. After separately analyzing the data of each parameter, results of all the protocol components were normalized on a 1-5 scale. Subsequently, three rules were applied to decide the variety to recommend. First, the improved variety should have a higher overall performance than the check or local or conventional variety. Secondly, not more than one parameter should have a value of 1. Thirdly, varieties with a mean value of >4, 3-4, 2-3 and <2 were considered as highly recommended, recommended, acceptable and not acceptable, respectively (de Roo et al., 2017). Furthermore, to summarize and visualize all the data on one panel, a spider graph was employed.

RESULTS AND DISCUSSION

Productivity

All the yields and yield related components were significantly different between the treatments/varieties at 5 % probability level. Sanate (T1) had the highest yield followed by Hobora (T3) and Hidase (T5) (Table 1). There is a significant difference at P<0.001 among the treatments/varieties for grain yield, biomass yield, plant height and maturity date. Sanate had the highest grain yield (7211.8kg/ha) than Hobora (6366.8kg/ha) and Hidase (5667.6kg/ha) while Hogana variety provided the lowest grain yield (4213.8kg/ha). But there is no significant difference among the varieties/treatments for flowering date.

As can be seen in Table 1, the varieties showed significant difference for maturity date. Hidase had the shortest maturity date (101 days) followed by Mada walabu (110 days); Hogana (117 days) had long maturity date. Maturity date is an important trait for farmers of the study area in which they are interested in. Early maturing variety gives chance for mixed cropping (chick pea is planted after wheat harvest with the remaining soil moisture). The result obtained from this study is in line with the study of Bekele et al (2015) in which Hidase variety was preferred by farmers because of its early maturity (in addition to its productivity) and its compatibility with chick pea for mixed cropping (Figure 1).

The grain yield of Sanate variety (T1) has a 27% yield advantage over the standard check (Hidase, T5), and it has a 169.6, 143.2 and 156.6% yield advantage over the national, regional and zonal average yield of bread wheat in 2016/2017 Meher season of CSA data respectively (CSA 2017). As observed from the average yield

Table 1. Mean value of agronomic parameters of bread wheat validation trial

Treatment/Variety	Grain yield (kg/ha)	Biomass yield (kg/ha)	Flowering date	Maturity date	Plant height (m)	Harvest index
1. Sanate	7211.8[a]	36106[a]	69[a]	115[ab]	1.05[a]	0.20[ab]
2. Mada Walabu	4917.2[d]	27297[b]	65[a]	110[b]	0.85[bc]	0.18[bc]
3. Hobora	6366.8[b]	28393[b]	66[a]	113[ab]	0.88[b]	0.22[a]
4. Hogana	4213.8[e]	25141[b]	68[a]	117[a]	0.77[c]	0.16[c]
5. Hidase	5667.6[b]	30237[b]	58[b]	101[c]	0.83[bc]	0.19[bc]
Means	5675.4	29430.85	65	110.96	0.88	0.19
CV%	5.3	9.18	5	3.08	7.75	10.8
LSD	405.08	5236.8	4.4	6.63	0.09	0.02

Figure 1. Field performance of Wheat validation trial at Becho.

obtained from experimental site of all treatments/varieties under evaluation, it is by far greater than the average yield recorded by the CSA 2016/17 for national average (2675 kg/ha), regional average (2975 kg/ha) and zonal average(2811 kg/ha).

Acceptability

Farmers' preference analysis was carried out using CIAT approach (Guerrero et al., 1993). A total of eleven farmers (6 experiment host farmers and 5 neighbor farmers) were asked to list the criteria (traits) that they use to assess the varieties, and the traits listed were checked to see if they were up to their expectation. Accordingly, the farmers identified 5 traits, namely, biomass yield, resistant/tolerant to disease, maturity time, tillering capacity and head size. To detect the relative importance of the traits, a pair-wise ranking was carried out (Table 2). The farmers rated each of the varieties with the developed traits using likert scale (1=Excellent, 2=very good, 3=good 4=poor, 5= very poor) (Table 2).

At the end, acceptability score of each variety was calculated by summing up the scores of all the farmers, and dividing it by the maximum possible score. Then, they were converted to percentage (Table 3).

Based on the acceptability percentage, Sanate was ranked first with acceptability level of 96%, followed by Hobora (74%) and Hidase (65%); but Hogana was ranked last, making it the lowest preferred variety among the farmers with acceptability rating of 24%. In addition to the general scores and ranks given by the farmers, most of the farmers were also interested in some of the varieties with early maturation days. As stated earlier, early maturing variety can provide the chance for mixed cropping (wheat-chick pea). In this regard, Hidase and Mada Walabu could attract the attention of farmers. But, the productivity level of Mada Walabu is low as compared to the other varieties. For instance, it is lesser than Sanate and Hidase by 46.84 % and 15.27 %,

Table 2. Pair wise ranking of set criteria for farmers' preference.

Correlation	Disease resistance (1)	Maturity time (2)	Biomass yield (3)	Tillering (4)	Head size (5)	Number of occurrence	Rank
Disease resistance (1)		1	1	1	1	4	1
Maturity time (2)			2	2	5	2	3
Biomass yield (3)				4	3	1	4
Tillering (4)					5	1	4
Head size (5)						2	2

Table 3. Acceptability score for bread wheat varieties.

S/N	Variety	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	Total	Acceptability (%)	Rank
1	Sanate	23	22	23	22	19	23	23	23	21	23	23	245	96	1
2	M/Walab	13	15	15	17	16	15	15	14	14	13	13	160	62	4
3	Hobora	13	15	15	18	22	15	18	18	19	18	18	189	74	2
4	Hogana	6	5	5	5	5	5	5	5	5	5	5	56	21	5
5	Hidase	16	18	15	14	13	14	14	15	16	16	16	167	65	3

respectively.

Profitability

Profitability analysis is another important element of the integrated validation protocol used to analyze the marginal rates of return to investement among the varities. This analysis is very important to identify the most profitable bread wheat varieties economically from the validated varieties. To estimate this economic effect, CIMMYT (1988) procedure was used. In so doing, the average grain yield of the cultivars was adjusted downwards by 10% in calculating gross field benefits. This was done to compensate for the possible inflated estimation of average grain yield that could arise because of the mode of input application and the small plot effect. The cost of seed is the only input cost that was found to vary across treatments. This implies that the difference in average grain yield and the cost of seed are the only factors that could influence marginal benefit.

The results show that the validated wheat varieties have different results: Sanate had the maximum net benefit (86,531.65 Birr/ha), followed by Hobora (71,793.96 Birr/ha) and Hidase (69,564.16 Birr/ha). Variety Hogana has the least net benefit of about 54,507.63 Birr/ha (Table 4).

Gender and nutrition

In most areas of rural Ethiopia, both male and female members of farm households are involved in various types of farm activities. Newly introduced technologies and practices may require more family labor, particularly women face a heavy work burden, and such burden intensifies when the family does not have the means to hire daily laborers in peak seasons (Assefa et al, 2015; de Roo et al, 2017). In this evaluation of improved wheat varieties, it was observed that the agronomic management practices of both the improved and check varieties of wheat were not different in drawing labor with respect to gender. In such cases, the validation protocol guides used to rate the varieties were the same with the conventional, with a normalization value of 3; thus all the varieties were rated similarly having an integrated score of 3.

In terms of nutrition, all the cultivars are not nutritionally dense, hence a 'No' response was given to all cultivars by following the validation protocol. It is assumed that cereals are not considered as good sources of nutrition compared to pulses (nutritionally cereals are less dense than pulses).

Environmental sustainability

For environmental sustainability, the protocol recommends two variables as proxies: nutrient depletion and pesticide. For this validation activity, no data were collected on nutrient depletion. However, the use of pesticides for the control of broad leaf weeds was the common practice for most farmers due to the difficulty of controlling weed by hand as it needs more labor (majority of the farm households cannot cover with their family labor). Pesticides have acute and chronic toxicity effects on humans; they also harm the environment (pollinators, drinking water, non-target organisms etc). Even though,

Table 4. Profitability analysis for bread wheat varieties.

Inconstant variable	Varieties				
	Sanate	Mada-Walabu	Hobora	Hogana	Hidase
Average grain yield (kg/ha)	7211.8	4917.2	6366.8	4213.8	5667.6
Adjusted grain yield (kg/ha)	6490.62	4425.48	5730.12	3792.42	5100.84
Average straw yield (kg/ha)	28894.2	22374.8	22026.2	20,927.2	24569.4
Adjusted straw yield (kg/ha)	26,004.78	20,137.32	19,823.58	18,834.48	22,112.46
Gross field benefits of grain (Birr/ha)	51,924.96	35,403.84	45,840.96	30,339.36	40,806.72
Gross field benefits of straw (Birr/ha)	36,406.69	28,192.24	27,753.00	26,368.27	30,957.44
Total Gross field benefits (Birr/ha)	88,331.65	63,596.08	73,593.96	56,707.63	71,764.16
Cost of seed (Birr/ha)	1800	1800	1800	2200	2200
Total costs that vary (Birr/ha)	1800	1800	1800	2200	2200
Net benefits (Birr/ha)	86,531.65	61,796.08	71,793.96	54,507.63	69,564.16
Marginal benefit	4,807.32	3433.12	3988.55	2477.62	3162.00

Average yield (kg/ha) = average yield of a given variety over farmers' fields calculated as kg/ha. Adjusted yield (kg/ha) = average yield adjusted downwards by 10% expressed as kg/ha. Gross field benefits (Birr/ha) = Adjusted yield (kg/ha) × field price of the crop (Birr/kg). Cost of seed (Birr/ha) = Cost of seed for a given cultivar calculated as Birr/ha. Total costs that vary (Birr/ha) = sum of associated costs (in this case, it would be similar to the cost of seed). Net benefit (Birr/ha) = Gross field benefits (Birr/ha) - total costs that vary (Birr/ha). Marginal benefit (%)= Net benefit (Birr/ha)/Total costs that vary×100.

Table 5. Integrated scoring of technologies for wheat validation trial

Variable	Sanate	Mada-Walabu	Hobora	Hogana	Hidase
Productivity (tonnes/ha)	5	4	5	4	5
Profitability (Birr/ha)	4	2	3	2	3
Acceptability	5	2	4	2	4
Gender/Labour	3	3	3	3	3
Nutrition (yes or no)	N	N	N	N	N
Pesticide use	1	1	1	1	1
Mean	3.6	2.4	3.2	2.4	3.2

Integrated Pest Management (IPM) approach was used to manage pests, participant farmers in the validation trial used 2-4, D to control broad leaf weeds. This herbicide is grouped under class II of WHO (2010) classification. The protocol rates such graded herbicides to have a score of 1 (lowest value) in the normalization of the integrated scoring. Due to the application of the stated pesticide in all of the varieties, each variety was rated 1. This in fact has affected the sum of the integrated scoring. The rating of environmental sustainability pulled down the scoring of high yielding, highly accepted and more profitable varieties. For instance, the mean score of Sanate (so far the favourite variety) would have been 4.4 out of 5 but was forced to stand at 3.6. This implies the sensitivity of the validation trial to environmental sustainability.

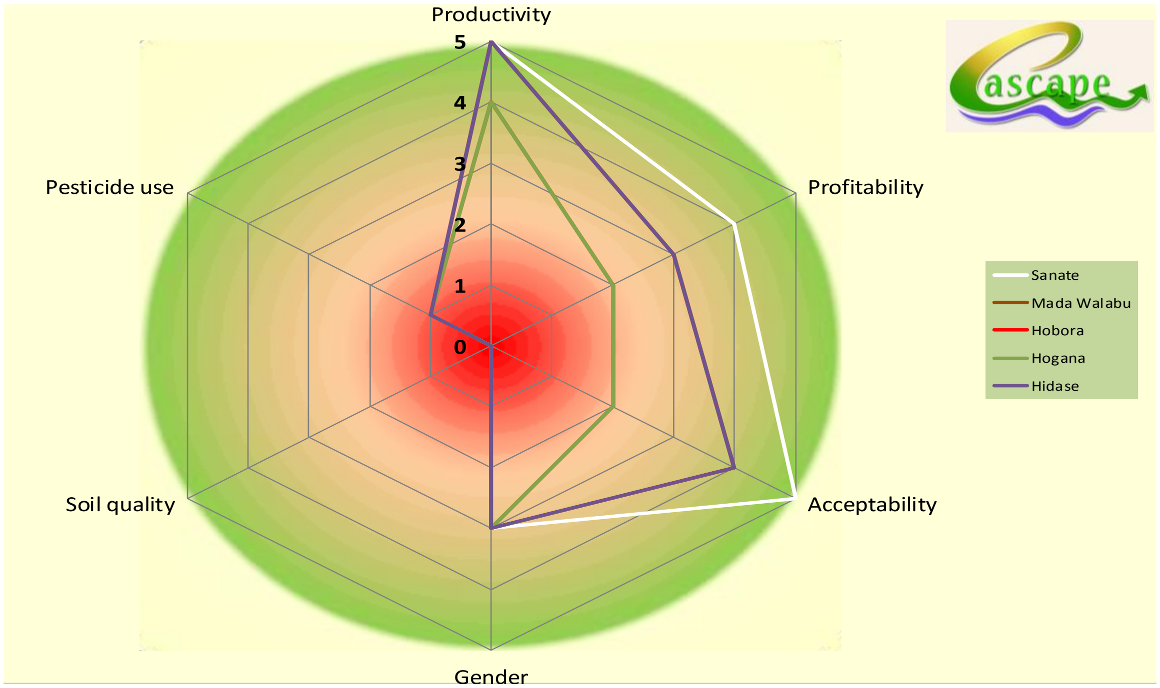
Integration and visualization of results

So far the discussion has been on each of the parameters that constitute the integrated validation protocol of technology validation. However, the final decision as regard which variety should be promoted is done based on the integrated score results. So, it is now necessary to construct a single score by integrating the parameters for each of the varieties. Hence, the results on yield performance, profitability, acceptability, gender, nutrition and pesticide use have been normalized into a 1-5 scale as presented in Table 5.

Based on the rules of decision making and the integrated scoring of improved technologies, two of the improved varieties (other than the check variety) meet the requirements to be recommended. Therefore, we recommend Sanate and Hobora varieties in addition to Hidase for Becho and other areas with similar agro-ecological conditions in the central highlands of Ethiopia (Figure 2).

Conclusion

Over the past two decades, both wheat production and



	Sanate	M/Walabu	Hobora	Hogana	Hidase
Relative area	1.00	0.37	0.73	0.37	0.73

Figure 2. Spider diagram of integrated scoring of wheat production technology validation.

consumption have shown increasing trends in Ethiopia. Wheat import has also grown significantly over the past decade. Yet, this substantial increase in domestic production and import of wheat has not reversed the increasing trend in wheat and wheat product prices, implying an even faster growth of wheat demand. Wheat yield in Ethiopia needs to improve further to level-up with Africa and world average wheat yields, which were 13 and 32% higher than the average wheat yield in Ethiopia, respectively. Beyond agro-climatic and political factors contributing to lower yields, technology could play a more dominant role in productivity, enable Ethiopia to enhance its yields and achieve at least a sufficient yield to feed and change the living standard of its growing population.

According to the set protocol for validation, agronomic data like days to flowering and days to maturity, plant height, disease and pest score, grain yield, and biomass yield were collected from the selected plots. Economic data and farmers' preference, environmental sustainability, nutrition and gender aspect were also part of the collected data and the data were analysed and arranged in integrated validation of technologies so that the best performing technology was identified for further recommendation. Therefore, Sanate and Hobora varieties were recommended for Becho areas and other areas with similar agro-ecological conditions in the central highlands of Ethiopia.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Selection of cassava (*Manihot esculenta* Crantz) genotypes based on agro-morphological traits in Angola

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The aim of the present study is to select superior cassava genotypes based on agro-morphological traits using three non-parametric indices and to correlate them in order to verify the degree of agreement between them. Traits such as number of branches, plant height, stem diameter, distance between internodes, height of the first branch, number of roots, root diameter, root length, shoot yield and root yield in experiments conducted in the Experimental Farm of Malanje Food Company were evaluated. Data collected were subjected to an analysis of variance and to Scott and Knott clustering test. Mean values were subjected to multiplicative indices of sum of classification and genotype-ideotype distance. The morpho-agronomic traits used to assess the 40 cassava genotypes pointed out the existence of promising materials that can be used to diversify cassava cultivation in Angola. The sum of classification and genotype-ideotype distance indices allowed a more realistic ranking of cassava genotypes. The genotype-ideotype distance index did not present any correlation with the multiplicative and sum of classification indices as well. Genotypes Tio Jojo, Ngana Yuculu, Kimbanda, Vermute, Jaca Vermelha and Jaca Branca have the potential to be incorporated into cassava cultivation in Angola

Key words: *Manihot esculenta*, multiplicative index, sum of classification index, genotype-ideotype distance index, variability.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a high rusticity and low soil-fertility demanding crop, a fact that allows it

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Figure 1. The roots and leaves of Northern and Western Angola.

to be grown in a wide range of areas (Nassar et al., 2008). Tubers are used in human and animal diets (Fukuda et al., 2005), besides being used as raw-material in countless industrial goods (cassava flour, tapioca flour, or starch, cassava gum and other). The world production of cassava in 2016 was 277.1 million tons (FAO, 2018), and Angola ranked 9th with approximately 10 million tons.

Northern and Western Angola are the regions hosting the highest cassava production areas and their populations use to consume the roots and leaves (Figure 1) as vegetables. Moreover, cassava can replace wheat in the bread and cereals in some regions, since it is a subsistence crop and its production technology is relatively simple and has a high ability to adapt to different soil and weather conditions.

It is important to highlight that some farmers in Angola insist on using the same planting material employed by their ancestors, which is experiencing genetic erosion or increased susceptibility to pests (Muondo, 2013). It is necessary performing studies to feature different genotypes in Angola, assess their agronomic potentials in order to diversify the cultivated genotypes. Although assessments of genotypes' performances are relevant, only few research in this field have been conducted in Angola. According to Garcia and Souza Junior (1999), the obtainment of genotypes, presenting acceptable values of the traits of interest is not an easy task. However, methods that help breeders to improve their decision-making processes are essential. Selection indices were developed in order to facilitate the selection of superior genotypes, which constitute an additional character set through the optimum combination of many traits. It was done in order to efficiently allow a simultaneous selection (Lessa et al., 2010; Rocha et al., 2012) to enhance the phenotypic value of the selected population. Smith (1936) developed the selection index theory, which is widely applied in the genetic enhancement of plants. Indices developed after the selection index for use under specific conditions (Garcia and Souza Júnior, 1999; Lin, 1978; Pesek and Baker, 1969) require genetic-parameter estimates known as parametric indices. These indices are often applied to populations or when genotypes form a random sample. Yet, one can count on the selection of non-parametric indices, which do not need estimates of genetic parameters. Moreover, these indices can be used either in random samples or in selected genotypes, that is fix samples (Lessa et al., 2010).

The multiplicative index was proposed by Elston (1963) who takes into account all traits presenting similar economic relevance. According to Garcia and Souza Júnior (1999), this index adapts to recurrent selection programs as the final stages of enhancement programs, although it does not require parameter estimates and does not assume the existence of the genotypic value of the population to be enhanced.

The index based on sums and ranks was proposed by Mulamba and Mock (1978) and it classifies genotypes based on each of the traits organized in favoring enhancement order. The order number presented in each trait is summed and, in this case, the lower the value of the sum, the better the genotypic development in the selection.

The index based on the genotype-ideotype distance (Schwarzbach, 1972; Wricke and Weber, 1986) allows defining the optimum values for each trait; therefore, it enables creating an ideal genotype or ideotype. The Euclidian or Mahalanobis distance can be used in this index to calculate dissimilarities; thus, genotypes presenting the lowest ideotype values in the matrix are selected. The adoption of selection indices to genetically enhance cassava cultures could help breeders to make the best decisions about the selection of genotypes that aggregate high production and other traits of interest in the same individual (Lessa et al., 2017).

In light of the foregoing, the aims of the present study

Table 1. Charcteristics of the 40 cassava cultivars studied.

Origin	Main growing provinces	Cultivars
Malanje	Nordern	Waticamana
Malanje	Nordern	Maria dia Pedro
Malanje	Nordern	Hoto
Malanje	Nordern and Western	Mata Capim
Malanje	Nordern and Western	Kambaxi
Malanje	Nordern and Western	Paco Vermelho
Cuanza Norte	Nordern	Tio Jojo
Malanje	Nordern	Verdinha
Malanje	Nordern	Mukoto ua Nguadi (Pé de perdiz)
Cuanza Norte	Nordern	Paco branco
Cuanza Norte	Nordern	Munenga
Cuanza Norte	Nordern	Kimbanda
Cuanza Norte	Nordern	Suzi
Cuanza Norte	Nordern	Jaca Branca
Cuanza Norte	Nordern	Jaca Vermelha
Cuanza Norte	Nordern	Kalazula
Uíge	Countrywide	Ngana Rico 1 (Uíge)
Uíge	Countrywide	TMS3
Uíge		Mandioca Banana
Uíge		Rio Dange
Uíge	Countrywide	Cassandi
	Countrywide	Vermute
Malanje	Nordern	Guita
Malanje	Nordern	Chico dia kombe
Malanje	Nordern	TMS 4025 (precoce de Angola)
Malanje	Nordern	Kalami
Malanje	Countrywide	Baco
Malanje	Nordern	Katenda
Malanje	Nordern	Malanje
Malanje	Countrywide	Ngana Rico 2 (Malanje)
Malanje	Nordern and Western	Kalawenda
Malanje	Nordern and Western	Gonçalo
Malanje	Nordern	Mundele Paco
Malanje	Nordern	Suingui
Malanje	Nordern	NganaYuculu
Malanje	Nordern	Muringa
Malanje	Nordern	Kinzela
Uíge	Nordern and Western	Mpelo
Malanje	Nordern	Gueti
Malanje	Nordern	Kapumba

were to select superior cassava genotypes based on agro-morphological traits by using three non-parametric indices, as well as to correlate them in order to check the degree of agreement between them.

MATERIALS AND METHODS

The study was conducted in the Malanje Food Company's experimental field for two cropping campaigns (2015/16 and 2017/18). The forty (40) cassava genotypes assessed were provided by the Agronomic Investigation Institute (IIA)'s germplasm maintained in Malanje Agricultural Experimental Station, and in IDA of Cuanza Norte and Uíge. These provinces are located at latitude 8^{o} 49' South and longitude 13^{o} 13' East, at 368 m above sea level (IGCA, 2016) and covered a total area of 8,960 Km^2. Details on the forty (40) genotypes are presented in Table 1.

The local soil was classified as fersialitic (Diniz, 1973). According to INAMET (2004), the climate of the region was humid subtropical, the annual mean temperature was 26°C with a thermal amplitude of 14°C, a relative humidity between 80 and 85%, and a mean annual

Figure 2. Mechanical harvesting of the roots by plots, at the CAM experimental station, after the vegetative cycle of the crop, with the aid of coupled to the tractor (P900).

rainfall between 1000 and 1200 mm well distributed throughout the year.

The trial was arranged in a completely randomized block design with four repetitions. Each plot encompassed five rows of 10 plants, thus totalizing 50 plants per plot. Each row was 10 m long, spaced 0.90 m from each other. The distance between plants was 0.90 m.

The soil was plowed and harrowed before planting. It was applied 350 kg ha^{-1} of compound fertilizer (N-P-K: 12-24-12). The cover fertilizer was applied 250 kg ha^{-1} of N-P-K (16-8-12) six months after planting. Planting was mechanically performed with an 80 HP tractor (ISO- 9001, Mainland, China). The tractor was coupled to a two-row cassava planter (Bazuca 1) for 13.5 cm long stakes and horizontally placed in 0.10 m-deep grooves.

Stakes were treated before use by immersing for five minutes in a solution containing 80% Maconzebe (1 kg), 80% Fipronil (1 kg), Boron (1 L), Manganese (1 L) at 1500 L/water. Weeds were controlled manually with hoes at different development phases and stages. The herbicides Capizade and Flumioxazine were used at planting in order to avoid weeds during the initial growth of cassava plants.

Cuts were performed in December 02, 2016 and in February 21, 2018 at maturity. All plants of the five rows of each plot were harvested. The 10 parameters measured were (i) number of branches (NB), (ii) plant height (PH), (iii) stem diameter (SD), (iv) length of internodes (ID), (v) height of the first branch (HFB), (vi) number of tubers (NR), (vii) root diameter (RD), (viii) root length (RL), (ix) shoot yield (SY), and (x) root yield (RY). NB resulted from the ratio of the sum of the number of sprouts in the stem cutting over the number of plants subjected to evaluation. PH was measured from ground level up to the most distal tip. SD was measured with a caliper at 10 cm from the ground. ID was the mean distance between knots of the plant stems. HFB was measured from ground to the first branch. NR was the ratio of the number of roots in the stem cuttings over the number of plants subjected to evaluation. RD was the mean diameter of ten roots randomly sampled in each experimental plot. RL was the mean length of ten randomly sampled roots in each experimental plot. SY was recorded by weighing the shoot of all useful plants in the experimental plots. RY of a cultivar was the weight of roots of all useful plants of the corresponding experimental plots.

Harvests were mechanized and preceded by cutting of the areal part at maturity (Figure 2). The harvest was performed with a tuber crops harvester (P9000) coupled to the tractor.

Data collected were subjected to individual and combined analyses of variance. Mean values of the genotypes were grouped using the Scott-Knott test. Pearson's correlation coefficients of the variables were also estimated. All the above-mentioned analyses were performed using the Statistics R Software (R Core Team, 2018).

The multiplicative index (ELSTON, 1963) was calculated using the following formula:

$$I_{Ei} = \log \prod_{j=1}^{m} (x_{ij} - k_j) = \log [(x_{i1} - k_1)(x_{i2} - k_2)\dots(x_{in} - k_n)],$$

Where, I_{Ei} is the multiplicative index; x_{ij} is the mean of trait j measured in genotype i, and k is the lowest selectable value $\left[K_j = \frac{n\,(min.\ xij) - máx.\ xij}{n-1}\right]$; n is the number of genotypes, and min. x_{ij} and max x_{ij} are the lowest and highest mean of trait *j,* respectively.

The sum of classification index (Mulamba and Mock, 1978) was provided by the expression $\left[I_{MM} = \sum_{j=1}^{m} n^{ij}\right]$, where I_{MM} is the sum of classification index and n_{ij} is the number of classification of genotype *I* in relation to trait *j*.

The Euclidian distance was adopted for the index based on the genotype-ideotype distance (Schwarzbach, 1972; Wricke and Weber, 1986):

$$\left(D_{ij} = \sqrt{\sum_{j=1}^{m} d^{ij}}^{\,2}\right)$$

Where, in D_{ij} is the Euclidian distance between genotype *I* and ideotype *I*, and d*ij* is the standard deviation between the mean of trait *j* measured in genotype *i* (x_{ij}) and the value attributed to the ideotype in this trait (x_{ij}), i.e., $d_{ij} = (x_{ij} - x_{ij})/\sigma_j$. Standardization avoids the possibility of having traits measured in larger units influencing the value of the index more than other traits and, consequently, influencing the classification of cassava genotypes.

The ideal phenotypic value, the higher mean values of plant height (PH), number of tubers (NR), root yield (RY) and shoot yield (SY) and the mean values of the other traits were taken into account in the definition of the ideotype necessary for the calculation of the genotype-ideotype distance. Values attributed to the ideotype were NB = 2.32, PH = 193.88 cm, SD = 8.98 cm, ID =

8.33 cm, HFB = 46.68 cm, RN = 2.63, RD = 21.95 cm, RL = 30.44 cm, SY = 32.26 kg, and RY = 46.02 kg.

RESULTS AND DISCUSSION

Factors obtained linking the highest and lowest mean frame of the residues from the individual analysis of the 10 traits used form the trials conducted in 2015/2016 and 2017/2018; they recorded values lower than 7 indicating an homogeneity of variances observed in experimental errors. Therefore, the option was made for a joint analysis (Table 2). Studies related to individual analysis of variance have been developed in different cultures including cassava (Vieira et al., 2015a,b; Vieira et al., 2016; Fernandes et al., 2016), tomatoes (Costa et al., 2015), and tree species (Oliveira et al., 2014).

The joint analysis of variance for all the traits showed no genotype x campaign interaction. However, the lack of genotype x campaign interaction could be associated with the extreme variance observed in some of the treatments that could have masked real differences between accessions (Table 3).

Almeida et al. (2014a) assessed the morphological and yield evaluation applied to peanut produced by small farmers in Bahia Reconcavo and they did not observe a genotype x day after emergence (DAE) interaction for any of the variables considered in their study.

The coefficient of experimental variation in the joint analysis of variance ranged from 12.76% in PH to 49.02% in SY. These results were comparable to those obtained in a *M. esculenta* interspecific hybrids trial by Oliveira (2011) where CV varied from 12.79 to 57.08% for length x central lobe width (LCLW). However, RD presented value higher than that found in the present study.

It is known that shoot yield is a variable of extreme relevance for cassava cultures, since it represents the amount of fresh matter produced per plant. This variable can be used in human diets, in forage production for animal consumption and, mainly, in cassava cuttings (maniva) obtained for new cultivations (Fernandes et al., 2016). Root diameter is also important for cassava root production. Thicker roots are the favorite because smaller diameters impair the shelling operation management. Therefore, this process does not help cassava processing, since small roots are used for animal feeding and, sometimes, rejected and left in the field. It is worth highlighting that the height of the first branch contributes to easier upkeep operations. According to Vieira et al. (2013), varieties presenting the highest first branch or that do not present any branch and high plant height are the favorite ones, since they are directly related to easy cultural traces, to the availability of branches for new cultivations, to easy mechanized cultivation and easy harvest.

With regard to the number of branches (NB), which has significant influence on root yield, genotypes Verdinha, Ngana Rico 2, Kinzela, Waticamana, Mpelo, Kalawenda, Cassandi, Jaca Branca, Gonçalo and Guita were statistically different from the others ($p < 0.01$). These genotypes presented the highest values that varied from 2.51 for Guita to 3.40 for Verdinha (Table 4).

Varieties Tio Jojo, Kimbanda, Precoce de Angola, NganaYuculu, Banana, Jaca Vermelha, Malanje, Mundele Paco, Kalazula, Rio Dange, Vermute, Kambaxi, Munenga, Kalawenda, Kinzela; Kapumba, Muringa, Mata Capim, Hoto and Pé de perdiz stood out for variable ‘plant height’, since they recorded values that ranged from 194.13 to 224.11 cm (Table 4). Although there were no reports about the ideal height of cassava plants, authors such as Devide et al., (2009) and Guimarães (2013) believe that farm management and treatments tend to be easier when plants are taller, mainly in areas subjected to mechanized harvest, as well as tend to facilitate the consortium with other cultures such as beans and maize.

Plant height must not present excessive values (higher than 3 m), since it could allow plant bedding in areas subjected to strong wind and presenting fertile soils, as reported by Otsubo et al. (2009). These authors assessed cassava cultivated for industrial use in Cerrado areas in Mato Grosso do Sul State. Results from this study corroborated Foloni et al. (2010)’s finding from the assessment of cassava cultivars in Western São Paulo State where they recorded significant difference in plant height. The variation observed in plant height concerned environment influence and genotypic components. Such facts were also reported by Filho et al. (2000), Rimoldi et al. (2003), Rimoldi et al. (2006), Otsubo et al. (2009) and Vieira et al. (2015a, b), who recorded plants height of 252 cm in the assessment of the agronomic performance of sweet cassava accessions in Cerrado area of Minas Gerais State.

Genotypes Mata Capim, Tio Jojo, Kimbanda, Jaca Branca, Jaca vermelha, Banana, Malanje, Mundele Paco and Muring stood out for variable ‘internode distance (ID)’. The highest values recorded for root number (RN) were observed in genotypes Maria dia Pedro, Tio Jojo, Verdinha, Jaca Branca, TMS3, Banana, Baco, Vermute, Chico dia kombe, Precoce de Angola, Kalami, Baco, Katenda, Ngana Rico 2 and NganaYuculu and Muringa. It is known that the development of cassava plants is defined by the number of roots. These results indicated that the root number was well constituted in the initial development phases of the genotypes (Table 4).

Genotypes Waticamana, Kambaxi, Tio Jojo, Munenga, Kimbanda, Kalazula, Cassandi, Vermute, Guita, Precoce de Angola, Kalami, Katenda, Ngana Rico 2, Gonçalo, Suingui, NganaYuculu and Kinzela presented higher root yields (RY). Vieira et al. (2015a, b) assessed eight industrial cassava genotypes and observed that genotype BGMC 996 was the only one standing out in the root yield (RY) trait.

Table 5 depicts the means and posts of variables used

Table 2. Summary of individual analysis of variance for vegetative and root production traits.

Source of variation	Df	QM									
		NB	PH	SD	IE	HFB	RN	RD	RL	SY	RY
Campaign 2015/2016											
Blocks	3	0.37^{ns}	359.72^{ns}	19.60*	2.54^{ns}	445.60^{ns}	4.73^{ns}	46.52**	188.79**	30.54^{ns}	926.12*
Genotype	39	1.00*	683.69^{ns}	1.13^{ns}	2.06^{ns}	390.80^{ns}	1.36^{ns}	10.81^{ns}	51.64^{ns}	34.26^{ns}	463.89*
Residue	117	0.64	644.67	1.05	1.77	338.02	1.19	7.99	43.79	31.41	299.98
Overall mean		2.59	162.48	6.70	8.46	48.03	2.38	22.85	28.91	13.35	39.57
CV (%)		30.83	15.63	15.33	15.73	38.28	45.78	12.37	22.89	41.99	43.77
Camapaign 2017/2018											
Blocks	3	4.81*	1238.39^{ns}	20.59**	1.19^{ns}	570.27**	5.06*	179.60**	321.11**	6518.54**	15560.93**
Genotypes	39	0.09^{ns}	1130.39**	2.97^{ns}	2.25^{ns}	226.16*	2.71*	9.86^{ns}	31.45^{ns}	593.11^{ns}	556.38^{ns}
Residue	117	0.10	583.12	2.37	1.61	134.59	1.60	14.21	42.79	468.67	460.74
Overall mean		2.10	225.27	11.25	8.20	45.34	2.88	21.04	31.97	51.17	52.47
CV (%)		14.87	10.72	13.69	15.49	25.59	44.00	17.92	20.46	42.31	40.91

** and *significant at 1% and 5%, respectively, ^{ns}, non-significant at 5% probability, Df, degree of freedom; NB, number of branches; SD, stem diameter; ID, internode length; HFB, height of the first branch; RN, number of roots; RD, root diameter; RL, root length; SY, shoot yield; RY, root yield.

Table 3. Summary of joint analysis of variance for vegetative and root production traits

Source of variation	Df	QM									
		NB	PH	SD	ID	HFB	RN	RD	RL	SY	RY
Blocks (Campaigns)	6	2.59**	799.06^{ns}	20.10**	1.87^{ns}	507.93*	4.89**	113.06**	254.95**	3274.54**	8243.53**
Genotypes	39	0.64**	1197.82**	2.18^{ns}	2.43^{ns}	329.87^{ns}	2.72**	10.57^{ns}	41.74^{ns}	325.01^{ns}	679.39**
Campaign	1	18.88**	315350.22**	1661.07**	5.69^{ns}	577.84^{ns}	19.82**	262.99**	748.41**	14439.54**	13312.80**
Gen. x Campai	39	0.45^{ns}	616.25^{ns}	1.92^{ns}	1.88^{ns}	287.10^{ns}	1.35^{ns}	10.10^{ns}	41.34^{ns}	302.36^{ns}	340.88^{ns}
Residue	234	0.37	613.90	1.71	1.69	236.31	1.39	11.10	43.29	250.04	380.36
Overall mean		2.35	193.87	8.98	8.33	46.68	2.63	21.94	30.44	32.26	46.02
CV (%)		25.84	12.78	14.58	15.62	32.93	44.93	15.18	21.61	49.02	42.38

**and *significant at 1% and 5%, respectively, in the F test. ^{ns}non-signifcant at 5% probability. Gen, genotype; Campai, campaign; Df, degree of freedom; NB, number of branches; SD, stem diameter; ID, internode length; HFB, height of the first branch; RN, number of roots; RD, root diameter; RL, root length; SY, shoot yield; RY, root yield.

to calculate the Sum of Posts Index (I_{MM}), which ranked genotypes Tio Jojo, Ngana Yuculu, Kimbanda and Jaca Vermelha in the first, second, third and fourth positions, respectively. Genotypes Vermute, Ngana Rico 2, Jaca Branca and Banana ranked the fifth, sixth and eight position, respectively, based on the classification order of the index (Table 5).

Genotype Tio Jojo ranked first for plant height (PH), height of the first branch (HFB) and root yield (RY); fourth for internode length (ID), twelfth for shoot yield (SY), thirteenth for stem diameter (SD) and root number (RN), fifteenth for root length (RL), twentieth for root diameter (RD) and the smallest number of branches (NB). Genotype Tio Jojo ranked first according to the sum of classification index (Table 5), which was similar to its rank in the multiplicative index (Table 6). This positive result recorded by variety Rio Jojo was also observed in agronomic featuring (Table 4). This variety stood out for plant height, internode length, root number and root yield, and this result revealed a promising genotype that can be recommended to cassava growers.

Ngana Yuculu ranked seven in the index suggested by Elston (1963); therefore, this variety ranked second in the sum of classification index. According to Garcia (1999), the use of this index is simple and does not require making adjustments in the means, just as it happens in the multiplicative index. It is necessary adjusting the units of traits in order to find the lowest selectable value (kj); therefore, this is the methodological differential. Such factor likely influenced the change on genotype ranking. The same ranking changes were observed for genotypes Kimbanda, Jaca Vermelha, Banana, Jaca Branca, Ngana

Table 4. Grouping of mean values of the agro-morphological traits for which the ANOVA detected significant differences.

Genotypes	NB	PH (cm)	SD (cm)	ID (cm)	HFB (cm)	RN	RD (cm)	RL (cm)	SY (kg)	RY (kg)
Waticamana	2.65^{a}	189.04^{b}	8.80^{a}	8.51^{b}	50.75^{a}	2.59^{b}	20.75^{a}	32.93^{a}	30.13^{a}	56.08^{a}
MariadiaPedro	2.20^{b}	178.03^{b}	8.34^{a}	7.88^{b}	46.12^{a}	3.06^{a}	21.08^{a}	34.50^{a}	20.56^{a}	32.40^{b}
Hoto	2.20^{b}	194.99^{a}	8.34^{a}	8.38^{b}	49.13^{a}	2.41^{b}	21.94^{a}	30.20^{a}	30.38^{a}	41.11^{b}
MataCapim	2.20^{b}	195.58^{a}	8.79^{a}	8.76^{a}	44.87^{a}	1.91^{b}	22.91^{a}	30.99^{a}	37.13^{a}	43.53^{b}
Kambaxi	2.14^{b}	200.49^{a}	9.37^{a}	8.33^{b}	41.21^{a}	1.99^{b}	20.73^{a}	30.19^{a}	22.00^{a}	54.95^{a}
PacoVermelho	2.18^{b}	178.45^{b}	9.03^{a}	8.45^{b}	38.17^{a}	2.69^{b}	19.64^{a}	30.20^{a}	42.50^{a}	36.33^{b}
TioJojo	2.13^{b}	224.11^{a}	9.21^{a}	9.09^{a}	61.24^{a}	2.86^{a}	21.99^{a}	31.01^{a}	36.06^{a}	66.72^{a}
Verdinha	3.40^{a}	187.44^{b}	8.52^{a}	7.90^{b}	50.30^{a}	3.84^{a}	20.64^{a}	30.85^{a}	34.50^{a}	44.40^{b}
Pédeperdiz	2.39^{b}	194.13^{a}	8.96^{a}	8.26^{b}	54.77^{a}	2.01^{b}	20.50^{a}	28.46^{a}	27.63^{a}	45.24^{b}
Pacobranco	2.07^{b}	180.61^{b}	8.07^{a}	8.07^{b}	36.11^{a}	2.29^{b}	23.58^{a}	27.84^{a}	34.94^{a}	45.02^{b}
Munenga	2.37^{b}	199.14^{a}	9.06^{a}	8.03^{b}	40.86^{a}	2.43^{b}	21.24^{a}	27.61^{a}	26.19^{a}	48.29^{a}
Kimbanda	2.39^{b}	218.79^{a}	8.72^{a}	10.02^{a}	57.88^{a}	2.48^{b}	22.44^{a}	30.09^{a}	31.13^{a}	64.09^{a}
Suzi	2.45^{b}	190.95^{b}	9.90^{a}	7.80^{b}	42.62^{a}	2.20^{b}	22.96^{a}	29.36^{a}	25.69^{a}	36.67^{b}
JacaBranca	2.58^{a}	190.09^{b}	9.09^{a}	8.77^{a}	55.24^{a}	2.86^{a}	22.58^{a}	31.41^{a}	23.75^{a}	46.06^{b}
JacaVermelha	2.34^{b}	207.36^{a}	9.44^{a}	9.05^{a}	41.69^{a}	2.40^{b}	23.46^{a}	31.31^{a}	33.31^{a}	41.54^{b}
Kalazula	2.28^{b}	202.28^{a}	9.65^{a}	8.24^{b}	52.11^{a}	2.52^{b}	21.61^{a}	27.71^{a}	39.63^{a}	52.80^{a}
NganaRico1	2.45^{b}	174.05^{b}	8.04^{a}	8.11^{b}	47.67^{a}	1.92^{b}	21.98^{a}	29.18^{a}	23.13^{a}	44.05^{b}
TMS3	2.10^{b}	188.37^{b}	9.68^{a}	8.22^{b}	43.60^{a}	3.05^{a}	22.94^{a}	33.06^{a}	25.13^{a}	37.56^{b}
Banana	2.25^{b}	210.65^{a}	9.95^{a}	8.97^{a}	48.90^{a}	3.93^{a}	20.63^{a}	35.51^{a}	19.00^{a}	36.78^{b}
RioDange	2.05^{b}	201.38^{a}	8.67^{a}	8.15^{b}	49.31^{a}	1.95^{b}	23.38^{a}	28.87^{a}	28.25^{a}	40.50^{b}
Cassandi	2.59^{a}	183.99^{b}	9.72^{a}	8.22^{b}	38.94^{a}	2.21^{b}	22.46^{a}	30.30^{a}	32.38^{a}	51.91^{a}
Vermute	2.05^{b}	201.18^{a}	9.16^{a}	8.20^{b}	43.41^{a}	3.90^{a}	22.68^{a}	32.15^{a}	40.56^{a}	54.73^{a}
Guita	2.51^{a}	177.96^{b}	8.31^{a}	7.81^{b}	37.17^{a}	2.00^{b}	22.75^{a}	29.18^{a}	31.38^{a}	52.62^{a}
Chicodiakombe	1.87^{b}	191.08^{b}	9.32^{a}	8.39^{b}	40.17^{a}	2.9^{a}	20.31^{a}	27.84^{a}	27.63^{a}	33.74^{b}
P.deAngola	2.26^{b}	212.84^{a}	8.59^{a}	7.84^{b}	59.91^{a}	3.12^{a}	20.14^{a}	28.36^{a}	37.38^{a}	52.34^{a}
Kalami	2.35^{b}	180.52^{b}	8.90^{a}	7.60^{b}	48.54^{a}	2.88^{a}	22.99^{a}	30.14^{a}	35.00^{a}	48.36^{a}
Baco	2.12^{b}	179.49^{b}	8.83^{a}	8.03^{b}	46.72^{a}	3.16^{a}	21.53^{a}	32.54^{a}	30.69^{a}	36.46^{b}
Katenda	2.28^{b}	190.49^{b}	8.76^{a}	8.29^{b}	50.77^{a}	2.99^{a}	21.25^{a}	30.68^{a}	32.75^{a}	60.79^{a}
Malanje	2.09^{b}	207.10^{a}	9.34^{a}	9.59^{a}	42.97^{a}	2.54^{b}	21.18^{a}	24.13^{a}	47.00^{a}	40.51^{b}
NganaRico2	2.96^{a}	175.37^{b}	8.46^{a}	8.41^{b}	47.53^{a}	3.71^{a}	23.91^{a}	30.40^{a}	32.25^{a}	60.31^{a}
Kalawenda	2.64^{a}	198.37^{a}	9.17^{a}	7.76^{b}	54.74^{a}	2.52^{b}	21.81^{a}	28.85^{a}	27.94^{a}	33.76^{b}
Gonçalo	2.55^{a}	181.06^{b}	9.13^{a}	7.64^{b}	41.01^{a}	2.59^{b}	22.96^{a}	31.70^{a}	32.00^{a}	49.84^{a}
MundelePaco	2.15^{b}	205.02^{a}	9.73^{a}	9.29^{a}	36.33^{a}	2.13^{b}	23.31^{a}	32.63^{a}	36.50^{a}	33.36^{b}
Suingui	2.16^{b}	183.94^{b}	8.54^{a}	8.17^{b}	50.15^{a}	2.11^{b}	22.43^{a}	32.95^{a}	32.38^{a}	50.85^{a}
NganaYuculu	2.17^{b}	210.73^{a}	9.59^{a}	7.61^{b}	49.09^{a}	3.57^{a}	23.41^{a}	32.43^{a}	40.00^{a}	58.85^{a}
Muringa	2.27^{b}	196.10^{a}	9.04^{a}	8.99^{a}	40.81^{a}	2.77^{a}	20.54^{a}	34.96^{a}	40.63^{a}	36.45^{b}

Table 4. Contd.

Kinzela	2.75[a]	197.3[a]	8.26[a]	79.0b	52.87[a]	20.9[b]	20.48[a]	27.73[a]	38.31[a]	52.95[a]
Mpelo	26.5[a]	186.34[b]	8.05[a]	8.34[b]	48.56[a]	1.65[b]	22.99[a]	28.76[a]	36.00[a]	41.24[b]
Gueti	2.32[b]	193.07[b]	9.20[a]	7.62[b]	44.27[a]	2.45[b]	22.76[a]	31.78[a]	39.38[a]	43.35[b]
Kapumba	2.29[b]	196.92[a]	9.34[a]	8.48b	40.84[a]	2.46b	20.95[a]	28.88[a]	29.19[a]	34.41[b]

Means followed by the same letter in the columns belong to the same group; according to Scott-Knott test; at 5% significance level; NB number of branches; SD, stem diameter; ID, internode length; HFB, height of the first branch; RN, number of roots; RD, root diameter; RL, root length; SY, shoot yield; RY, root yield.

Table 5. Original Means ($\bar{x}$) and post of variables used to calculate the Sum of Post Index (I_{SP}) for the 40 cassava genotypes.

Genotype	NB		PH		SDDC		ID		HFB		RN		RD		RL		SY		RY		I_{SP}
	$\bar{x}$	Posto	$\bar{x}$	Posto	$\bar{x}$	Posto	$\bar{x}$	Posto	$\bar{x}$	Posto	$\bar{x}$	Posto	$\bar{x}$	Posto	$\bar{x}$	Posto	$\bar{x}$	Posto	$\bar{x}$	Posto	
Waticamana	2.65	4	189.04	26	8.80	25	8.51	10	50.75	10	2.59	17	20.75	31	32.93	6	30.13	27	56.08	6	162 (10) (((10)[1]
Maria dia Pedro	2.20	25	178.03	37	8.34	34	7.88	32	46.12	22	3.06	8	21.08	29	34.50	3	20.56	39	32.40	40	269 (37)
Hoto	2.20	26	194.99	19	8.34	35	8.38	15	49.13	14	2.41	26	21.94	22	30.20	21	30.38	26	41.11	27	231 (28)
Mata Capim	2.20	27	195.58	18	8.79	26	8.76	9	44.87	23	1.91	39	22.91	12	30.99	16	37.13	10	43.53	23	203 (20)
Kambaxi	2.14	32	200.49	12	9.37	9	8.33	17	41.21	30	1.99	36	20.73	32	30.19	23	22.00	38	54.95	7	236 (30)
Paco Vermelho	2.18	28	178.45	36	9.03	21	8.45	12	38.17	37	2.69	16	19.64	40	30.20	22	42.50	2	36.33	35	249 (35)
Tio Jojo	2.13	33	224.11	1	9.21	13	9.09	4	61.24	1	2.86	13	21.99	20	31.01	15	36.06	12	66.72	1	113 (1)
Verdinha	3.40	1	187.44	28	8.52	32	7.90	30	50.30	11	3.84	3	20.64	33	30.85	17	34.50	16	44.40	21	192 (14)
Pé de perdiz	2.39	13	194.13	20	8.96	22	8.26	19	54.77	5	2.01	34	20.50	36	28.46	33	27.63	31	45.24	19	232 (29)
Paco branco	2.07	37	180.61	33	8.07	38	8.07	27	36.11	40	2.29	28	23.58	2	27.84	35	34.94	15	45.02	20	275 (38)
Munenga	2.37	15	199.14	13	9.06	19	8.03	28	40.86	32	2.43	25	21.24	27	27.61	39	26.19	33	48.29	17	248 (34)
Kimbanda	2.39	14	218.79	2	8.72	28	10.02	1	57.88	3	2.48	22	22.44	18	30.09	25	31.13	24	64.09	2	139 (3)
Suzi	2.45	11	190.95	23	9.90	2	7.80	35	42.62	28	2.20	30	22.96	9	29.36	26	25.69	34	36.67	32	230 (27)
Jaca Branca	2.58	8	190.09	25	9.09	18	8.77	8	55.24	4	2.86	14	22.58	16	31.41	13	23.75	36	46.06	18	160 (7)
Jaca Vermelha	2.34	17	207.36	6	9.44	8	9.05	5	41.69	29	2.40	27	23.46	3	31.31	14	33.31	17	41.54	25	151 (4)
Kalazula	2.28	20	202.28	9	9.65	6	8.24	20	52.11	8	2.52	20	21.61	24	27.71	38	39.63	6	52.80	10	161 (9)
Ngana Rico 1	2.45	12	174.05	40	8.04	40	8.11	26	47.67	19	1.92	38	21.98	21	29.18	27	23.13	37	44.05	22	282 (40)
TMS3	2.10	35	188.37	27	9.68	5	8.22	21	43.60	25	3.05	9	22.94	11	33.06	4	25.13	35	37.56	30	202 (19)
Banana	2.25	24	210.65	5	9.95	1	8.97	7	48.90	16	3.93	1	20.63	34	35.51	1	19.00	40	36.78	31	160 (8)
Rio Dange	2.05	38	201.38	10	8.67	29	8.15	25	49.31	13	1.95	37	23.38	5	28.87	30	28.25	29	40.50	29	245 (33)
Cassandi	2.59	7	183.99	30	9.72	4	8.22	22	38.94	36	2.21	29	22.46	17	30.30	20	32.38	19	51.91	13	197 (17)
Vermute	2.05	39	201.18	11	9.16	16	8.20	23	43.41	26	3.90	2	22.68	15	32.15	10	40.56	4	54.73	8	154 (5)
Guita	2.51	10	177.96	38	8.31	36	7.81	34	37.17	38	2.00	35	22.75	14	29.18	28	31.38	23	52.62	11	267 (36)
Chico dia kombe	1.87	40	191.08	22	9.32	12	8.39	14	40.17	35	2.89	11	20.31	38	27.84	36	27.63	32	33.74	38	278 (39)
P. de Angola	2.26	23	212.84	3	8.59	30	7.84	33	59.91	2	3.12	7	20.14	39	28.36	34	37.38	9	52.34	12	192 (15)
Kalami	2.35	16	180.52	34	8.90	23	7.60	40	48.54	18	2.88	12	22.99	7	30.14	24	35.00	14	48.36	16	204 (22)
Baco	2.12	34	179.49	35	8.83	24	8.03	29	46.72	21	3.16	6	21.53	25	32.54	8	30.69	25	36.46	33	240 (32)

Table 5. Contd.

Katenda	2.28	21	190.49	24	8.76	27	8.29	18	50.77	9	2.99	10	21.25	26	30.68	18	32.75	18	60.79	3	174 (11)
Malanje	2.09	36	207.10	7	9.34	10	9.59	2	42.97	27	2.54	19	21.18	28	24.13	40	47.00	1	40.51	28	198 (18)
Ngana Rico 2	2.96	2	175.37	39	8.46	33	8.41	13	47.53	20	3.71	4	23.91	1	30.40	19	32.25	21	60.31	4	156 (6)
Kalawenda	2.64	6	198.37	14	9.17	15	7.76	36	54.74	6	2.52	21	21.81	23	28.85	31	27.94	30	33.76	37	219 (25)
Gonçalo	2.55	9	181.06	32	9.13	17	7.64	37	41.01	31	2.59	18	22.96	10	31.70	12	32.00	22	49.84	15	203 (21)
Mundele Paco	2.15	31	205.02	8	9.73	3	9.29	3	36.33	39	2.13	31	23.31	6	32.63	7	36.50	11	33.36	39	178 (12)
Suingui	2.16	30	183.94	31	8.54	31	8.17	24	50.15	12	2.11	32	22.43	19	32.95	5	32.38	20	50.85	14	218 (24)
NganaYuculu	2.17	29	210.73	4	9.59	7	7.61	39	49.09	15	3.57	5	23.41	4	32.43	9	40.00	5	58.85	5	122 (2)
Muringa	2.27	22	196.10	17	9.04	20	8.99	6	40.81	34	2.77	15	20.54	35	34.96	2	40.63	3	36.45	34	188 (13)
Kinzela	2.75	3	197.53	15	8.26	37	7.90	31	52.87	7	2.09	33	20.48	37	27.73	37	38.31	8	52.95	9	217 (23)
Mpelo	2.65	5	186.34	29	8.05	39	8.34	16	48.56	17	1.65	40	22.99	8	28.76	32	36.00	13	41.24	26	225 (26)
Gueti	2.32	18	193.07	21	9.20	14	7.62	38	44.27	24	2.45	24	22.76	13	31.78	11	39.38	7	43.35	24	194 (16)
Kapumba	2.29	19	196.92	16	9.34	11	8.48	11	40.84	33	2.46	23	20.95	30	28.88	29	29.19	28	34.41	36	236 (31)

[1]values between parameters indicate the final rank of the genotype. NB, number of branches; SD, stem diameter; ID, internode length; HFB, height of the first branch; RN, number of roots; RD, root diameter; RL, root length; SY, shoot yield; RY root yield.

Rico 2 and Vermute (Table 5).

Genotypes Ngana Yuculu and Ngana Rico 2 ranked fifth and fourth, respectively, for traits RN (3.5 and 3.7), RY (58.8 Kg and 60 Kg) and SY (40.0 Kg). However, the low position of genotype Ngana Rico 2 for variable shoot yield did not make genotype recommendation feasible.

Genotypes Tio Jojo, Kimbanda, Vermute, and Kalazula ranked first, second, third, and fourth, respectively, based on the multiplicative index. On the other hand, genotypes Jaca Vermelha, Jaca Branca, Ngana Yuculu, and Waticamana ranked fifth, sixth, seventh, and eight, respectively, based on the order of classification of scores or on the centered means (xi - kj) of the index (Table 6).

Genotype Tio Jojo ranked first in the multiplicative index and showed genetic material selectable, since it recorded the best means for traits PH (224.11 cm), HFB (61.24 cm), RY (66.7 Kg). These traits are relevant for the selection of a superior genotype.

Kimbanda ranked second in the multiplicative index and presented the second best performance in traits PH (218.79 cm), HFB (57.88 cm) and RY (64.09 Kg), besides ranking first in ID (10.02 cm). The high shoot yield highlighted the multiuse potential (human and animal diets) of genotype Kimbanda (Table 6).

Kimbanda ranked between the seventh and the tenth position in the other traits. However, such ranking did not limit the genotype selection, since this variety stood out for most relevant traits.

Vermute ranked third in the multiplicative index and eleventh for character PH, twenty sixth for HFB and eighth for RY (Table 6). Vermute also ranked fourth for character SY (40.56 cm). However, the genotype recorded the second highest mean for trait RN (3.90).

Kalazula ranked fourth based on the classification of multiplicative index and sixth for traits SY (39.63 Kg) and SD (9.65 cm), eighth for HFB (52.11 cm) and tenth for RY (52.80 Kg). Kalazula ranked ninth for the mean of trait PH (201.28 cm). This variety recorded intermediate means in the other traits. Means observed for this genotype were higher than the national mean, although it was among the six more productive genotypes. This result does not make its selection feasible.

Genotype Jaca Vermelha ranked the fifth position in the multiplicative index and recorded the sixth highest mean for PH (207.36 cm), twenty-ninth for HFB (41.69 cm), twenty-fifth for RY (41.54 Kg). Jaca Vermelha also ranked the fourth position for trait ID (9.05 cm) and third for RD (23.46 cm). However, the low performance of genotype Jaca Vermelha in the other traits resulted in its low ranking in the multiplicative index (Table 6).

Genotype Jaca Branca ranked six in the multiplicative index and presented the fourth highest mean for HFB (55.24 cm), eighth for NB (2.58) and seventh for ID (8.77). It is worth highlighting that the low performance of Jaca Branca in the other traits resulted in its low ranking in the multiplicative index.

Table 6. Original ($\bar{x}$) and centered means (x_i - k_j) of the assessed variables used to calculate the multiplicative index (I_M) of cassava genotypes.

Genotypes	NB		PH		SD		ID		HFB		RN		RD		RL		SY		RY		I_M
	$\bar{x}$	xij - kj	$\bar{x}$	xij - kj	$\bar{x}$	xij - kj	$\bar{x}$	xij - kj	$\bar{x}$	xij - kj	$\bar{x}$	xij - kj	$\bar{x}$	xij - kj	$\bar{x}$	xij - kj	$\bar{x}$	xij - kj	$\bar{x}$	xij - kj	
Waticamana	2.65	0.82	189.04	16.27	8.80	0.81	8.51	0.97	50.75	15.28	2.59	1.00	20.75	1.22	32.93	9.09	30.13	11.85	56.08	24.56	5.71 (8) (8)[1]
Maria dia Pedro	2.20	0.37	178.03	5.26	8.34	0.35	7.88	0.34	46.12	10.65	3.06	1.47	21.08	1.55	34.50	10.66	20.56	2.28	32.40	0.88	2.08 (39)
Hoto	2.20	0.37	194.99	22.22	8.34	0.35	8.38	0.84	49.13	13.66	2.41	0.82	21.94	2.41	30.20	6.36	30.38	12.10	41.11	9.59	4.68 (19)
Mata Capim	2.20	0.37	195.58	22.81	8.79	0.80	8.76	1.22	44.87	9.40	1.91	0.32	22.91	3.38	30.99	7.15	37.13	18.85	43.53	12.01	5.13 (12)
Kambaxi	2.14	0.31	200.49	27.72	9.37	1.38	8.33	0.79	41.21	5.74	1.99	0.40	20.73	1.20	30.19	6.35	22.00	3.72	54.95	23.43	4.15 (33)
Paco Vermelho	2.18	0.35	178.45	5.68	9.03	1.04	8.45	0.91	38.17	2.70	2.69	1.10	19.64	0.11	30.20	6.36	42.50	24.22	36.33	4.81	2.66 (36)
Tio Jojo	2.13	0.30	224.11	51.34	9.21	1.22	9.09	1.55	61.24	25.77	2.86	1.27	21.99	2.46	31.01	7.17	36.06	17.78	66.72	35.20	7.02 (1)
Verdinha	3.40	1.57	187.44	14.67	8.52	0.53	7.90	0.36	50.30	14.83	3.84	2.25	20.64	1.11	30.85	7.01	34.50	16.22	44.40	12.88	5.38 (11)
Pé de perdiz	2.39	0.56	194.13	21.36	8.96	0.97	8.26	0.72	54.77	19.30	2.01	0.42	20.50	0.97	28.46	4.62	27.63	9.35	45.24	13.72	4.59 (21)
Paco branco	2.07	0.24	180.61	7.84	8.07	0.08	8.07	0.53	36.11	0.64	2.29	0.70	23.58	4.05	27.84	4.00	34.94	16.66	45.02	13.50	2.11 (38)
Munenga	2.37	0.54	199.14	26.37	9.06	1.07	8.03	0.49	40.86	5.39	2.43	0.84	21.24	1.71	27.61	3.77	26.19	7.91	48.29	16.77	4.46 (23)
Kimbanda	2.39	0.56	218.79	46.02	8.72	0.73	10.02	2.48	57.88	22.41	2.48	0.89	22.44	2.91	30.09	6.25	31.13	12.85	64.09	32.57	6.85 (2)
Suzi	2.45	0.62	190.95	18.18	9.90	1.91	7.80	0.26	42.62	7.15	2.20	0.61	22.96	3.43	29.36	5.52	25.69	7.41	36.67	5.15	4.25 (29)
Jaca Branca	2.58	0.75	190.09	17.32	9.09	1.10	8.77	1.23	55.24	19.77	2.86	1.27	22.58	3.05	31.41	7.57	23.75	5.47	46.06	14.54	5.91 (6)
Jaca Vermelha	2.34	0.51	207.36	34.59	9.44	1.45	9.05	1.51	41.69	6.22	2.40	0.81	23.46	3.93	31.31	7.47	33.31	15.03	41.54	10.02	5.93 (5)
Kalazula	2.28	0.45	202.28	29.51	9.65	1.66	8.24	0.70	52.11	16.64	2.52	0.93	21.61	2.08	27.71	3.87	39.63	21.35	52.80	21.28	5.94 (4)
Ngana Rico 1	2.45	0.62	174.05	1.28	8.04	0.05	8.11	0.57	47.67	12.20	1.92	0.33	21.98	2.45	29.18	5.34	23.13	4.85	44.05	12.53	1.85 (40)
TMS3	2.10	0.27	188.37	15.60	9.68	1.69	8.22	0.68	43.60	8.13	3.05	1.46	22.94	3.41	33.06	9.22	25.13	6.85	37.56	6.04	4.87 (16)
Banana	2.25	0.42	210.65	37.88	9.95	1.96	8.97	1.43	48.90	13.43	3.93	2.34	20.63	1.10	35.51	11.67	19.00	0.72	36.78	5.26	4.83 (18)
Rio Dange	2.05	0.22	201.38	28.61	8.67	0.68	8.15	0.61	49.31	13.84	1.95	0.36	23.38	3.85	28.87	5.03	28.25	9.97	40.50	8.98	4.35 (27)
Cassandi	2.59	0.76	183.99	11.22	9.72	1.73	8.22	0.68	38.94	3.47	2.21	0.62	22.46	2.93	30.30	6.46	32.38	14.10	51.91	20.39	5.07 (15)
Vermute	2.05	0.22	201.18	28.41	9.16	1.17	8.20	0.66	43.41	7.94	3.90	2.31	22.68	3.15	32.15	8.31	40.56	22.28	54.73	23.21	6.08 (3)
Guita	2.51	0.68	177.96	5.19	8.31	0.32	7.81	0.27	37.17	1.70	2.00	0.41	22.75	3.22	29.18	5.34	31.38	13.10	52.62	21.10	3.01 (35)
Chico dia kombe	1.87	0.04	191.08	18.31	9.32	1.33	8.39	0.85	40.17	4.70	2.89	1.30	20.31	0.78	27.84	4.00	27.63	9.35	33.74	2.22	2.51 (37)
P. de Angola	2.26	0.43	212.84	40.07	8.59	0.60	7.84	0.30	59.91	24.44	3.12	1.53	20.14	0.61	28.36	4.52	37.38	19.10	52.34	20.82	5.11 (13)
Kalami	2.35	0.52	180.52	7.75	8.90	0.91	7.60	0.06	48.54	13.07	2.88	1.29	22.99	3.46	30.14	6.30	35.00	16.72	48.36	16.84	4.37 (26)
Baco	2.12	0.29	179.49	6.72	8.83	0.84	8.03	0.49	46.72	11.25	3.16	1.57	21.53	2.00	32.54	8.70	30.69	12.41	36.46	4.94	4.18 (31)
Katenda	2.28	0.45	190.49	17.72	8.76	0.77	8.29	0.75	50.77	15.30	2.99	1.40	21.25	1.72	30.68	6.84	32.75	14.47	60.79	29.27	5.69 (9)
Malanje	2.09	0.26	207.10	34.33	9.34	1.35	9.59	2.05	42.97	7.50	2.54	0.95	21.18	1.65	24.13	0.29	47.00	28.72	40.51	8.99	4.34 (28)
Ngana Rico 2	2.96	1.13	175.37	2.60	8.46	0.47	8.41	0.87	47.53	12.06	3.71	2.12	23.91	4.38	30.40	6.56	32.25	13.97	60.31	28.79	5.55 (10)
Kalawenda	2.64	0.81	198.37	25.60	9.17	1.18	7.76	0.22	54.74	19.27	2.52	0.93	21.81	2.28	28.85	5.01	27.94	9.66	33.76	2.24	4.38 (25)
Gonçalo	2.55	0.72	181.06	8.29	9.13	1.14	7.64	0.10	41.01	5.54	2.59	1.00	22.96	3.43	31.70	7.86	32.00	13.72	49.84	18.32	4.42 (24)
Mundele Paco	2.15	0.32	205.02	32.25	9.73	1.74	9.29	1.75	36.33	0.86	2.13	0.54	23.31	3.78	32.63	8.79	36.50	18.22	33.36	1.84	4.21 (30)
Suingui	2.16	0.33	183.94	11.17	8.54	0.55	8.17	0.63	50.15	14.68	2.11	0.52	22.43	2.90	32.95	9.11	32.38	14.10	50.85	19.33	4.84 (17)
NganaYuculu	2.17	0.34	210.73	37.96	9.59	1.60	7.61	0.07	49.09	13.62	3.57	1.98	23.41	3.88	32.43	8.59	40.00	21.72	58.85	27.33	5.90 (7)

Table 6. Contd.

Muringa	2.27	0.44	196.10	23.33	9.04	1.05	8.99	1.45	40.81	5.34	2.77	1.18	20.54	1.01	34.96	11.12	40.63	22.35	36.45	4.93	5.08 (14)
Kinzela	2.75	0.92	197.53	24.76	8.26	0.27	7.90	0.36	52.87	17.40	2.09	0.50	20.48	0.95	27.73	3.89	38.31	20.03	52.95	21.43	4.48 (22)
Mpelo	2.65	0.82	186.34	13.57	8.05	0.06	8.34	0.80	48.56	13.09	1.65	0.06	22.99	3.46	28.76	4.92	36.00	17.72	41.24	9.72	3.07 (34)
Gueti	2.32	0.49	193.07	20.30	9.20	1.21	7.62	0.08	44.27	8.80	2.45	0.86	22.76	3.23	31.78	7.94	39.38	21.10	43.35	11.83	4.68 (20)
Kapumba	2.29	0.46	196.92	24.15	9.34	1.35	8.48	0.94	40.84	5.37	2.46	0.87	20.95	1.42	28.88	5.04	29.19	10.91	34.41	2.89	4.17 (32)
Ki	1.83		172.77		7.99		7.54		35.47		1.59		19.53		23.84		18.28		31.52		

[1]values between parameters indicate the final rank of the genotypes; NB, number of branches; SD, stem diameter; ID, internode length; HFB, height of the first branch; RN, number of roots; RD, root diameter; RL, root length; SY, shoot yield; RY root yield.

Ngana Yuculu ranked seventh in the multiplicative index and recorded the fourth highest mean for traits PH and RD, and fifth for SY, RY and RN. Genotype Ngana Yuculu ranked seventh for SD (9.59), ninth for RL (32.43). Finally, genotype Waticamana ranked eighth in the multiplicative index and recorded the following performance: 5th for NB, 6th for RL and RY, 9th for ID and 10th for HFB.

Almeida et al. (2014b), Lessa et al. (2010), and Pedrozo et al. (2009) observed that the multiplicative index was efficient to estimate selection gains similar to those of indices proposed by Mulamba and Mock (1978), Pesek and Baker (1969), Smith (1936) and Hazel (1943). Pedrozo et al. (2009) observed that the multiplicative index recorded better selection efficiency than the sum of post (Mulamba and Mock, 1978) and the classic (Hazel, 1943; Smith, 1936) indices when they tested the efficiency of different indices in the selection of superior sugarcane genotypes.

Table 7 presents the values recorded for the genotype-ideotype distance index. There was no significant correlation among this index and the indices Sum of Post (I_{MM}) and the multiplicative mulamba index.

Values attributed to ideotype in this index presented positive and negative deviations for some of the variables, except for traits PH, RN, RY and SY, which recorded the highest means and the highest overall trait means. Negative deviation means that the value attributed to the ideotype was higher than the mean of that trait in the genotype that is taken into account ($x_{Ij} > x_{ij} \rightarrow d_{ij} = (x_{ij} - x_{Ij}) < 0$).

Genotypes Hoto, Mata Capim, Katenda and Gueti ranked first, second, third and fourth in the genotype-ideotype index, respectively. Kalami, Munenga, Kapumba and Suingui ranked fifth, sixth, seventh and eighth, respectively, based on the classification order of the index (Table 7).

The genotype Precoce is one of the favorites of Malanje farmers, since it adapts well to the soil and weather conditions in the country and due to the tradition of keeping the cultivation of materials used by their ancestors. This variety ranked the fifteenth position in the evaluation of Mulamba and Mock, thirteenth in the multiplicative index and thirty-first in the genotype-ideotype distance index.

Accordingly, there is the need of implementing new studies to analyze the agronomic potential of different genotypes in order to identify productive materials capable of diversifying cassava cultivation in the province in Angola.

There was close relation (0.8895**) based on the Spearman correlation between the multiplicative and sum of classification indices (Table 8). This study has highlighted a high degree of correspondence between the two variables described above. Similar result was recorded by Lessa et al. (2017), who selected cassava genotypes based on three non-parametric indices and found high correlation (0.8809**) between results recorded for the multiplicative indices and the sum of classification. They concluded that the referred indices allowed a more appropriate selection. Lessa et al. (2010) assessed banana tree diploid hybrids and observed high correlation (0.83**) between results recorded for multiplicative indices and the sum of classifications. They concluded that the referred indices enabled a more appropriate selection.

It is worth highlighting that, among the six genotypes selected through multiplicative indices and the sum of classification, four of them are from de Cuanza Sul (Tio Jojo, Kimbanda, Jaca Vermelha, Jaca Branca) and two, from Malanje (Ngana Yuculu, Vermute). However, the selection conducted through cassava indices is quite promising, and it can be used in cassava enhancement programs.

Conclusion

The morpho-agronomic traits used to assess the

Table 7. Original means ($\bar{x}$) and deviations of variables used to calculate the Euclidian distance from genotype to ideotype (D_{ij}) in cassava genotypes.

Genotypes	NB		PH		SD		ID		HFB		NMR		DMR		CMR		PMPA		PMR		*Dij*
	$\bar{x}$	dij	$\bar{x}$	dij	$\bar{x}$	dij	$\bar{x}$	dij	$\bar{x}$	dij	$\bar{x}$	dij	$\bar{x}$	dij	$\bar{x}$	dij	$\bar{x}$	dij	$\bar{x}$	dij	
Waticamana	2.65	1.08	189.04	-0.40	8.80	-0.34	8.51	0.33	50.75	0.63	2.59	-0.07	20.75	-1.04	32.93	1.09	30.13	-0.33	56.08	1.09	2.35 (11)[1]
Maria dia Pedro	2.20	-0.52	178.03	-1.30	8.34	-1.22	7.88	-0.81	46.12	-0.09	3.06	0.74	21.08	-0.75	34.50	1.78	20.56	-1.84	32.40	-1.48	3.73 (33)
Hoto	2.20	-0.52	194.99	0.09	8.34	-1.22	8.38	0.09	49.13	0.38	2.41	-0.37	21.94	0.00	30.20	-0.11	30.38	-0.29	41.11	-0.53	1.56 (1)
Mata Capim	2.20	-0.52	195.58	0.14	8.79	-0.36	8.76	0.78	44.87	-0.28	1.91	-1.23	22.91	0.84	30.99	0.24	37.13	0.76	43.53	-0.27	2.01 (2)
Kambaxi	2.14	-0.73	200.49	0.54	9.37	0.75	8.33	0.00	41.21	-0.85	1.99	-1.09	20.73	-1.06	30.19	-0.11	22.00	-1.61	54.95	0.97	2.82 (20)
Paco Vermelho	2.18	-0.59	178.45	-1.26	9.03	0.10	8.45	0.22	38.17	-1.33	2.69	0.11	19.64	-2.01	30.20	-0.11	42.50	1.61	36.33	-1.05	3.39 (29)
Tio Jojo	2.13	-0.77	224.11	2.47	9.21	0.45	9.09	1.38	61.24	2.27	2.86	0.40	21.99	0.04	31.01	0.25	36.06	0.60	66.72	2.25	4.42 (36)
Verdinha	3.40	3.73	187.44	-0.53	8.52	-0.87	7.90	-0.78	50.30	0.56	3.84	2.08	20.64	-1.14	30.85	0.18	34.50	0.35	44.40	-0.18	4.66 (38)
Pé de perdiz	2.39	0.16	194.13	0.02	8.96	-0.03	8.26	-0.13	54.77	1.26	2.01	-1.06	20.50	-1.26	28.46	-0.87	27.63	-0.73	45.24	-0.09	2.37 (12)
Paco branco	2.07	-0.98	180.61	-1.08	8.07	-1.73	8.07	-0.47	36.11	-1.65	2.29	-0.58	23.58	1.42	27.84	-1.14	34.94	0.42	45.02	-0.11	3.45 (30)
Munenga	2.37	0.08	199.14	0.43	9.06	0.16	8.03	-0.54	40.86	-0.91	2.43	-0.34	21.24	-0.61	27.61	-1.24	26.19	-0.95	48.29	0.25	2.08 (6)
Kimbanda	2.39	0.16	218.79	2.04	8.72	-0.49	10.02	3.06	57.88	1.74	2.48	-0.25	22.44	0.43	30.09	-0.15	31.13	-0.18	64.09	1.96	4.58 (37)
Suzi	2.45	0.37	190.95	-0.24	9.90	1.77	7.80	-0.96	42.62	-0.63	2.20	-0.73	22.96	0.88	29.36	-0.47	25.69	-1.03	36.67	-1.02	2.87 (21)
Jaca Branca	2.58	0.83	190.09	-0.31	9.09	0.22	8.77	0.80	55.24	1.33	2.86	0.40	22.58	0.55	31.41	0.42	23.75	-1.34	46.06	0.00	2.38 (13)
Jaca Vermelha	2.34	-0.02	207.36	1.10	9.44	0.89	9.05	1.30	41.69	-0.78	2.40	-0.39	23.46	1.32	31.31	0.38	33.31	0.16	41.54	-0.49	2.57 (17)
Kalazula	2.28	-0.23	202.28	0.69	9.65	1.29	8.24	-0.16	52.11	0.85	2.52	-0.19	21.61	-0.29	27.71	-1.20	39.63	1.16	52.80	0.74	2.52 (16)
Ngana Rico 1	2.45	0.37	174.05	-1.62	8.04	-1.79	8.11	-0.40	47.67	0.15	1.92	-1.21	21.98	0.03	29.18	-0.55	23.13	-1.43	44.05	-0.21	3.17 (24)
TMS3	2.10	-0.87	188.37	-0.45	9.68	1.34	8.22	-0.20	43.60	-0.48	3.05	0.72	22.94	0.87	33.06	1.15	25.13	-1.12	37.56	-0.92	2.78 (19)
Banana	2.25	-0.34	210.65	1.37	9.95	1.86	8.97	1.16	48.90	0.35	3.93	2.23	20.63	-1.15	35.51	2.22	19.00	-2.08	36.78	-1.00	4.85 (40)
Rio Dange	2.05	-1.05	201.38	0.61	8.67	-0.59	8.15	-0.32	49.31	0.41	1.95	-1.16	23.38	1.25	28.87	-0.69	28.25	-0.63	40.50	-0.60	2.50 (15)
Cassandi	2.59	0.86	183.99	-0.81	9.72	1.42	8.22	-0.20	38.94	-1.21	2.21	-0.72	22.46	0.45	30.30	-0.06	32.38	0.02	51.91	0.64	2.46 (14)
Vermute	2.05	-1.05	201.18	0.60	9.16	0.35	8.20	-0.23	43.41	-0.51	3.90	2.18	22.68	0.64	32.15	0.75	40.56	1.30	54.73	0.94	3.19 (26)
Guita	2.51	0.58	177.96	-1.30	8.31	-1.28	7.81	-0.94	37.17	-1.48	2.00	-1.08	22.75	0.70	29.18	-0.55	31.38	-0.14	52.62	0.72	3.04 (22)
Chico dia kombe	1.87	-1.69	191.08	-0.23	9.32	0.66	8.39	0.11	40.17	-1.01	2.89	0.45	20.31	-1.42	27.84	-1.14	27.63	-0.73	33.74	-1.33	3.19 (25)
P. de Angola	2.26	-0.31	212.84	1.55	8.59	-0.74	7.84	-0.89	59.91	2.06	3.12	0.84	20.14	-1.57	28.36	-0.91	37.38	0.80	52.34	0.69	3.63 (31)
Kalami	2.35	0.01	180.52	-1.09	8.90	-0.15	7.60	-1.32	48.54	0.29	2.88	0.43	22.99	0.91	30.14	-0.13	35.00	0.43	48.36	0.25	2.08 (5)
Baco	2.12	-0.80	179.49	-1.18	8.83	-0.28	8.03	-0.54	46.72	0.01	3.16	0.91	21.53	-0.36	32.54	0.92	30.69	-0.25	36.46	-1.04	2.31 (10)
Katenda	2.28	-0.23	190.49	-0.28	8.76	-0.41	8.29	-0.07	50.77	0.64	2.99	0.62	21.25	-0.61	30.68	0.10	32.75	0.08	60.79	1.60	2.01 (3)
Malanje	2.09	-0.91	207.10	1.08	9.34	0.69	9.59	2.28	42.97	-0.58	2.54	-0.15	21.18	-0.67	24.13	-2.76	47.00	2.31	40.51	-0.60	4.67 (39)
Ngana Rico 2	2.96	2.17	175.37	-1.51	8.46	-0.99	8.41	0.15	47.53	0.13	3.71	1.85	23.91	1.71	30.40	-0.02	32.25	0.00	60.31	1.55	4.10 (35)
Kalawenda	2.64	1.04	198.37	0.37	9.17	0.37	7.76	-1.03	54.74	1.25	2.52	-0.19	21.81	-0.12	28.85	-0.70	27.94	-0.68	33.76	-1.33	2.60 (18)
Gonçalo	2.55	0.72	181.06	-1.05	9.13	0.29	7.64	-1.25	41.01	-0.88	2.59	-0.07	22.96	0.88	31.70	0.55	32.00	-0.04	49.84	0.41	2.3 0(9)
Mundele Paco	2.15	-0.70	205.02	0.91	9.73	1.44	9.29	1.74	36.33	-1.61	2.13	-0.85	23.31	1.19	32.63	0.96	36.50	0.67	33.36	-1.37	3.80 (34)
Suingui	2.16	-0.66	183.94	-0.81	8.54	-0.84	8.17	-0.29	50.15	0.54	2.11	-0.89	22.43	0.42	32.95	1.10	32.38	0.02	50.85	0.52	2.15 (8)
NganaYuculu	2.17	-0.62	210.73	1.38	9.59	1.17	7.61	-1.30	49.09	0.37	3.57	1.61	23.41	1.27	32.43	0.87	40.00	1.21	58.85	1.39	3.73 (32)

Table 7. Contd.

Muringa	2.27	-0.27	196.10	0.18	9.04	0.12	8.99	1.20	40.81	-0.91	2.77	0.24	20.54	-1.22	34.96	1.98	40.63	1.31	36.45	-1.04	3.27 (27)
Kinzela	2.75	1.43	197.53	0.30	8.26	-1.37	7.90	-0.78	52.87	0.96	2.09	-0.92	20.48	-1.28	27.73	-1.19	38.31	0.95	52.95	0.75	3.30 (28)
Mpelo	2.65	1.08	186.34	-0.62	8.05	-1.77	8.34	0.02	48.56	0.29	1.65	-1.68	22.99	0.91	28.76	-0.74	36.00	0.59	41.24	-0.52	3.09 (23)
Gueti	2.32	-0.09	193.07	-0.07	9.20	0.43	7.62	-1.28	44.27	-0.38	2.45	-0.31	22.76	0.71	31.78	0.59	39.38	1.12	43.35	-0.29	2.06 (4)
Kapumba	2.29	-0.20	196.92	0.25	9.34	0.69	8.48	0.27	40.84	-0.91	2.46	-0.29	20.95	-0.87	28.88	-0.68	29.19	-0.48	34.41	-1.26	2.15 (7)
Ideotype	2.35		193.88		8.98		8.33		46.68		2.63		21.95		30.44		32.26		46.02		

Table 8. Spearman correlation between the final ranks of genotypes through Sum of posts (I_{SP}), multiplicative indices (I_M) and the Euclidian Distance from the genotype to the ideotype (D_{ij}).

Indices	I_M	D_{ij}
I_{SP}	0.8895**	-0.2377^{ns}
I_M		0.0030^{ns}

** Significant at 1% probability in the t test, ^{ns} non-significant at 5% probability are coming.

40 cassava genotypes pointed out the existence of promising materials that can be used to diversify cassava cultivation in Angola. The sum of classification and genotype-ideotype distance indices allowed a more realistic ranking of cassava genotypes. The genotype-ideotype distance index did not present any correlation with the multiplicative and sum of classification indices as well. Genotypes Tio Jojo, Ngana Yuculu, Kimbanda, Vermute, Jaca Vermelha and Jaca Branca have the potential to be incorporated into cassava cultivation in Angola.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of different doses of *Azospirillum brasilense* and nitrogen fertilizer in wheat crop

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The objective of the present work is to evaluate the effect of different doses of nitrogen combined with different doses of *A. brasilense* in the agronomic characteristics of wheat. The experiment was conducted in Curuguaty, Paraguay in 2017 and the variety used was Canindé 11. The experimental design is a completely randomized block with factorial ordering and four repetitions. The treatments are a combination of: three doses of N, 0, 40, 80 kg ha^{-1} and 4 doses of *A. brasilense,* 0, 700, 1000 and 1300 mg kg^{-1} of wheat seeds. The variables analyzed were plant height, number of spikes per plant, thousand grain weight, hectoliter weight and yield. With the exception of plant height, significant interaction between treatments was observed in all variables. Inoculation with 1300 mg kg^{-1} of *A. brasilense* associated with the application of 130 kg N ha^{-1} promotes the highest yields of wheat grains.

Key words: *Triticum aestivum,* dystrophic bacterium, winter cereal.

INTRODUCTION

Wheat (*Triticum aestivum* L.) belongs to the family of gramineae whose center of origin is the Middle East (Garcia, 2005). It is the most important cereal in the world for its physical and chemical properties of gluten for manufacturing of bread and use in large quantities for pastry and other foods. The use of nitrogen fertilizers in the world increases year after year but has a very low assimilation rate for crops, losing more than 50% of the soil (up to 80%) by leaching, resulting in contamination (eutrophication of water mantles) and the increase in the cost of production. To appease this event there are microorganisms that have the ability to promote the growth of plants by providing nutrients such as nitrogen through biological fixation. In Paraguay, since 2003 the wheat crop reached a great growth in areas of sowing and export. In the year 2017, approximately 430000 ha was planted with an average yield of 1630 kg ha^{-1} and production of 700000 tons of grain (CAPECO, 2017). The sustainable production of the crop can be fulfilled with the combination of several factors of production such as adequate tillage, sowing, cultivation care, use of certified seeds, phytosanitary measures and good fertilization of the crop; the latter is essential and aims to replenish the nutrients to the soil that have been extracted by crops,

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with adequate amounts of nutrients you can get higher return, but without decreasing soil fertility (Mellado, 2008). Among the inputs used, nitrogen fertilization represents a large part of the productive costs and its application in cereals, such as wheat, significantly raises the cost of production. However, it is essential, because of nitrogen, to be the most limiting macro element in wheat productivity since it determines the number of tillers, being essential in the nodes formation phase and at the beginning of stem elongation (Sala et al., 2005). Thus, due to the growing search for sustainability in agricultural production systems, some authors have presented, as an alternative form of nitrogen fertilizer economics, the biological nitrogen fixation (BNF), which may supplement or even replace the utilization of these fertilizers (Baldani and Baldani, 2005; Bergamaschi et al., 2007, Hungria et al., 2010). The use of bacteria such as *A. brasilense* can reduce the fertilizer application level by 40-50%, which reduces the cost of production without a decrease in the yield of the crop, betting on a sustainable production of the wheat crop. These bacteria can directly stimulate the growth of plants, through various mechanisms such as the capacity of fixation of atmospheric nitrogen, production of phytohormones, solubilization of minerals and nutrients, increase in the volume of the root and induction of resistance to pathogens. The objective of this work was to evaluate the effect of inoculation with *A. brasilense*, associated with N rates and the grain yield of wheat.

MATERIALS AND METHODS

The study was conducted in the municipality of Curuguaty, in the state of Canindeyú, Paraguay (24°28'18'' S and 55°41'32'' W, at an altitude of 335 m). The soil in the experimental area was classified as a Rhodic paleudult, Ultisol order. The area has been cultivated with annual crops for more than 12 years, and the no-tillage system has been used for the past 8 years. Since the crop planted before wheat sowing was corn, only soybean and corn were cultivated in the 2 years before the study. The average temperature was 23°C, and the annual average precipitation was 1,300 mm (Figure 1). The climate type is Cfa, according to Köppen's classifications, subtropical humid mesothermal dry winter with rainfall well distributed throughout the year and hot summers. The experimental design was randomized complete blocks with four replicates, in a 3×4 factorial arrangement: three N doses: 0, 40, 80 kg ha^{-1}; four *A. brasilense* rates: 0, 700, 1000, and 1300 mg kg^{-1} of wheat seed. The experimental plots were composed of 10 lines with 5 m length and spaced at a 0.20 m distance, and the useful area of the plot comprised the central eight lines, excluding 0.5 m from the ends. The herbicide used in the experimental areas was glyphosate (1,600 g a.i. ha^{-1}) for desiccation; this product was applied 2 weeks before wheat sowing.

The chemical attributes of the topsoil (depth of 0.00–0.20 m) were determined in 2017 before the initiation of the experiment, following the methodology proposed by Raij et al. (2001). The following results were obtained: 11.45 mg dm^{-3} P (resin); 7.37 mg dm^{-3} S-SO_4; 19.38 g dm^{-3} organic matter; pH 5.40 ($CaCl_2$); 0.27 3.45, 0.61, and 3.18 $Cmol_c$ dm^{-3} K, Ca, Mg, and H+Al, respectively; 0.9, 2.5, 78.8, and 5.2 mg dm^{-3} Cu, Fe, Mn, and Zn, respectively and base saturation of 57.63%. Based on the results of soil analysis and the need to increase base saturation to 70%, as recommended by Cantarella et al. (1997), 2.5 Mg ha^{-1} of dolomitic limestone (ECCE 88%) was applied to the soil 50 days before sowing wheat. Furthermore, based on the results of soil analysis and culture requirements, 28, 98, and 56 kg ha^{-1} N, P_2O_5, and K_2O, respectively, were supplied for sowing fertilization. Inoculation of wheat seeds with *A. brasilense* (to achieve a density of 2×10^8 CFU mL^{-1}) was performed using 0, 700, 1000 and 1300 mL of the liquid inoculant Azototal per kilogram of wheat seed. The inoculant was mixed with the seeds in the shade using a clean mixer 1 h before sowing after treatment of the seeds with insecticide and fungicide. For seed treatment, the fungicides carbendazim + thiram (45 g + 105 g a.i. per 100 kg of seed) and the insecticides imidacloprid + thiodicarb (45 g + 135 g a.i. per 100 kg of seed) were used. The experimental area was managed under a no-tillage system. The cultivar used was Caninde 11 with mechanical seeding on 5/10/2016 and density of 76 seeds per meter. The growth of weeds was managed with the application of the herbicide metsulfuron-methyl (3 g a.i. ha^{-1}) 30 days after emergence (DAE) of wheat. Nitrogen fertilization was performed manually 35 DAE, and the fertilizer was spread on the soil surface without incorporation on the sides and at approximately 10 cm from the sowing lines to avoid contact with the plants. The plants were harvested manually at 108 DAE. Plant height at maturity (defined as the distance (m) from the ground level to the apex of the spike) was determined. The following characteristics were also evaluated in ten plants at harvest: number of spikelets, by counting all spikelets with grains; hectoliter mass, corresponding to the mass of wheat grains in a 100-L container determined on a 1/4 scale after adjusting the water content of the grains to 13% (wet basis); mass of 1000 grains, measured in a 0.01-g precision scale at 13% (wet basis); and yield, determined by counting the spikes of plants present in the four useful lines of each plot. After mechanical tracking, the grains were quantified, and the data were converted into kg ha^{-1} at 13% (wet basis). All statistical analyses were performed using the SISVAR statistical program (Ferreira, 2003). The data obtained were submitted to variance of analysis and when statistical differences were verified, their averages were obtained using Tukey test at 5% probability.

RESULTS AND DISCUSSION

Of the analyzed variables, all presented a significant interaction among the factors using doses of *A. brasilense* associated with nitrogen doses, with the exception of plant height, in which significantly different variances were observed for N doses (Table 1).

The different doses of *A. brasilense* did not significantly affect the height of wheat plant (Table 2). Similar results were found by Barbieri et al. (2012) that concluded there was no influence of inoculation with *A. brasilense* in plant height with irrigation. Also, Ferreira et al. (2014) and Galindo et al. (2015) observed no influence with the inoculation of wheat leaves with *A. brasilense* in the Cerrado Region. These results disagree with Bashan et al. (2004), who demonstrated that *Azospirillum* spp. stimulates the growth and productivity of plants like wheat. There is evidence literature that supports the beneficial root bacteria inoculated in wheat; also in rice, oats, maize, sorghum and other grasses (Dos Reis et al., 2000; Pan et al., 2002) exert an effect growth, because the BBR uses the organic compounds excreted by the

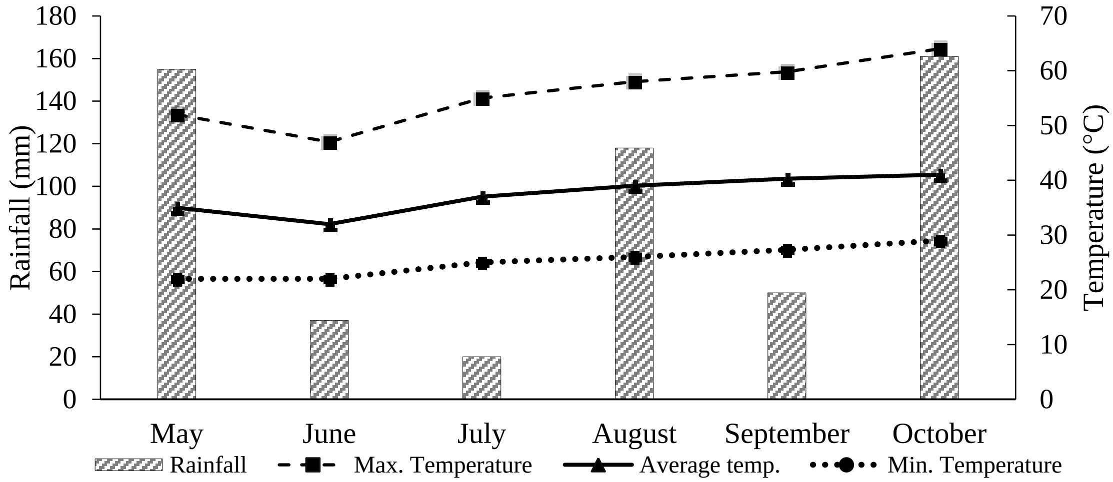

Figure 1. Rainfall, average, maximum and minimum temperature during wheat cultivation from May to October 2017 obtained from the weather station located in the municipality of Curuguaty, in the state of Canindeyú, Paraguay.

Table 1. Summary of analysis of variances for plant height (PHEIG), number of spikes per plant (NESP), thousand grains weight (TGRW), hectoliter weight (HECW) and yield (YIELD) of wheat using different doses of *A brasilense* and N.

Source of variation	DF	Mean sum of squares				
		PHEIG	NESP	TGRW	HECW	YIELD
A. brasilense rates	3	20.13^{ns}	0.33**	0.61 ^{ns}	38.30**	775060.68**
N rates	2	181.15**	0.31**	9.11**	11.40**	2903617.04**
Interaction	6	6.82^{ns}	0.08**	3.99*	2.64**	369520.22**
Error	33	10.82	0.02	1.41	0.47	24362.74
CV (%)		5.95	9	3.25	0.81	7.74
Average		55.27	1.74	36.55	84.95	2016.41

Table 2. Height of wheat plants submitted to inoculation of different doses of *A. brasilense* and N under field conditions.

A. brasilense **doses (mg kg^{-1} seed)**	**Plant height (cm)**
0	54.48
700	53.87
1000	56.15
1300	56.57
DMS	3.63
N doses (kg ha^{-1})	
0	51.40
40	56.86
80	57.54
DMS	2.85
CV (%) = 5.95	

Source: *Curuguaty (*2017*)*.

roots of wheat as a source of carbon and energy into substances that can stimulate greater radical absorption of the N. However, plant height was affected by the different doses of N where the highest height was

Table 3. Number of spikes per wheat plant submitted to inoculation of different doses of *A. brasilense* and N under field conditions.

N doses (kg ha^{-1})	***A. brasilense* doses (mg kg^{-1} seed)**			
	0	**700**	**1000**	**1300**
0	1.37^{bB}	$1.62^{b\ AB}$	$1.60^{b\ AB}$	$1.77^{b\ A}$
40	1.75^{aB}	$1.70^{b\ B}$	$1.47^{b\ B}$	$2.10^{a\ A}$
80	$1.62^{ab\ B}$	$1.97a^{A}$	$1.87^{a\ AB}$	$2.02^{b\ A}$
CV (%) = 9.00				

Means followed by the same letter, lowercase in the columns and upper case in the lines, do not differ by the LSD test (t test) at the 5% probability level.
Source: Curuguaty (2017).

Table 4. Hectoliter weight in grams of wheat submitted to inoculation of different doses of *A. brasilense* and N under field conditions.

N doses (kg ha^{-1})	***A. brasilense* doses (mg kg^{-1} seed)**			
	0	**700**	**1000**	**1300**
0	80.43^{cC}	84.10^{bB}	85.60^{aA}	86.40^{aA}
40	82.82^{bC}	84.58^{abB}	85.63^{aBC}	86.74^{aA}
80	84.32^{aB}	85.70^{aA}	86.48^{aA}	86.72^{aA}
CV (%) = 0.81				

Means followed by the same letter, lowercase in the columns and upper case in the lines, do not differ by the LSD test (t test) at the 5% probability level.
Source: Curuguaty (2017).

observed with the dose of 80 kg N ha^{-1}. These results coincide with those of Zagonel et al. (2002), who verified that with the increase of the dose of N increase of the height of plants of wheat occurs. However, Zagonel and Fernandes (2007) found varied responses of cultivars to increase the dose of N for plant height which also suggests the influence of genetic factors. For Castro et al. (2008), plant height is influenced by the availability of nitrogen in the soil, since this nutrient participates directly in cell division and expansion and the photosynthetic process, which would explain the positive response of the N doses applied in the corn crop height growth; it corroborates with Gross et al. (2006), who recommend that nitrogen fertilization done in coverage, in one application or two, influences plant height. However, this increment is not favorable, since the greater length of the plants is usually accompanied by a greater predisposition to lodging.

Significant interaction between doses of N and *A. brasilense* was observed for the number of ears per plant (Table 3). The best results were 2.10 ears per plant with the combination of 40 kg ha $^{-1}$ of N and 1300 mg of *A. brasilense* per kg of seeds (Table 3). According to Lopes et al. (2007), the number of ears per area is dependent on the genotype, where fertilization does not become a preponderant factor in the final result, corroborating with the results obtained in this study. On the other hand, Espindula et al. (2010) observed a linear increase in the number of ears of wheat at doses of N of 0, 40, 60, 80, 100 and 120 kg N ha^{-1}. This is probably because the higher doses of N promote greater vegetative vigor, especially in the phases of tillering and differentiation of the reproductive meristem, which results in higher values for these production components (Espindula et al., 2010)

The variable hectoliter weight was influenced by the interaction between nitrogen and *A. brasilense* (Table 4), and the combination of 40 kg N ha^{-1} and 1300 mg kg^{-1} seeds provided higher hectoliter weight, but did not differ statistically with the other doses of N. However, Trindade et al. (2006), when testing doses of urea, found values of decreasing hectoliter mass, when they increased the dose of N of 0 to 200 kg ha^{-1}. Similarly, Feldmann (2014) observed that increasing N fertilization adversely affected the hectoliter weight of three wheat varieties. This response may be related to the increase in the incidence of foliar diseases due to N application, reducing the production of photoassimilates during the period of grain filling (Feldmann, 2014).

The highest averages of thousand grains were observed with the application of 80 kg ha^{-1} of N and no inoculation with *A. brasilense* (Table 5). These results are similar to those obtained by Baribieri et al. (2012) where plants inoculated with *A. brazilian* bacteria did not influence the weight of a thousand grains. In contrast to

Table 5. Weight of a thousand grains in grams of wheat submitted to inoculation of different doses of *A. brasilense* and N under field conditions.

N doses (kg ha^{-1})	***A. brasilense* doses (mg kg^{-1} seed)**			
	0	**700**	**1000**	**1300**
0	35.18^{bAB}	37.00^{aA}	34.70^{bB}	36.51^{aAB}
40	36.23^{bA}	35.82^{aA}	36.61^{abA}	37.21^{aA}
80	38.43^{aA}	36.84^{aA}	37.45^{aA}	36.67^{aA}
	CV (%)=3.25			

Means followed by the same letter, lowercase in the columns and upper case in the lines, do not differ by the LSD test (t test) at the 5% probability level.

Table 6. Yield of wheat in kg ha^{-1} submitted to inoculation of different doses of *A. brasilense* and N under field conditions.

N doses (kg ha^{-1})	***A. brasilense doses* (mg kg^{-1} seed)**			
	0	**700**	**1000**	**1300**
0	1200^{cB}	1726^{aA}	1806^{bA}	1563^{bA}
40	1594^{bB}	$1730^{a B}$	2337^{aA}	2540^{aA}
80	2561^{aA}	1966^{aB}	2527^{aA}	2642^{aA}
	CV (%)=7.74			

Means followed by the same letter, lowercase in the columns and upper case in the lines, do not differ by the LSD test (t test) at the 5% probability level.
Source: Curuguaty (2017).

that observed in this study, Sala et al. (2007) found that, with different strains of plant growth promoting bacteria, all strains used resulted in a larger mass of thousand grains in wheat. In this way, it is known that the interaction between the bacterium and the plant occurs in the rhizosphere, which is stimulated by root exudates. The composition of these exudates is dependent on soil type, nutrient availability, genotypes and environmental conditions. All these factors influence the response of the plants to inoculation, and in general, the benefits of the plant bacterium interaction are more accentuated in soils with low natural fertility.

The interaction between the N doses and doses of *A. brasilense* was significant for wheat grain yield. The best wheat grain yield in the 2017 harvest was the combination of 80 kg N ha^{-1} and 1300 mg kg^{-1} seed of A. *brasilense* (Table 6). These results agree with Hungria et al. (2010), Mendes et al. (2011), Bashan et al. (2004) and Didonet et al. (2004): they observed an increase in the production of wheat grains when associated with the use of *A. brasilense*. On the other hand, the results observed in the present work are related by Barbieri et al. (2012), who concluded that inoculation of seeds with *A. brasilense* did not interfere in the irrigated wheat yield in the cerrado Region. However, Sala et al. (2008) found significant effects on wheat grain yield (mean of 23.9% in relation to the control) in inoculated *A. brasilense* treatment, with and without the addition of nitrogen fertilization (Table 6).

Conclusions

The different doses of N and *A. brasilense* did not affect the plant height. The increase of N and *A. brasilense* positively affects the number of spikes per plant and hectoliter weight. The highest doses of N increase the thousand-grain weight. The inoculation with 1300 mg kg^{-1} seed of *A. brasilense*, in addition to the application of 130 kg N ha^{-1}, provides the highest grain yield.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Photosynthetic profiles and nutrimental characterization of yellow mango in Mexico

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Worldwide, Mexico represents the first exporter of mango. However, in recent years mango exports have decreased by 29 points due to a change in the preference of the American market; hence, it is essential to diversify the supply of mangoes exports. Measurement of the net photosynthesis response and internal CO_2 concentrations can provide data on important parameters of the physiology of a variety; these have been widely used in ecophysiological studies and allow the early evaluation of germplasm. The objective of the study is to do a physiological evaluation of 8 mango varieties (Nam Doc Mai, Rosigold, Mallika, Ivory, Alphonse, Neelum, Fairchild and Kesar) recently introduced to Mexico and 2 recently registered by INIFAP (Ataúlfo "Diamante" and Ataúlfo "Zafiro"), all with export potential. The work was carried out under 2 conditions (laboratory and greenhouse). For the photosynthesis registry, nursery plants approximately 18 months old were used (net photosynthesis, stomatal conductance, internal CO_2 concentration and evapotranspiration, SPAD units and nutrients (NO^{3-}, K^+, Ca^{2+} y Na^+). In both conditions (laboratory and nursery), it was found that the cultivars with the highest levels of the physiological variables, photosynthesis, concentration of chlorophyll and nutrients in the leaf were Fairchild, Mallika and Kesar. The cultivars such as Rosygold and Nam Doc Mai and Ivory, in contrast, those with the lowest levels were Ataulfo Zafiro, Ataulfo Diamante, Alphonse and Neelum. The evapotranspiration (Evap), net photosynthesis (PN) and concentration of Intercellular CO_2 (Cint) kinetics were used to describe that all the cultivars presented a similar behavior and evidenced differences in the intensity of the same.

Key words: *Mangifera indica* L., chlorophyll, photosynthesis, nutrients.

INTRODUCTION

There are approximately 150 commercial mango cultivars in the world (Galán, 2009). Mexico is the main exporter; however, out of the total volume produced (1.4 million tons per year), only 10% is exported. The main cultivars

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for the international market are: Tommy Atkins, Kent, Haden, Keitt, and Ataúlfo, which is the only polyembryonic cultivar (Ayala-Garay, 2009, Ledin, 1957). Mexico has favorable physical and climatic conditions for the optimum development of the crop (SENASICA, 2009).

To establish an adequate management strategy for different mango cultivars, it is necessary to understand fundamental aspects of their physiology, such as photosynthesis. During this process, CO_2 moves from the atmosphere to the internal sub-stomata cavities through the stomata, and from there to the carboxylation site inside the stroma. This last component of CO_2 diffusion is called mesophyll conductance (gm) (Taiz and Zeiger, 2002; Long and Bernacchi, 2003; Flexas et al., 2008).

González et al. (2011) reported a contrasting varietal comparison of the environmental effects in some commercial orchards of Guerrero and Chiapas. Manila mango in Guerrero was the variety that photosynthesized faster, while in Chiapas the highest rate was observed in Tommy Atkins and Haden, followed by Ataulfo. These biophysical and biochemical processes, as well as environmental variables such as light intensity and temperature, can have different effects on the net rate of CO_2 assimilation (Sharkey et al., 2007). In red varieties, the carbon increases as there is more CO_2 in the environment, followed by the Ataúlfo variety (González et al., 2011). Mango is characterized by relatively high nutrient requirements (Mora et al., 2017); the N content is the most important factor in the determination of the photosynthetic rate per foliar surface unit (Agustí and Fonfría, 2010). In the cv. Kent, the contents of N and K decrease in flowering, which is explained by its greater content in the productive stage. P behaves homogeneously during the crop cycle. In the case of Ca, the levels increase as the productive cycle starts. This is explained by the age of the leaf because as it increases, the Ca and Mg contents also increase (Mora et al., 2017).

N forms a structural part of the chlorophyll molecule, which is the main pigment that gives green coloration to plants and is responsible for absorbing the light energy necessary to initiate the process of photosynthesis. The use of portable chlorophyll meters has been validated in countries such as the United States since 1994. In our country, thanks to the MPM Project, it is used since 1998, with very promising results for crops such as rice, wheat, beet and corn among others (Díaz et al., 2002). A review of the literature on the measurement of chlorophyll content with portable meters shows that there are no reports employed in mango foliage.

Therefore, in the present work the objective of evaluating the following physiological parameters was proposed: chlorophyll content for the determination of total chlorophylls of the biomass; net photosynthesis (A $\mu mol.m^{-2}.s^{-1}$); stomatal conductance (gs $\mu mol.m^{-2}.s^{-1}$); internal concentration of CO_2 (Ci $\mu mol.m^{-2}.s^{-1}$); among others. In the nutritional analysis of the samples, portable ionometers were used to estimate the content of NO_3^-, K^+, Ca_2^+ and Na^+ $\mu mol.m^{-2}.s^{-1}$, in mature mango leaves with 50 days of development (dod) of Nam Doc Mai, Rosigold, Mallika varieties, Ivory, Alphonse, Neelum, Fairchild, Kesar and selections Ataúlfo "Diamante" and Ataúlfo "Zafiro". The expected results will help identify differences among materials in order to select those with the best characteristics. The registration of these parameters will allow one to have more elements to make decisions about the selection of cultivars in the establishment of new commercial orchards.

MATERIALS AND METHODS

Experimental site

The research was conducted during the spring-autumn productive cycle (2016) at the Headquarters of the Master in Agricultural Sciences and Local Management of the Autonomous University of Guerrero, Tuxpan Unit (18º 20 '39' 'N, 99º 29' 53 '' O), in Iguala de la Independencia, Guerrero, Mexico, at 757 masl; its average annual temperature is 25.8°C and has approximate average rainfall of 1, 015 mm (García, 1988). Grafted plants were used with the cultivars Nam Doc Mai, Rosigold, Mallika, Ivory, Alphonse, Neelum, Fairchild and Kesar, recently introduced by the Fairchild Tropical Botanic Garden, as well as the national Ataulfo “Diamante” and Ataúlfo “Zafiro” selections, all of approximately 18 months age. The plants were planted in black polyethylene bags with a capacity of 5 L; they were fertilized weekly with a nutrient solution Steiner (1.0 L per plant poured into the soil and 1.0 mL L-1 sprinkled on the foliage) and watered until field capacity every third day.

Determination of physiological profiles in laboratory and nursery

Vegetative shoots were marked and when the leaves had 50 days of development (dod), the photosynthesis evaluations and SPAD units started. At the end of this phase, the leaves were cut to determine NO_3^-, K^+, Ca_2^+, Na^+ and chlorophyll. Each determination was made using the same leaves.

Laboratory

The plants were left for a seven-day adaptation period at the Plant Physiology Laboratory of the Autonomous University of Guerrero (UAGro). The temperature (26 ± 3°C) and relative humidity (70 ± 10%) were controlled using a LG® humidifier and the photoperiod (12:12h and 450 ± 50 lm) using PAR lamps. After the adaptation period, a randomized complete block design was used, and the experimental units consisted of 4 leaves attached to each plant, and a total of 4 plants (repetitions) per treatment. Every 2 h, the temperature, relative humidity and photoperiod in the laboratory were recorded with a Hobo® data logger, model U12.

Nursery

The plants were left for a seven-day adaptation period at the UAGro Fruit Tree Nursery, with polypropylene mesh (50% shade); the plants were established in black polyethylene bags of 27 cm by 27 cm of 5 l of capacity. After the adaptation period, the experiment was established using a randomized complete block design, with 4 leaves attached to each plant as an experimental unit and a total of 4 plants (repetitions) per treatment. The temperature (29 ± 3ºC), relative humidity (60 ± 10%) and photoperiod (12±1 h and 800-1009 lm) were recorded every 2 h with a Hobo® data logger, model U12.

Either at laboratory and nursery conditions, measurements were taken every 48 h at 10:00 am for 18 and 24 days on: photosynthesis, SPAD units, nutrients (NO_3^-, K^+, Ca_2^+ and Na^+). Foliage was also collected for total chlorophyll determination.

Determination of photosynthesis

This was quantified based on net photosynthesis (*A*), stomatal conductance (*gs*), internal concentration of CO_2 (*Ci*) and evapotranspiration (*Evap* $mmol.m^{-2}.s^{-1}$) with a TPS-2 (portable photosynthesis system) and PP system® software. Measurements were made on the anterior, middle and posterior part of mature leaves of 50 dod (4 per plant), based on the aforementioned variables; the area under the photosynthetic progress curve (AUPPC) was estimated with the method of trapezoidal integration (Campbell and Madden, 1990).

SPAD units

These were calculated with a Minolta SPAD® 502 (Soil Plant Analysis Development, Minolta Co. Ltd., Osaka, Japan); measurements were made on the front, middle and back of four mature leaves per plant of 50 dod. The SPAD units (chlorophyll content) were calculated by variety, based on the measurements made, the area under the progress curve (AUPPC) estimated with the trapezoidal integration method was calculated (Campbell and Madden, 1990).

Determination of total chlorophylls

The spectrophotometric method proposed by Hansmann (1973) was applied on 25 g of foliar samples chosen at random; those were crushed and suspended in 700 ml of acetone-water at 80% (v/v) as extractive solvent of the pigments. This was done several times to extract all the pigmentation. Subsequently, the extracted samples were transferred to plastic tubes and centrifuged at 15,000 rpm for 20 min. The samples were removed and decanted in glass tubes and flat bottomed, adjusted to 10 ml, allowing standing for 10 min. The optical density of the supernatant was determined by the AOAC method (1980), based on the following formula: Total chlorophyll = 8.2 (A663) + 20.2 (A645); where A663 and A645 correspond to the absorbance at 663 and 645 µm wavelength, measured with a spectrophotometer. The equation proposed by Parsons and Strickland (1963) was used for quantification**.**

Nutritional analysis

For estimating NO_3^-, K^+, Ca_2^+ and Na^+, portable LAQUAtwin Horiba Scientific® ionometers were used. The equipment was calibrated at 2 points with solutions at 200 and 2000 ppm according to the operations manual. For the measurement, ripe mango leaves of 50 dod were cut (4 per plant) and 1 ml of sap was extracted; finally the sample was placed in the equipment and after 3 and a half min where the results were obtained. Based on the results, the nutrient content was obtained by variety.

Correlation analysis

Pearson correlation coefficient (r) of the SPAD units against total chlorophylls and photosynthetic kinetics by variety was calculated.

Statistical analysis

A normality analysis was performed using the MinitabR statistical software. In addition to analysis of variance and separation of means SMD ($p \leq 0.05$) with statistical analysis software SAS, v.9.1.3 (SAS Institute Inc, 2003) for the variables: A, gs, Ci, Evap, Chlorophyll SPAD, total chlorophylls and content of NO_3^-, K^+, Ca_2^+ and Na^+.

RESULTS AND DISCUSSION

Physiological characterization in laboratory and nursery

Photosynthesis

The net photosynthesis (*A*), a main indicator of physiological activity, as measured in laboratory showed that Ivory, Alphonse, Rosygold, Neelum and Nam Doc Mai had the highest photosynthetic capacity ($p \leq 0.05$). According to Damián et al. (2009) *Ci*, shows the internal concentration of CO_2 available for photosynthesis in chloroplasts. In this sense the largest amount of interior carbon was recorded in A. Diamante, Ivory, Fairchild, Alphonse, Rosigold, Nam Doc Mai and A Zafiro; and referring to the group with the highest rate of evaporation, it could be observed that the varieties that transpired most were Kesar, Mallika, A. Diamante, Ivory, Fairchild, Alphonse, Neelum, A. Zafiro, regarding *gs.* There were no differences between cultivars (Table 1).

In the nursery trial it was found that Fairchild, Rosygold, Neelum, Alphonse and Nam Doc Mai had the highest rate *A* ($p \leq 0.05$), whilst Ivory, Fairchild, Alphonse Rosygold, Nam Doc Mai and A. Zafiro recorded the highest amount of carbon interior and Kesar, Mallika, Rosygold, Neelum and A. Zafiro recorded the highest levels of evaporation. Ivory and Fairchild recorded the lowest levels of gs, the rest presented the highest levels (Table 2).

González et al. (2011) report that the varieties Rosigold, Nam Doc Mai, Ivory and Mallika photosynthesize at similar speeds than Ataúlfo Diamante, Haden and the improved selections of Ataúlfo 4, 8 and Manila Cotaxtla selection. It is noteworthy that, although there was variability in the significances between each variable, there was, generally, similar behavior of cultivars in the laboratory and nursery.

There is a direct relationship between the availability of carbohydrates in leaves and the harvest; therefore, photosynthetic rate can be a limiting factor for this. A severe defoliation of the tree by the attack of insects or a disease, during the phase of linear growth, the low rate of photosynthesis can limit the development of the fruits and the total harvest (Agustí and Fonfría, 2010). Urban and Alphonsout (2007) reported that ringing reduces net

Table 1. Net photosynthesis, stomatal conductance, internal concentration of CO_2 and evapotranspiration in mature leaves (50 dod) of ten mango cultivars under laboratory conditions.

Cultivar	*A*	*gs*	*Ci*	*E*
Kesar	18.85^{c}	203.6^{a}	666.79^{c}	2.21^{a}
Mallika	18.65^{c}	223.3^{a}	693.60^{bc}	2.17^{ab}
A. Diamante	19.01^{c}	222.3^{a}	734.45^{abc}	1.95^{abc}
Ivory	20.06^{abc}	183.46^{a}	778.34^{abc}	1.98^{abc}
Fairchild	19.45^{bc}	185.48^{a}	788.23^{ab}	1.99^{abc}
Alphonse	22.66^{ab}	190.24^{a}	776.00^{abc}	2.06^{abc}
Rosigold	22.99^{a}	206.40^{a}	807.34^{a}	1.90^{bc}
Neelum	22.78^{a}	248.30^{a}	668.10^{c}	2.20^{a}
Nam Doc Mai	22.95^{a}	216.36^{a}	730.55^{abc}	1.86^{c}
A. Zafiro	18.28^{c}	192.49^{a}	719.65^{abc}	1.95^{abc}

*Means followed by same letters in the columns are not significantly different, SMD test ($p \le 0.05$). Net photosynthesis (*A*), stomatal conductance (*gs*), internal concentration of CO_2 (*Ci*) and evapotranspiration (*EVAP*).

Table 2. Net photosynthesis, stomatal conductance, internal concentration of CO_2 and evapotranspiration in mature leaves (50 dod) of ten mangoes cultivars under nursery conditions.

Cultivar	*A*	*gs*	*Ci*	*E*
Kesar	12.30^{b}	40.91^{abc}	926.14^{abc}	0.64^{a}
Mallika	13.23^{b}	49.71^{a}	791.66^{Bc}	0.62^{ab}
A.Diamante	13.92^{b}	43.02^{abc}	685.49	0.54^{bc}
Ivory	13.44^{b}	33.13^{c}	1109.60^{a}	0.39^{d}
Fairchild	17.03^{b}	36.14^{bc}	1079.80^{a}	0.49^{cd}
Alphonse	14.24^{ab}	38.84^{abc}	1008.65^{ab}	0.49^{cd}
Rosigold	14.80^{ab}	47.35^{ab}	846.81^{abc}	0.57^{abc}
Neelum	14.32^{ab}	40.58^{abc}	790.54^{bc}	0.59^{abc}
NamDocMai	15.04^{ab}	38.07^{abc}	1055.62^{ab}	0.53^{bc}
A.Zafiro	14.05^{b}	44.56^{abc}	865.27^{abc}	0.55^{zbc}

*Means followed by same letters in the columns are not significantly different, SMD test ($p \le 0.05$). Net photosynthesis (A), stomatal conductance (gs), internal concentration of CO_2 (Ci) and evapotranspiration (*EVAP*).

photosynthesis and stomatal conductance to a similar extent, in 77 and 71%, respectively, within 20 days after banding, and both remained below 2.1 µm $CO2 \cdot m^{2 \cdot s-1}$ and 0.06 µmol H_2O m^{-2} s^{-1}, respectively, until the beginning of flowering. An extensive literature review on mango plants to document the positive relationship of the highest photosynthetic rate with high fruit production shows that there is no literature available. Additionally, it has been reported that in fruits such as peach (*Prunus persica*), plum (*Prunus domestica*), cherry (*Prunus cerasus*) and almond (*Prunus dulcis*), a high photosynthetic capacity of the tree ensures an abundant harvest so that photosynthesis can become a limiting factor in cases such as competition between organs and/or when for various reasons there are major stress or defoliation phenomena (Agustí and Fonfría, 2010).

Photosynthetic kinetics

The cultivars showed a similar behavior for variables *A*, *gs*, *Ci* and *Evap*, during the period of laboratory study (Figure 1). A similar trend was observed for nursery evaluations (Figure 2); however, differences were found in their intensity ($p \le 0.05$), where only the high, medium and low kinetics were represented (Figures 1 and 2).

Lu et al. (2012) reported that 5 cultivars of mango, Kensington Pride, Strawberry, Haden, Irwin and Tommy Atkins showed a significant seasonal variation in *A* and *gs*, with the maximum values being registered during the wet season and the minimum during the dry season. The values of *Evap* were not significantly different among the cultivars during the wet season; however, they were significantly different during the dry season. Among the

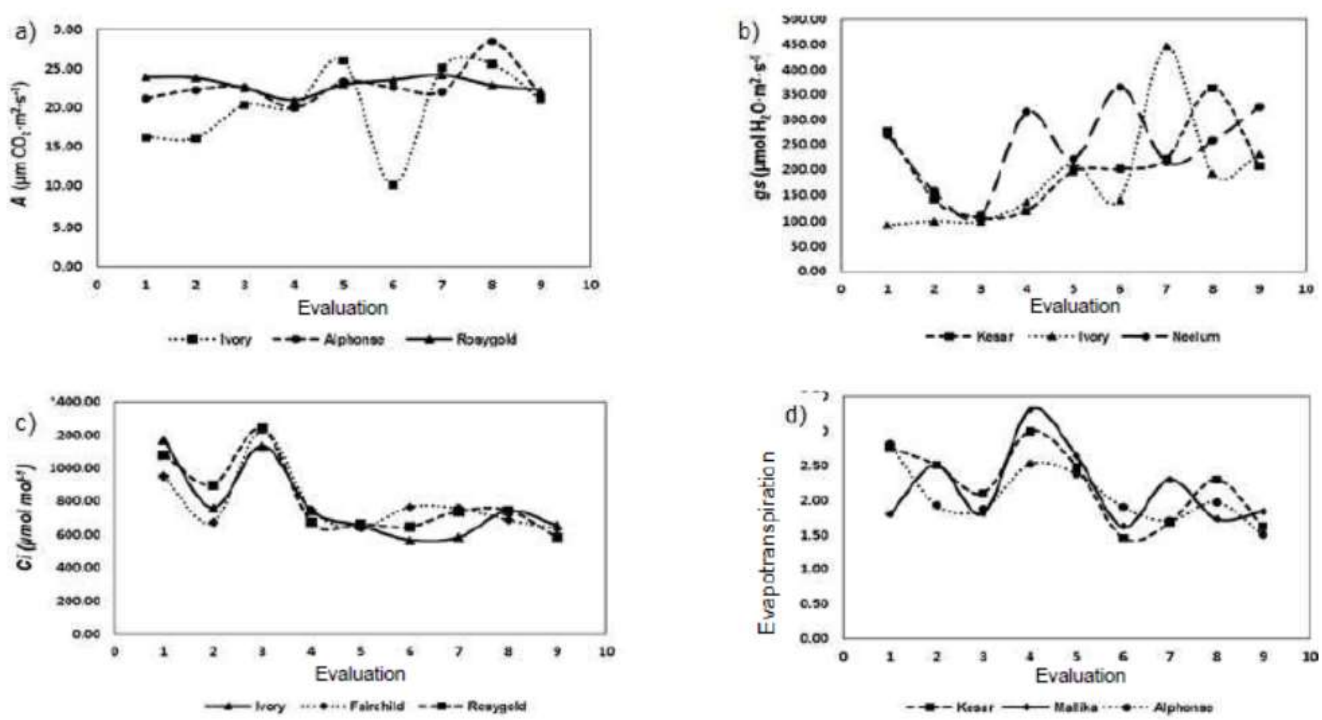

Figure 1. Kinetics of net photosynthesis (a), stomatal conductance (b), internal concentration of CO2 (c) and evaporation (d) of three mango cultivars (*Mangifera indica* L.) during nine sampling dates under laboratory conditions.

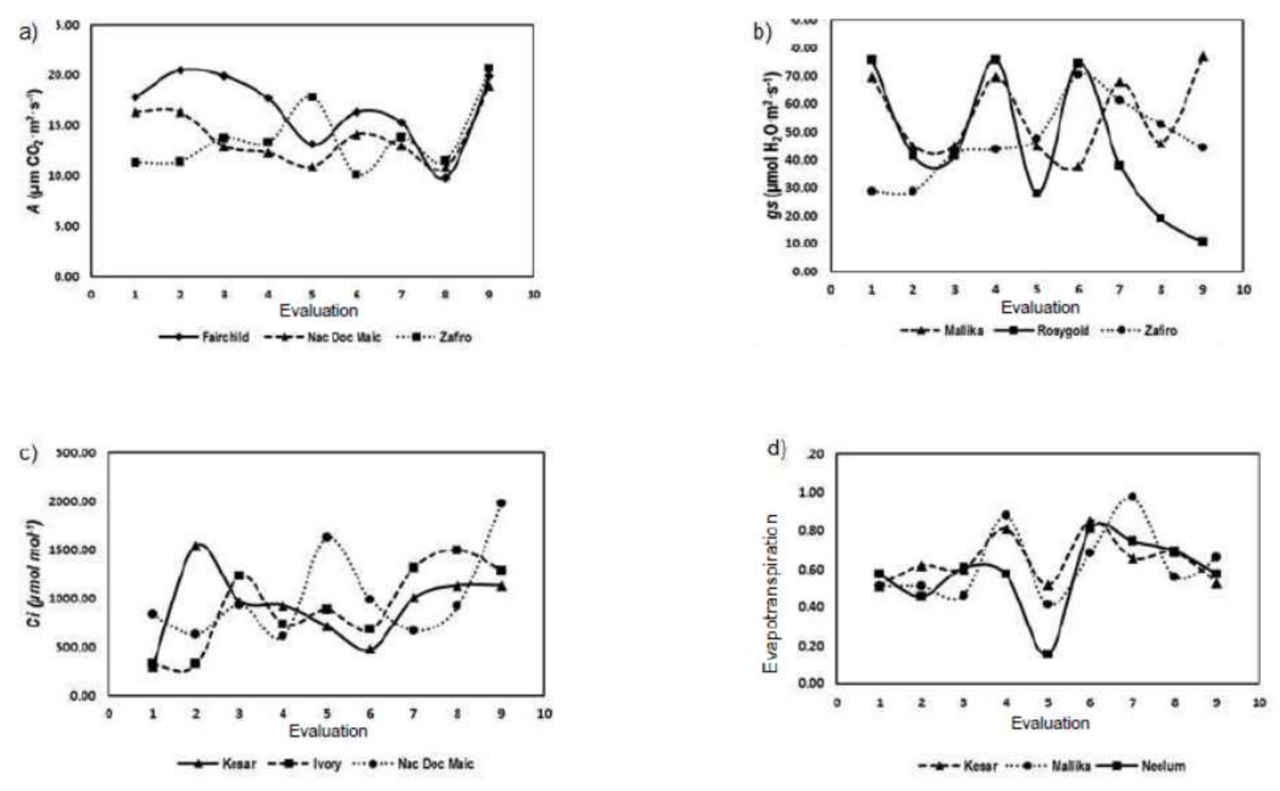

Figure 2. Kinetics of net photosynthesis (a), stomatal conductance (b), internal concentration of CO_2 (c) and evaporation (d) of three mango cultivars (*Mangifera indica* L.) during nine sampling dates under nursery conditions.

Table 3. SPAD units and area under the curve of photosynthetic progress (AUPPC) in mature leaves (50 dod) of ten mango cultivars under laboratory conditions.

Cultivar	SPAD502	AUPPC
Kesar	44.24[d]	1761.14[c]
Mallika	52.65[ab]	2136.73[a]
A.Diamante	48.93[c]	1974.56[b]
Ivory	52.50[ab]	2098.96[a]
Fairchild	53.50[a]	2157.97[a]
Alphonse	49.42[c]	1958.61[b]
Rosigold	47.60[c]	1918.06[b]
Neelum	44.73[d]	1789.70[c]
NamDocMai	52.29[ab]	2104.41[a]
A.Zafiro	50.07[bc]	1976.87[b]

Table 4. SPAD units and area under the curve of photosynthetic progress (AUPPC) in mature leaves (50 dod) of ten mango cultivars under nursery conditions.

Cultivar	SPAD502	AUPPC
Kesar	46.06[ef]	473.72[g]
Mallika	62.94[a]	676.61[a]
A.Diamante	48.56[de]	537.53[ef]
Ivory	54.32[bc]	599.81[bc]
Fairchild	57.12[b]	631.86[b]
Alphonse	49.52[cde]	551.12[def]
Rosigold	51.82[bcd]	570.51[cde]
Neelum	42.69[f]	470.00[g]
NamDocMai	53.40[bcd]	589.46[cd]
AZafiro	48.33d[e]	523.40[f]

*Means followed by the same letter in columns are not significantly different, SMD test (p≤0.05).

cultivars the difference of *A* is relevant to indicate the capacity of the cultivars for particular environments

SPAD (chlorophyll)

It is one of the most reliable, non-destructive devices focused on determining the level of chlorophyll in a plant. The cultivars with the highest concentration of chlorophyll in the laboratory per unit area were Fairchild, Mallika, Ivory and Nam Doc Mai (Table 3); the cultivar that presented the highest concentration of chlorophyll in the nursery was Mallika (Table 4), but the obtained results were like those found in the laboratory test. Ramírez et al. (2011) confirm the reliability of chlorophyll foliar content (µg per mg of leaf) from SPAD data, demonstrating the feasibility of using SPAD-502 (Minolta) reducing time, work and evaluation costs obtaining regression analysis that can be used in greenhouse and field. The use of portable chlorophyll meters is emerging as a technological opportunity, profitable, economical and feasible to be used, but it must be calibrated for each cultivar (Callejas et al., 2013).

Nutrients

Currently, it is required to obtain express information from chemical analyses, so the measurement of ions in the cellular extract of the foliage with specific portable ionometers is widely used in intensive production systems. A review of the literature on the concentration of nutrients shows that there are no literature reports on the use of portable ionometers brand Horiba Scientific® type LAQUAtwin in mango foliage. However, Tapia et al. (2003) refer to the existence in the market of technical equipment to determine *in situ* the nutritional status of the crop, like the specific ionometers for NO_3, P and K, etc.,

Table 5. Nutrients: (NO_3^-), (K^+), (Ca^{2+}) and (Na^+) in mature leaves (50 dod) on ten mango cultivars under laboratory conditions.

Cultivar	NO^{3-}	K^+	Ca^{2+}	Na^+
Kesar	490.00^{a}	236.17^{b}	19.00^{bc}	54.75^{a}
Mallika	430.00 ^{b}	280.50^{a}	5.75^{e}	31.95 ^{b}
A. Diamante	250.00^{d}	234.16^{b}	12.00^{de}	17.66^{def}
Ivory	208.83^{e}	172.66^{cd}	24.66^{ab}	19.83^{de}
Fairchild	267.50^{c}	213.83	15.16^{cd}	23.00^{cd}
Alphonse	116.16^{h}	134.11^{d}	15.50^{cd}	25.91^{c}
Rosigold	90.25 ^{i}	146.00^{d}	25.91^{a}	14.12^{efg}
Neelum	142.50^{f}	168.94^{d}	7.75^{e}	28.79^{bc}
Nam Doc Mai	128.75^{g}	152.50^{d}	22.91^{ab}	14.00f^{g}
A. Zafiro	86.00 ^{i}	172.47^{cd}	8.33^{e}	8.83 ^{g}

*Means followed by the same letter in columns are not significantly different, SMD test ($p \leq 0.05$).

Table 6. Nutrients: (NO_3^-), (K^+), (Ca_2^+) and (Na^+) in mature leaves (50 dod) on ten mango cultivars under nursery conditions.

Cultivar	NO_3^-	K^+	Ca^{2+}	Na^+
Kesar	192.25^{a}	303.83^{e}	14.00^{de}	20.37^{a}
Mallika	190.00^{a}	301.33^{e}	22.50^{bc}	20.12^{a}
A. Diamante	167.25^{b}	343.67^{d}	11.75^{e}	18.12^{a}
Ivory	134.50^{e}	334.67^{d}	34.75^{a}	21.62^{a}
Fairchild	149.12^{d}	304.33^{e}	17.87^{cd}	14.75^{a}
Alphonse	106.00^{f}	294.00^{f}	20.75^{c}	15.25^{a}
Rosigold	74.00^{g}	387.50^{a}	21.25^{bc}	19.00^{a}
Neelum	162.50^{bc}	304.33^{e}	12.12^{e}	20.50^{a}
Nam Doc Mai	155.00^{cd}	374.91^{d}	12.50^{e}	16.62^{a}
A. Zafiro	127.50^{e}	391.00^{a}	25.50^{b}	17.75^{a}

based on the solution of soil and cell extract; the ionometers can provide information instantly about the nutritional status of the tree. Kesar and Mallika presented the highest levels of Nitrogen (NO_3^-); Mallika statistically surpassed the rest of the cultivars for (K^+); Kesar, Mallika and Neelum had the highest concentration of (Na^+); Rosygold, Ivory and Nam Doc Mai exceeded the rest of the cultivars with respect to Ca^{2+}), under laboratory conditions (Table 5). In nursery, the highest concentration of Nitrogen (NO_3^-) was recorded in the cultivars Kesar and Mallika, similar to the results in laboratory test; no statistical differences were found among cultivars for (Na^+); Ivory, A. Zafiro, Mallika and Rosigold registered the highest amount of (Ca_2^+); for the case of (K^+), Rosygold and Ataúlfo-Zafiro statistically surpassed the rest of the treatments (Table 6). The results are partially like those found in the laboratory test. These values are high to that reported in avocado (*Persea americana*) by Arellano et al. (2017), for NO_3^-, K^+ and Na^+ there were no statistical differences; Ca^{2+} reported statistical differences with low concentrations. N fertilization is one of the most important growth factors in the production of yield and quality in production. Adequate supply of this nutrient is associated with adequate levels of chlorophyll, vigorous vegetative growth, high photosynthetic activity and carbohydrate synthesis, on which the yield depends on (Castro et al., 2004).

Chlorophylls and SPAD units

Fairchild, Nam Doc Mai, A. Zafiro and Mallika had the highest concentrations of photosynthetic pigments, like those obtained by the SPAD method (Table 7). A positive relationship was found between the analysis by spectrophotometry (mg*g^{-1}pf^{-1} of chlorophyll) with the SPAD units obtained in the laboratory (r=0.78) (Figure 3). Borres et al. (2017) report a correlation of a color sensor known as digital image analysis and SPAD 502 in Carabao mango shows that the two methods can detect the reading value of the specimen with almost uniform precision. The results indicate that the SPAD 502 device

Table 7. Concentration of total chlorophylls in mature leaves (50 dod) on ten mango cultivars using the method proposed by Hansmann (1973).

Cultivar	Mg*g^{-1}pf^{-1} de chlorophyll
Kesar	1.32^{cd}
Mallika	1.61^{abc}
A. Diamante	1.32 ^{cd}
Ivory	1.56^{abc}
Fairchild	1.91^{a}
Alphonse	1.25^{cd}
Rosigold	1.48^{bc}
Neelum	1.06^{d}
Nam Doc Mai	1.86^{ab}
A. Zafiro	1.62^{abc}

*Means followed by the same letter in columns are not significantly different, SMD test ($p \leq 0.05$).

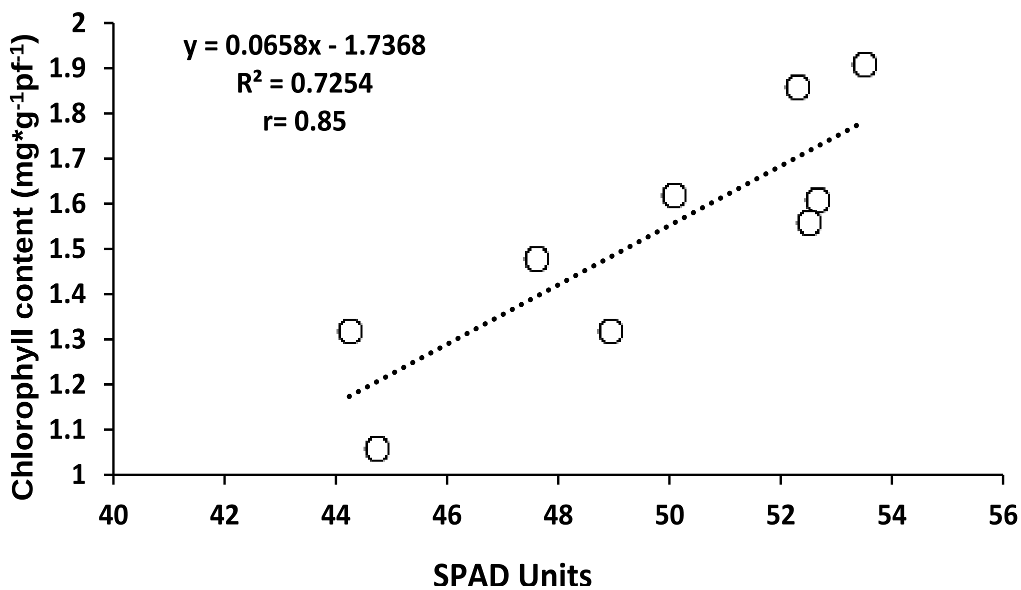

Figure 3. Correlation analysis (the correlation analyzes were made through a linear regression model) of the chlorophyll content (mg * g-1pf-1) with the method proposed by Hansmann (1973) and the SPAD units using a kit SPAD® 502 (Soil Plant Analysis Development, Minolta Co. Ltd., Osaka, Japan), in mature leaves (50 ddd) of 10 mango cultivars evaluated in laboratory.

can be a practical substitute for digital image analysis and spectrophotometric analysis (mg*g^{-1}pf^{-1} of chlorophyll) and it can be used for rapid, accurate, non-destructive usage and estimation of chlorophyll content in mango leaves.

A close relationship was also determined between the SPAD units registered in nursery and laboratory (Figures 4 and 5). A literature review on the concentration of SPAD units and correlation of different environmental conditions showed that there are no literature reports for mango. Márquez et al. (2017) report a linear regression between SPAD units and total chlorophyll content of juvenile avocado plants 'Hass' under 3 treatments of solar radiation, no statistical differences were found between the chlorophyll contents estimated from SPAD units in these 3 treatments; those conditions are different to the partially found when comparing the laboratory and nursery tests (Tables 3 and 4); significant differences were observed, with higher content of total chlorophylls in laboratory conditions.

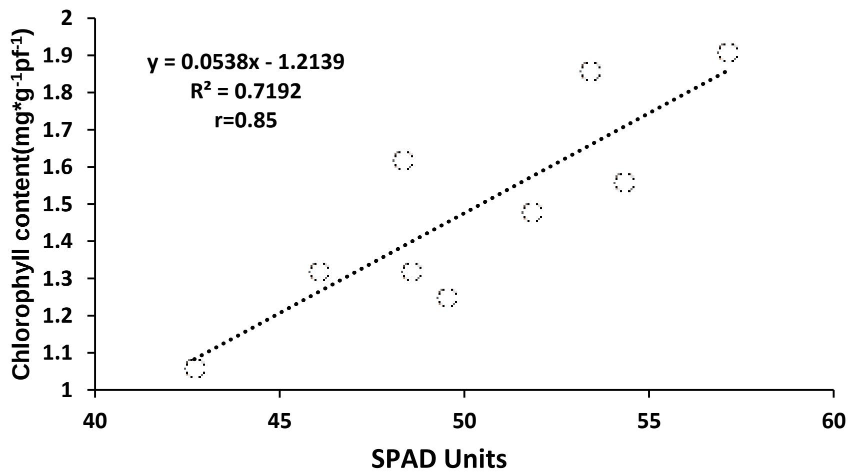

Figure 4. Correlation analysis (the correlation analyzes were made through a linear regression model) of the chlorophyll content (mg * g-1pf-1) with the method proposed by Hansmann (1973) and the SPAD units using a kit SPAD® 502 (Soil Plant Analysis Development, Minolta Co. Ltd., Osaka, Japan), in mature leaves (50 ddd) of 10 mango cultivars evaluated in nursery conditions.

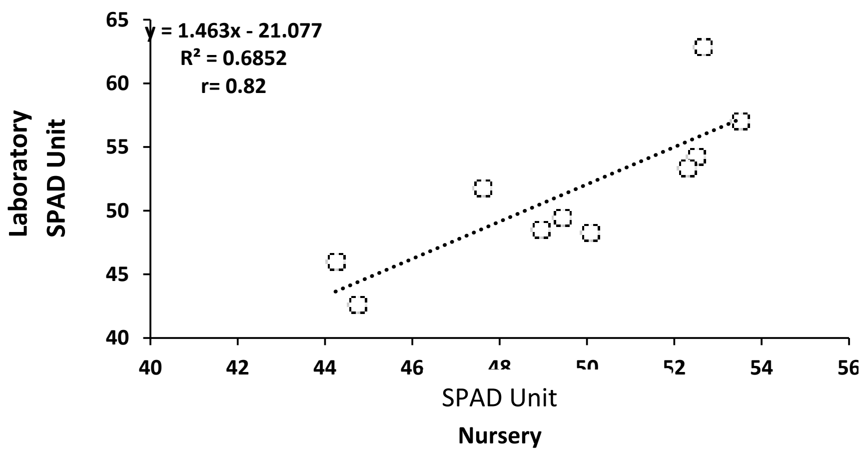

Figure 5. Correlation analysis and linear regression between the SPAD units registered using a SPAD® 502 (Soil Plant Analysis Development, Minolta Co. Ltd., Osaka, Japan), in mature leaves (50 ddd) of 10 mango cultivars evaluated in nursery and laboratory.

Conclusion

The cultivars with the highest levels of photosynthesis, chlorophyll concentration and nutrients were: Ivory, Alphonse, Rosygold, Neelum and Nam Doc Mai (Laboratory), Fairchild, Rosygold, Neelum, Alphonse and Nam Doc Mai (Nursery); Fairchild, Mallika, Ivory and Nam Doc Mai (Laboratory), Mallika (Nursery); Kesar, Mallika NO_3^-, Mallika K^+, Kesar, Mallika, Neelum Na^+, Rosygold, Ivory, Nam Doc Mai Ca^{2+} (Laboratory), Kesar, Mallika NO_3^-, Ivory, A. Zafiro, Mallika, Rosigold Ca^{2+}, Rosygold, Ataulfo-Zafiro K^+ (Nursery), respectively.

The values of *Evap, gs*, *A* and *Ci*, presented similar kinetics, with differences in their intensity among cultivars.

A creative relationship was found between the chlorophyll content (mg*g^{-1}pf^{-1}) with the method proposed by Hansmann (1973) and the SPAD units, so the use of SPADs is an alternative method to estimate chlorophyll, and it is a non-destructive method.

This type of work allows an early decision making for the establishment of mainly perennial crops, where the evaluation of yield, resistance to water stress, susceptibilit y to pests and diseases, etc. can take years.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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