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Full Length Research Paper

Preliminary studies on termite damage on rural houses in the Central Rift Valley of Ethiopia

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Termites are serious pests of agricultural crops and rural houses in Ethiopia. Some attempts were made to control termites on crops. However, termite problem on rural houses is a neglected area regardless of the intensity of the problem which at times results in total collapses of newly constructed houses. To collect preliminary information on status of termite infestation to rural houses, surveys were conducted in three districts of the Central Rift Valley of Ethiopia in 2012. Data were collected by direct observations and through semi-structured interviews. A total of 58 houses were inspected in the three districts of which 91% were termite infested at deferent levels. About 81% of the houses aged less than 10 years. Over half of the homeowners used pre-construction preventive measures such as plastic sheet cover and painting with used engine oil. Even though termite infestation was common and serious, only 35% of the homeowners took post construction preventive measures mainly because of lack of knowledge on the problem. The post construction termite control methods used in the study area were removing or scratching mud tubes from the infested parts and painting of the houses with used engine oil. There was no evidence of using synthetic chemicals for the management of termites on rural houses. The local government officials or Development Agents were not aware of termite problems in rural houses as the problem was only seen as a secondary problem. Termite samples were collected from houses, wooden fences and mounds built attached to the exterior walls of the houses. The collected termites were only from the genera *Macrotermes* and *Odontotermes* where about 79% was found to be from the former genus. This study explicitly indicated that termites have a great impact on local houses leading to frequent repairing and rebuilding. This damage will eventually lead to deforestation and environmental degradation in addition to its economic impact and spread of the termites. According to key informants of the study areas termite resistant tree species became rare and/or went extinct since they are used for all types of construction. In this study, preliminary information which can clearly demonstrate the level of termite infestation on local houses was obtained which can serve as an important input for the government both for awareness creation and developing best termite management practices.

Key words: *Macrotermes*, *Odontotermes*, rural houses, survey, termites, termite control measures.

INTRODUCTION

Termites are social insects which belong to the insect order Isoptera. Termites are an essential member of the soil ecosystem and are found throughout the world (Abdel and Skai, 2011). They are the most important and most efficient lignocellulose decomposers. Though termites have beneficial values such as organic matter recycling, improving soil fertility and serving as food sources for other animals, they have also harmful effects which include damage to crops, forestry and wooden structures (Changlu et al., 2009; UNEP, 2000). Damage may extend to household furniture, paper products, many synthetic materials and food items. Each year hundreds of thousands of structures such as bridges, dams, decks, homes, retaining walls, roads, utility poles, and underground cables and pipes require treatment against termites (UNEP, 2000).

Of about 2800 described species of termites, 185 species are known as pests of agricultural settings and housing structures (Krishna and Weesner, 1970). The number of species causing damage to building is between 70 and 80 out of which 50 species are serious pests that require management (Edwards and Mill, 1986; Pearce, 1997).

More than 1,000 of the 2,600 recognized species of termites are found in Africa (UNEP, 2000). Some of the most economically important wood feeding species of termites found in the tropics, sub-tropics and temperate regions are in the genera *Coptotermes, Odontotermes, Macrotermes*, *Microcerotermes*, *Microtermes*, *Reticulitermes Ancisrotermes*, *Schedorhinotermes* and *Pseudacanthotermes* (Abdurahman, 2000; Ahmed and French, 2008).

Within the wide limits of their geographical distribution, termites will destroy all unprotected timber used in construction work or as fittings, unless it has been rendered toxic, unpalatable or is naturally resistant to termites (Harris, 1971). Termites may attack timber anywhere in a building from below floor level to the highest point in the roof. The workers of most subterranean species enter from the soil, either directly into timber, through cracks in concrete flooring or by constructing shelter tubes over brick or concrete footings and walls (Edwards and Mill, 1986).

The annual economic cost of structural damage to buildings from termites in urban areas is about $ 15-20 billion dollars worldwide (Geer, 2005; Abdel and Skai, 2011).

In the majority of the local houses in developing country like Ethiopia, the wall is made of mud, while the roof is grass thatched which is conducive for termite infestation. Thatching in African houses can be expected to last 5 to 6 years (Pearce, 1997). The wood/straw thatch buildings, characteristics of farming communities in Ethiopia and much of sub-Saharan Africa are susceptible to termite damage, particularly in the tropical savanna areas where Macrotermitinae are abundant. Abdurahman (1990) reported that in western Ethiopia thatched roof huts are destroyed in less than five years and corrugated iron roof houses in less than eight years.

The Central Rift Valley of Ethiopia is among the termite prone regions of the country probably next to western Ethiopia. However, no information is available on the severity of termites particularly on the local houses from this part of the country. Hence, the current study was initiated with the following objectives:

(a) To survey termite damage to rural wooden houses;
(b) To collect information on public opinion concerning termite damage to local houses and control practices used by the local people, and
(c) To identify termite species infesting local houses.

MATERIALS AND METHODS

Description of the study sites

Surveys of termite infested houses were conducted in four Peasant Associations (PAs) of three districts of the Central Rift Valley of Ethiopia. The PAS were Tuqa Langano (08°16'N, 38°55E,1686 masl) in Bora District, Oda Boqota (08°10'N, 38°50'E, 1666 masl) in Dugda District, Warja Washgula (07°56'N, 38°41'E, 1652 masl) and Garbi Widana Boramo (07°53'N, 38°41E, 1650 masl,) in Adami Tullu Jiddo Kombolcha District (Figure 1). The Central Rift Valley is well-known for its biodiversity and the vegetation is characterized by Acacia trees or species (Huib and Herco, 2006). The study sites were characterized by semi-arid climates. The average annual precipitation was about 700 mm of which 42% falls between June and September. The monthly maximum temperature varies from 25 to 30°C and the minimum temperature ranges between 10 and 20°C (Huib and Herco, 2006). The mean annual temperature was 20°C. The driest months were November and December, while May is the hottest month with a mean maximum temperature of 28°C. December is the coldest month with a mean minimum temperature of 10°C. The greatest proportion of the land is grown with maize and haricot bean (Mengistu, 2008).

The surveys were carried out from September 2012 to January 2013 just after the long rainy season which is said to be the highest termite activities period. Selection of the districts was proposed by the Agricultural Bureau at zonal and district levels based on termite abundance and accessibility.

Survey methods and data collection

The surveys were conducted using an open-ended semi-structured questionnaire and interviews with the homeowners, and observation of termite infested houses. The questionnaire was dispatched to 51 farmers selected randomly from the four PAs of the three districts and the respondents' filled the questionnaire with the help of Development Agents. Short training was also given to the farmers on how to fill the questionnaire. A total of fifty-eight homeowners, different from those who filled the questionnaire, were selected randomly and their houses were assessed for termite infestation.Before carrying out the assessment and the interview, each homeowner was asked whether his/her house was infested by termite or not. Termite infestation assessment to houses comprised of visual observation of signs such as termite galleries (mud tubes) on walls, pores in walls, damaged parts such as roofs (wood and

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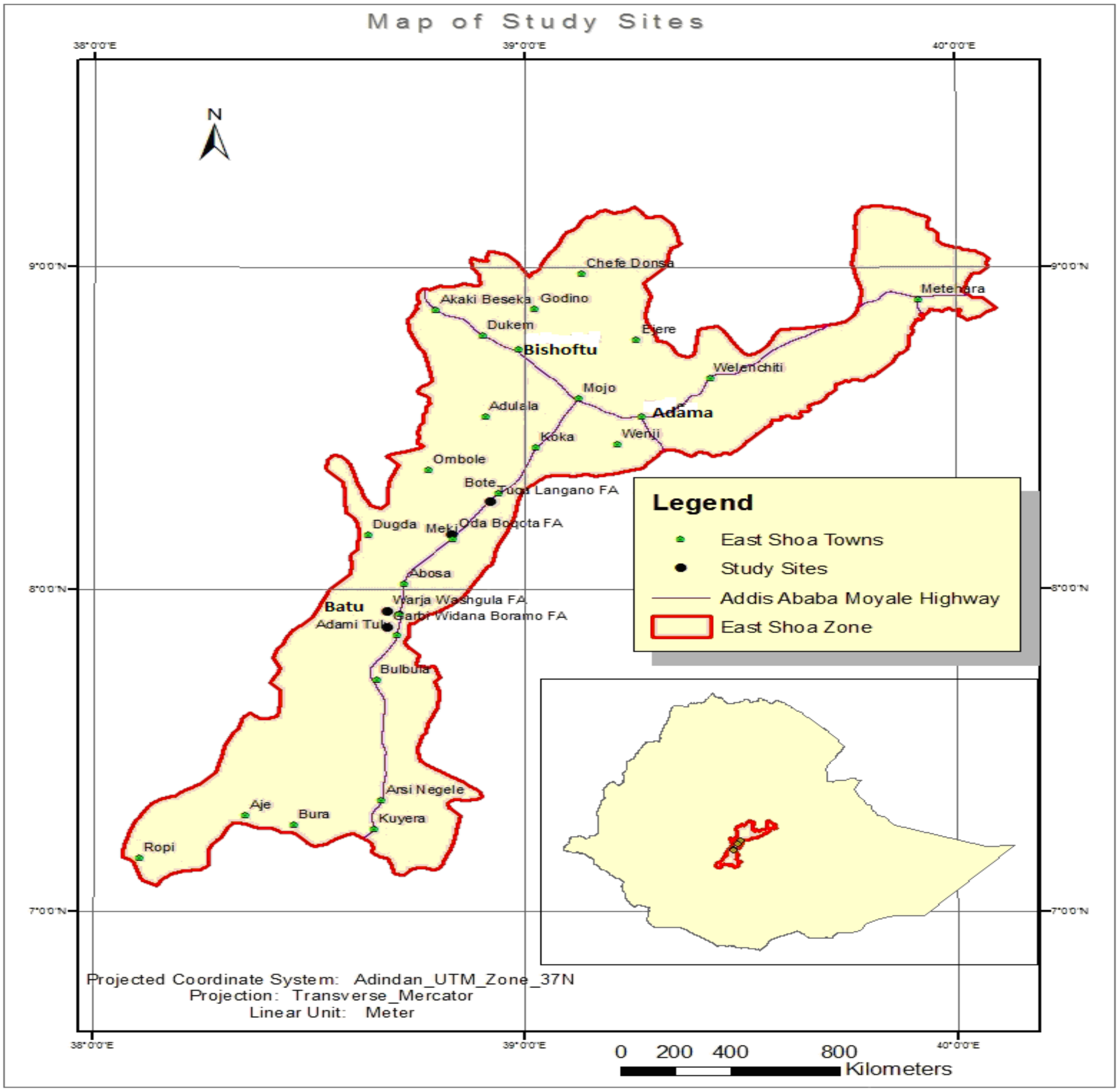

Figure 1. Map of the study sites.

grass), window and door frames, wood in walls and wooden furniture among others. Pieces of wood in the premises and wooden fences were also inspected for those houses which had wooden fences.

The age of the houses and when the wall was made of wood, the type of plant from which the wood came were also recorded by asking the owners. A house was said to be infested when there was any sign of termite attack to the house itself, furniture found in it, presence of mud tubes on walls or floors and spots of fecal pelletamong others. When a house was found infested, its condition was recorded as:

1. Slightly infested: Mud tubes on walls, roof, window and door frames, presence of mounds found externally at the base of walls and inside houses without any sign of damage or little damage.
2. Moderately infested: Woods in wall, window and door frames, grass in grass thatched roofs or woods supporting roofs partially eaten, but were not cut completely.
3. Severely infested but not collapsed: Window, door frames, some of the woods in wall and/or roof were eaten and cut completely, grass in roof thatched houses was eaten and the house drips as a result, window and/or door frames were cut and left their original normal position, or as a result of termite attack the house was tilted and was about to collapse.
4. Collapsed: The house was highly damaged and as a result tilted and the owner supported it by wooden pole to prevent it from collapsing, or totally collapsed.

Preconstruction preventive methods and post construction control measures used by the homeowners, type of wood in wooden wall houses, resistance level of the wood to termites, availability of the plants were recorded during the interviews. Termites were collected and preserved in 80% alcohol and were later identified with the help of taxonomic keys of Abdurahman (1991). Plant species used for the construction of the houses were identified at the National Herbarium of Addis Ababa University, using freshly collected plants

Table 1. Percent termite infestation on rural houses as affected by age.

Age distribution of the surveyed houses in year (n=58)	Percentage of houses belonging to each age group	Percentage houses infested by termites
1-3	20.7	19.0
4-6	44.8	39.7
7-9	17.2	15.5
10-12	10.3	10.3
13-15	5.2	5.2
16+	1.7	1.7

Table 2. Percent termite infested houses in relation to construction materials.

Wall material of the houses	Number of houses surveyed	Status of the houses in terms of termite infestation	
		none infested	Infested
Mud brick	35	8.6	51.7
Wood	23	0.0	39.7
Total	58	8.6	91.4

of the same species.

Data analysis

As the study was none replicated experiments descriptive statistics such as mean and percentage among others were used to determine termite infestation on rural houses. Data collected from respondents and participants were qualitatively interpreted.

RESULTS

Table 1 depicts the effect of age on termite infestation. Houses aging from 1 to 3 years were less infested than old houses greater than 7 years. Over 65% of the studied houses were less than 7 years old and the highest percent termite infestation for this age group houses were about 40%. Table 2 demonstrated that about 60% of the surveyed houses were made of mud brick, while 40% of them were wooden wall. Only 8.6% of the houses were free of termite infestation (Table 2). About 55% of the respondents indicated that within 1 to 2 years time newly built houses can be infested by termites. Less than 5% of the respondents indicated that newly built houses can be infested by termites within 7 to 8 years (Figure 2). Over 50% of the respondents indicated that newly built houses require repair within 3 to 4 years. Less than 5% of the respondents indicated that houses may require repair at greater than 8 years old (Figure 3).

Over 45% of the surveyed houses were 4 to 6 years old, while only 3% of the surveyed houses were greater than 16 years old (Figure 4). Nearly 50% of the surveyed houses were rated as severely termite infested houses, while 3% of the houses collapsed due to termites (Figure 5).

Samples of pictorial descriptions of termite infested houses are shown in Plates 1 to 3. The plates demonstrate a roof supporting timber completely cut by termites (Plate 1), termite infested houses supported by poles (Plate 2) and severely damaged door frame (Plate 3).

Both susceptible and resistant plant species were used for the construction of the surveyed houses (Table 3). *Acacia tortillis*, *Eucalyptus* spp., *Acacia albida*, *Balantes aegyptus* and *Croton macrostachyus* were the susceptible plant species used for the construction. The resistant plant species used in the construction include *Acacia etbaica*, *Dichrostachys cinera*, *Flueggea virosa* and *Acacia Senegal*.

Plastic sheet cover followed by used engine oil before construction and mud tube removal followed by wood ash and used engine after construction were found to be the major termite management options in the study areas (Table 4). About 79% of the termites causing damage to houses in the study area were the genus *Macrotermes*, while the rest 21% consists of the genus *Odontotermes*.

DISCUSSION

The absence of very old houses, the infestation of most of the houses, and severe damage recorded show frequent rebuilding of houses and termite severity to rural houses. Most of the farmers believed that houses would collapse if they were not repaired within six years after

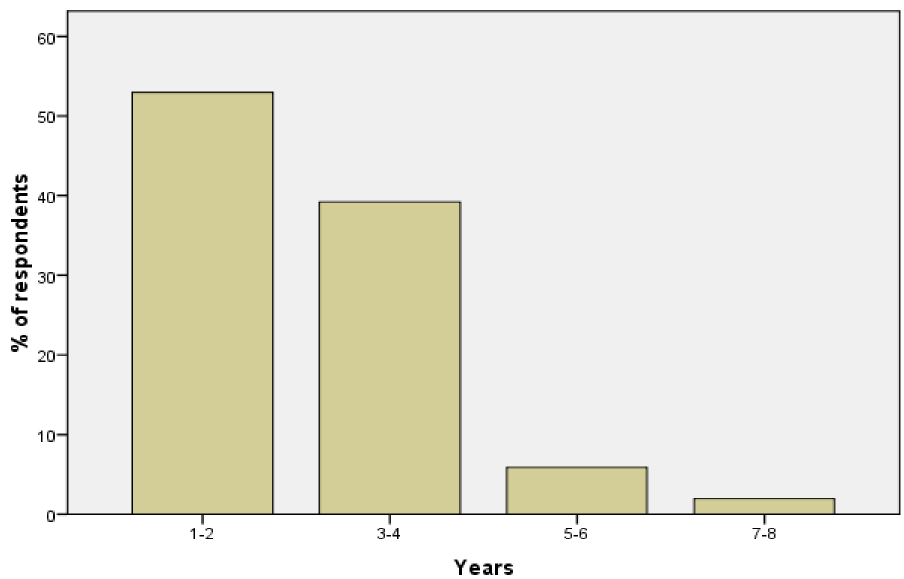

Figure 2. Percentage respondents showing years after which newly constructed houses can be infested by termites.

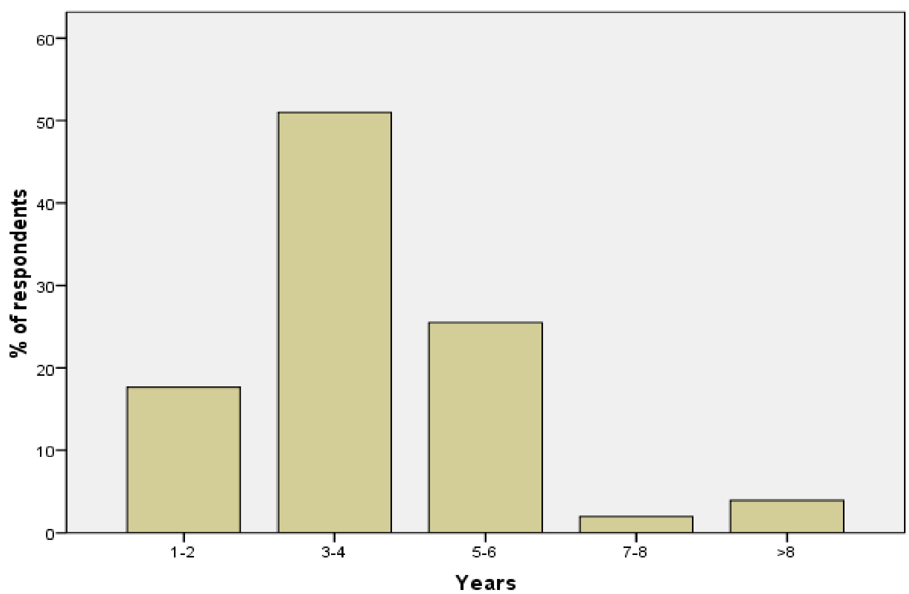

Figure 3. Percentage respondents showing years after which newly constructed houses need repair due to termite infestation.

construction. Termite damage to buildings in tropical countries is a serious concern which is in part due to the diversity of termites in these areas and poor building design (Abdel and Skai, 2011). Thatching in African houses can be expected to last 5 to 6 years (Pearce, 1997). In western Ethiopia thatched roof huts are destroyed in less than five years and corrugated iron roof houses in less than eight years (Abdurahman, 1990).

Higher infestation of wooden wall houses than mud brick houses could be attributed to the attraction of termites to wood (cellulose) used in construction and the woody debris left in soil and around houses after construction. It is also more likely that infested wooden wall houses have shorter life than mud brick houses because as termites eat woods in the former, the walls will lose support and eventually collapse. But in mud brick walls, termites simply move through the walls to reach the roof and thus they have little effect on the integrity of

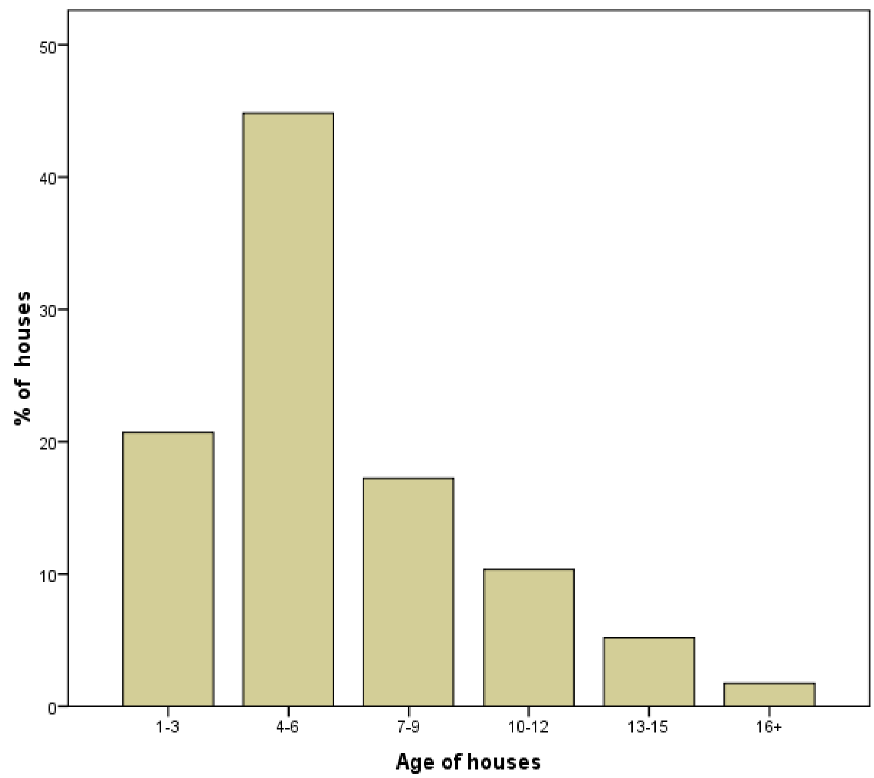

Figure 4. Percentage age distribution of surveyed houses.

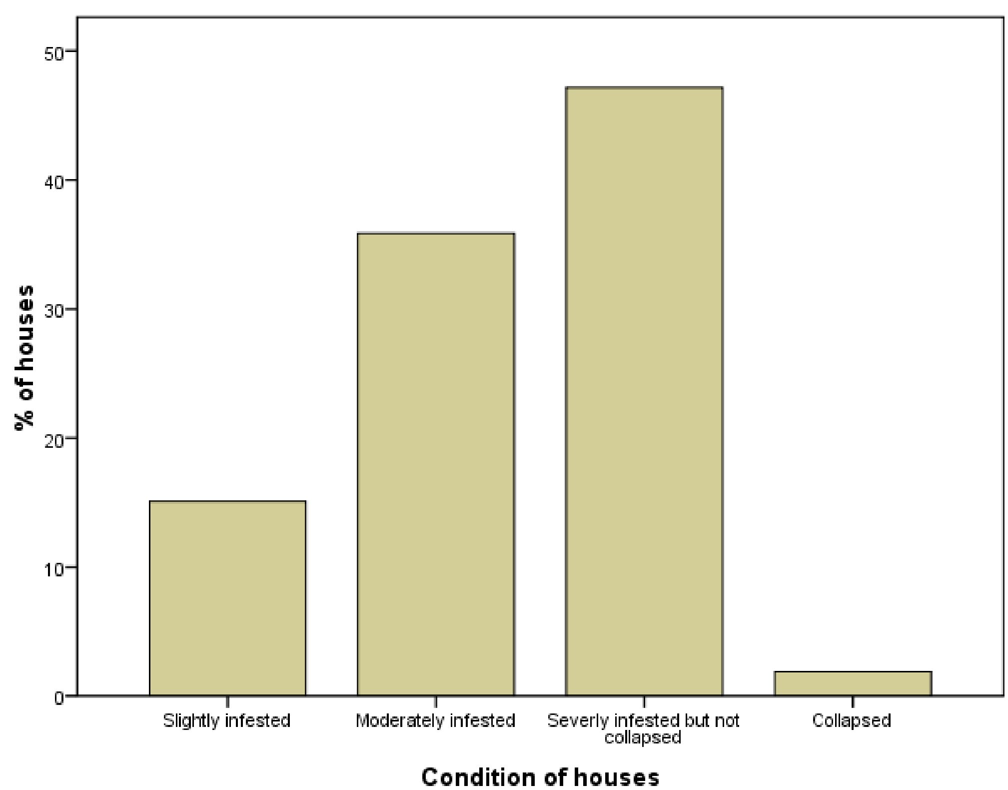

Figure 5. Percent of houses fall under different termite infestation category.

Plate 1. A roof supporting timber completely cut by termites.

Plate 2. Termite infested houses supported by poles.

the wall. But, once they have reached the roof, especially iron corrugated roof houses, which contain only a few roof supporting timbers, termites ring-cut the timbers at their junction with the wall leaving the roof without being fixed to the wall. As the damage is not usually visible, the homeowners do not take action timely, and thus the whole roof will be removed completely even by a slight wind. Some participants told the authors that in Warja Washgula Farmers' Association, roofs of 20 iron corrugated houses were removed by wind at the same time in the year 2008.

The homeowners used different kinds of wood species in building their houses and they were able to identify susceptible and resistant woods to termites that were used in their area for house construction. All farmers regarded *D. cinerea,* A. *etbaica*, and *F. virosa* as highly resistant to termites. Logan et al. (1990) reported that many timbers contain chemicals or complex mixtures of

Plate 3. Severely damaged door frame.

Table 3. Plant species used for the construction of the studied rural houses and their reaction to termites.

Plant reaction	Names of plants	
	Local name	Scientific name
Susceptible	Dhaddacha/Ajoo	*Acacia tortillis* (Forskk)
	Muka Bargama/Barzafii	*Eucalyptus* spp.
	Garbii	*Acacia albida* Del.
	Badana	*Balantes aegytica* (L.) Del
	Bakanissa	*Croton macrostachyus* Del.
Resistant	Doddota	*Acacia etbaica* Schweinf
	Geetoo/haxxee/jirmee	*Dichrostachys cinera* (L.) Wight & Am
	Daboobessa	*Flueggea virosa* (Willd) Voigt
	Saphanga/Qarxafaa	*Acacia Senegal* (L.) Willd

Table 4. Numbers of homeowners used different control/management strategies identified during the survey,

Management options	Preconstruction (%)		Post construction (%)	
	No. of users	% of users	No. of users	% of users
Synthetic termiticide (Malathion)	0	0.0	2	6.7
Herbicide	0	0.0	2	6.7
Wood ash	5	9.8	5	16.7
Decomposed cow dung and/or goat urine	1	1.9	2	6.7
Mound destruction/queen removal	0	0.0	2	6.7
Plastic sheet cover	24	47.1	2	6.7
Used engine oil	13	25.5	5	16.7
Mud tube removal (scratching)	-	-	8	26.7
Site selection	1	1.9	-	-
Debris removal /sanitation	1	1.9	1	3.3
Use of grass free of termites	2	3.9	-	-
Floor, perimeter – cement	1	1.9	0	0
Kerosine	0	0.0	1	3.3
Use of mud brick instead of wood	2	3.9	-	-
Sand, gravel	1	1.9	-	-

- = Not applicable.

chemicals that repel or kill termites or interfere with their gut fauna. Factors affecting wood consumption by termites are numerous and complexly related. Among the most important of these factors are wood species and hardness, presence of toxic substances, feeding inhibitors or deterrents, presence or absence of fungi and degree of fungal decay, moisture content of wood and soil among others (Hickin, 1971; Getachew et al., 2003; Regina et al., 2004; Behailu et al., 2011).

Over 90% of the houses were infested, although about 60% of the homeowners used preconstruction preventive measures implying that the methods are ineffective. Plastic sheets were the most popularly used method and their inefficacy could be attributed to their non-termite resistance and may be incorrect use. It is also practically impossible to exclude the house totally from termites by plastic materials. Hickin (1971) and Pearce (1997) have reported that plastic materials are often eaten by termites and their resistance depends mainly on their density, the compounds they contain, thickness, and intrinsic hardness. UNEP (2000) and Ahmed and French (2008) also reported that when certain plastic materials are used as exclusion or barrier they can be breached and bridged over by foraging mud tunnels. Use of engine oil was also ineffective in protecting houses from termite attack. Behailu et al. (2011) noted that at field condition stakes of different timber species, treated with used engine oil using hot-and-cold dipping open tank thermal method, were attacked by termites before the third year of staking

Farmers had awareness about the control of termites by mound destruction and queen removal and most of the homeowners believed that termites came out of the mounds which were found around their homes. *Macrotermes* termite mounds were recorded in the vicinity of most of the infested houses. However, only a very small proportion (3.5%) of farmers destroyed mounds after their houses were infested. About 79% of the termites sampled from infested houses belonged to mound-forming *Macrotermes* while the rest belonged to *Odontotermes* (21%). Therefore, the result of this study indicated that *Macrotermes* was a serious pest to wooden construction.

CONCLUSION AND RECOMMENDATIONS

This research has revealed that termites were serious pests of rural houses of resource poor farmers and the farmers were well aware of the problem. *Macrotermes* to a larger extent and *Odontotermes* to a lesser extent were the only termite genera found causing damage to rural houses. The farmers had attempted a number of traditional control methods mostly plastic sheets and painting of used engine oil, but they were ineffective. Other than the traditional management options attempted, the homeowners had no awareness regarding what measures they may take or whom to contact in order to safeguard their homes. Few persons realized that the safest and cheapest termite control measures are dusting of borates, like 20 Mule Team Borax (2014).

Frequent repairing and rebuilding of houses within a few years is uneconomical for subsistence farmers. Besides, it has negative environmental impacts as plants are the major source for building materials. Therefore, farmers should be given awareness about the general views of termites and ways by which they can protect their homes from damage. Therefore, there is a need for comprehensive termite control approaches, which should involve both the local communities, concerned government bodies and more use of resistant wood species.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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Full Length Research Paper

Major pearl millet diseases and their effects on-farm grain yield in Uganda

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Pearl millet (*Pennisetum glaucum*) is an important food and cash crop for many people living in the semi arid areas of Uganda. But information about the common diseases and their effect on yield is lacking yet it is important in designing a realistic and focused pearl millet breeding programme aimed at increasing yield. A disease survey was done in 2012 in the farmers' fields in the predominantly pearl millet growing districts of Kumi and Katakwi in eastern and Kitgum and Lamwo in northern Uganda to identify the major diseases of pearl millet and establish their incidence, severity correlation and effect on grain yield. The aim of the study therefore was to identify the major pearl millet diseases that affect production in Uganda. In terms of incidence, rust (*Puccinia substriata*) (73.58%) was the most frequent disease followed by ergot (*Claviceps fusiformis*) (62.98%), then leaf blast (*Pyricularia grisea*) (61.25%) and smut (*Moesziomyces penicillariae*) (26.76%). However, in terms of severity, leaf blast (62.20%) was the most severe followed by rust (43.33%), ergot (29.46%) and smut (14.18%). Using SPSSv20, backward model reduction regression of disease parameters against grain yield, results show disease severities of rust, ergot, leaf blast and incidences of smut and rust were the most important in affecting grain yield. The correlation of disease severity with grain yield further indicated that ergot and rust severities were causes of the significant effect on yield.

Key words: Pearl millet, diseases, severity, incidence, Uganda.

INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.], also known as bulrush millet, is a staple food for many people living in the semi arid agro-ecological zones of eastern (in teso region), northern (mainly in greater Kitgum district), northeastern and to some extent in northwestern (west nile districts) Uganda. It is a food and source of income and to a lesser extent forage crop and yeast for local brewing. As food, the grain is ground and used to make thin porridge known as ugi and thick porridge commonly known as atapa in teso region or kwon in northern region. In Teso region the flour is normally mixed with cassava flour to enhance the hardness of the atapa and tamerine or tangerine to improve the taste but in the north and northeastern regions nothing is mixed with the flour prior to making a pearl millet food product. It is an excellent source of yeast but there is decline in the use of pearl

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millet as yeast source because those who take such alcoholic drink claim to have severe headache thereafter. The stover is an important source of fodder in many countries where the crop is grown but in Uganda not much emphasis is put on the crop for this purpose.

It is cultivated as a subsistence rain-fed crop by people living in the semi arid agro-ecological zones in Uganda. In African countries, the national average grain yield of pearl millet is generally in the low range of 400-600 Kg ha^{-1} (FAO, 2002) and for Uganda yields between 0-900Kg ha^{-1} have been reported by farmers in this survey. However, in India the National Rainfed Area Authority (NRAA) (2012) reported a grain yield range of 1720 to 3870 Kg ha^{-1} and a productivity potential of over 5000 Kg ha^{-1} from farmers' fields. This shows a great increase in productivity since the potential productivity of 3000 Kg ha^{-1} was recorded from research centres over ten years age (Rai et al., 1999). The variation in yield at farmers' and research centres has been mainly attributed to biotic constraints faced in the production areas (Baltensperger, 2002; Crampton et al, 2009) and farmers growing inherently low yielding local landraces. Extensive studies have been done about pearl millet biotic constraints such as diseases and the inherent low yielding ability of the crop in the USA, India, West and Southern Africa but no studies have been conducted about the pearl millet disease and their association with yield in Uganda. For example in the USA, rust and blast have been reported to severely affect pearl millet and extensive research has been done on the two diseases to ascertain their effect on grain and fodder yield and quality (Wilson et al., 1996). In India and Western and Southern Africa, much research has been done and reported about downy mildew [*Sclerospora graminicola* (Sacc.) Schroet.] (Hash et al., 1999; Singh, 1995) as being the most important pearl millet disease in Asia and Africa (Williams, 1984); ergot which severely affects hybrids in India and OPVs in Africa (Arya and Kumar, 1982); rust, blast and smut diseases but no such studies and reports have been done to even identify the common diseases that affect pearl millet in Uganda. The objective of this study was therefore to identify the common pearl millet diseases and their association with yield.

MATERIALS AND METHODS

Study area

The study was conducted in two agro-ecological zones namely the Teso and the Northern farming systems which are characterized by dry months towards the end and beginning of the year. In the two agro-ecological zones annual crops such as sweet potatoes, cassava, and legumes are grown in addition to livestock and poultry rearing (Mwebaze, 2001). In the Teso zone the survey was conducted in Kumi and Katakwi districts while in the Northern zone Kitgum and Lamwo districts were covered (Figure 1). Data collection was done in January 2012 where one hundred and forty households were surveyed. Pearl millet is generally grown late in the second season starting October to January of the following year, thus this time was appropriate for conducting the survey as most of the farmers had not yet harvested so it was easy to conduct disease incidence and severity score on-farm.

The study

Pearl millet is mostly grown once every year and the study was done in January 2012 at the time when the crop in most fields was at physiological maturity. The crop is not grown by many farmers so purposive selection of pearl millet farmers who had grown pearl millet for at least two years was done. Prior to field data collection, demographic data about the household head (age and uses/importance of pearl millet) were collected using a semi-structured questionnaire. In Kumi (Kumi sub county) and Katakwi (Katakwi and Usuku sub counties) districts forty fields were selected for disease survey while thirty fields were selected from Kitgum (Kitgum town council, Mucwini, and Kitgim Matidi sub counties) and Lamwo (Agoro sub county) districts. Thus, a total of one hundred and forty pearl millet fields, also considered as replicates (Kutama et al., 2010), were covered in the study. In each, field five quadrants (2 x 4 m) were made (four at the corners and one in the middle of the field) and incidence score and disease severity was calculated by assessing fifty plants in each quadrant making a total of 250 plants per field (Thakur et al., 2003). Within the quadrant, the fifty plants were randomly selected and identification of diseases was done using the sorghum and pearl millet disease identification hand book developed for ICRISAT by William et al. (1978). Severity score for rust and leaf blast was noted on the third and fourth leaves from the top as these are reported to have a direct contribution to grain yield (Joshi et al., 2003). Infected leaf samples were collected for diseases which could not be identified using the field book and incubated in the laboratory for microscopic identification. In the laboratory, leaf samples were cut into small pieces and put on moist filter paper and incubated under UV light for three days for pathogen growth. Pathogen observation was done under the stereo while conidia were observed using compound light microscope. The percentage disease incidence was calculated using the formular;

%incidence = (total number of diseased plants/250 total plants selected) ×100

For leaf blast, leaf samples showing disease symptoms were collected and observed in the laboratory to confirm the presence of the pathogen *Pyricularia grisea* but for ergot, rust and smut this was not necessary as the pathogens are visible with unaided eyes. Ergot was identified basing on the condia commonly known as honey dew (Frederickson and Mantle, 1996) and severity score was recorded using the scale developed by Thakur and Williams (1980). Rust disease was identified based on the small reddish-brown to reddish orange, round to elliptical uredinia developing mainly on foliage (Ramakrishnan and Narasimhalu, 1941) and severity score was calculated using the Cobbs scale modified by Niks (2011). The leaf blast disease severity was scored using the 1–9 progressive scale developed at International Rice Research Institute (IRRI) for rice blast (IRRI, 1996) whereas the smut severity was scored using the 1 to 90% scale developed by Thakur and King (1988a).

Data analysis

Data were analysed using IBM SPSS statistics20. The yield data were transformed to base ten. The analysis of variance (ANOVA) at 5% probability was done to establish whether there was significant variation in disease incidence and severities across locations. A regression analysis was also done to assess the contribution of the major diseases to the farmers' grain yield. The Pearson's correlation analysis was also performed to establish the relationship

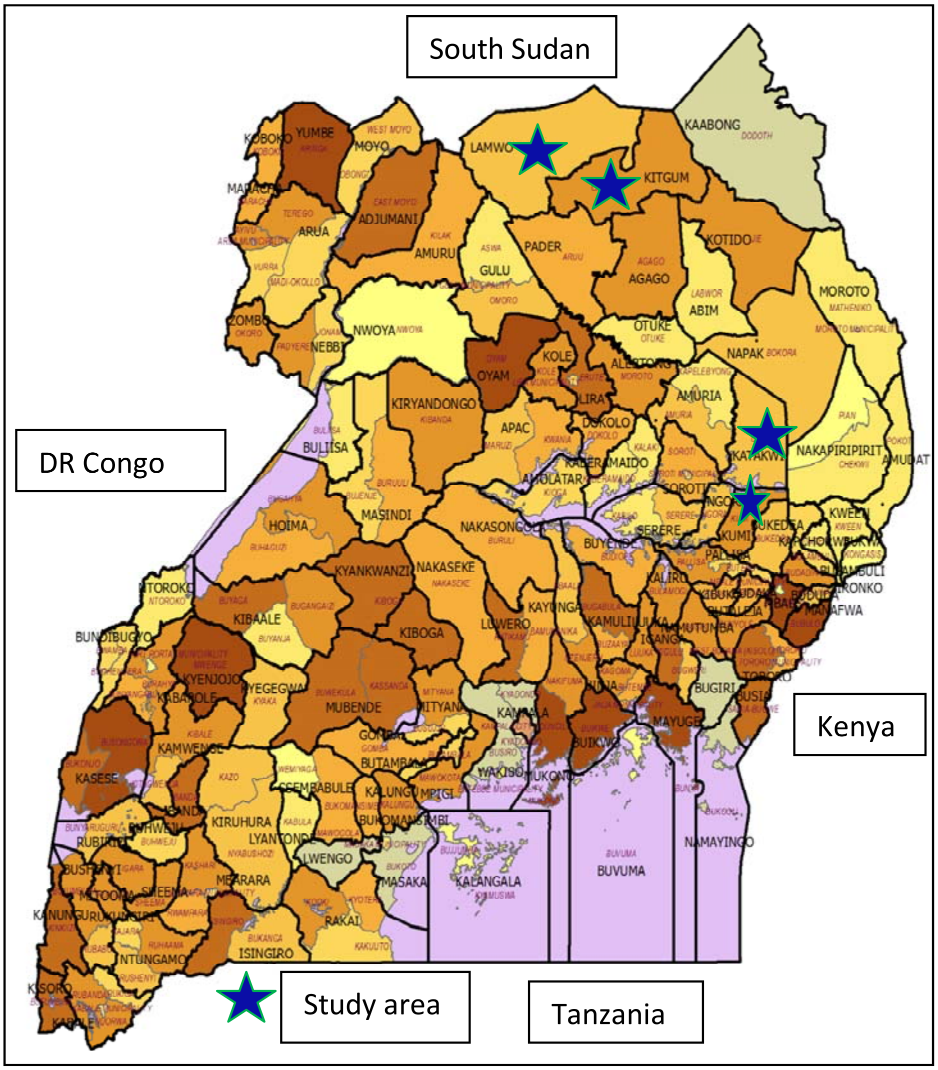

Figure 1. Map of Uganda showing the study area.

between disease severity and yield. A reduced regression model was developed to identify which disease parameters significantly affected yield. The yield was respondent variable, disease severity and incidence were the fixed effects and the district and region were the random effects of the mixed model analysis.

RESULTS

Demographic data about the age of the household head were collected and it was observed that the average age of the household heads was 47.85 years and the majority were in the range of 21-50 years old. In addition farmers were asked about the uses/importance of pearl millet in order to establish the significance of the crop to the farmers and results showed that most farmers cultivated pearl millet for food consumption (43.96%) followed by cash (35.53%) and brewing (17.22%). To a lesser extent some farmers barter the grain (1.47%) for other commodities while <1.00% of the farmers fed grains to poultry.

Disease symptoms and occurrence of ergot (Figure 2), smut (Figure 3), leaf blast (Figure 4) and rust (Figure 5) were observed in eastern and northern Uganda where the survey was conducted. These diseases occurred at different incidence and severity levels in the four districts. Generally, the diseases observed occurred at relatively high incidences of over 61% except for smut (26.76%), exserohilum leaf blight (8%) and cercospora leaf spot (7.5%) (Table 1). Results in Table 1 further show that rust (73.58%) caused by *Puccinia substriata* Ell. & Barth. *indica* Ramachar & Cumm. was the most prevalent disease in all the four districts surveyed followed by ergot (62.98%) caused by *Claviceps fusiformis* Loveless, blast (61.25%) caused by *Pyricularia grisea* (Cke.) Sacc. and smut (26.76%) caused by *Moesziomyces penicillariae* (Bref.) Vanky. The occurrence of rust (64.47 to 77. 15%)

Figure 2. Pearl millet panicle infected by ergot and smut.

Figure 4. Leaf blast.

Figure 3. Pearl millet panicles infected by smut.

Figure 5. Pearl millet rust disease.

was not significantly different (p=0.05) in all the four districts; statistically indicating that rust was distributed to almost the same extent in all the four study districts.

Occurrence of ergot (62.98%) and blast (61.25%) in the two regions was almost the same but significant variation existed within the districts. The ergot incidence

Table 1. Percentage incidences and severities of the common pearl millet diseases.

Region	District	%incidence						%severity						yield (Kg/ha)
		rust	ergot	blast	smut	exser	cerc	blast	ergot	rust	smut	Exser	cerc	
Eastern	Katakwi	77.15	80.92	62.26	28.08	15.00	5.00	67.67	60.15	37.56	17.18	10.00	2.00	484.83
	Kumi	76.78	12.93	29.80	16.34	2.00	0.00	43. 61	6.39	58.93	9.71	1.00	0.00	504.85
Northern	Kitgum	64.47	78.39	68.34	29.45	5.00	10.00	58.05	55.79	16.92	13.66	1.00	1.00	366.81
	Lamwo	75.91	79.68	84.59	33.18	10.00	15.00	64.14	47.68	19.73	19.50	5.00	3.00	514.97
	Mean	73.58	62.98	61.25	26.76	8.00	7.50	62.20	43.33	29.46	14.18	4.25	1.50	467.87
	Pvalue	0.05	0.00	0.00	0.95	0.10	0.07	0.01	0.00	0.03	0.00	0.40	0.68	0.13

Key: exser=exserohilum, cerc=cercospora.

significantly differed in the four districts ranging between 12.93% in Kumi district and 80.92% in Katakwi district. However, except for Kumi where the lowest ergot incidence was recorded, the other districts had almost the same high levels of ergot occurrence (78.39 to 80.92%). This shows that Kitgum, Katakwi and Lamwo can equally serve as hot spot areas for screening materials against ergot. The same trend was observed for leaf blast in all the four districts still there being a significant variation in the occurrence ranging from 29.80% in Kumi district to 84.59% in Lamwo district. Kitgum and Katakwi districts also had high occurrence of leaf blast greater than 62% and can thus also be hot spot areas for material screening against leaf blast. The smut, exserohilum and cercospora occurrences were low and not significantly different in all the four study districts.

Diseases severity significantly differed for blast, rust, ergot and smut but not for exserohilum and cercospora. For the significantly different diseases, leaf blast was the most severe disease (62.20%) followed by ergot (43.33%), rust (29.46%) and smut (14.18%) respectively. The blast severity significantly differed in the four districts with Kumi district having the lowest severity of 43.61% but this was still at above the resistance level of <10% level (Thakur et al., 2009). The ergot severity also differed in all the four districts. Except for Kumi district (6.39%) where farmers' materials were within the resistance range (≤10%), the ergot severity in Katakwi, Kitgum and Lamwo districts was above the susceptible level of ≥30% (Thakur et al., 1989). Both the highest and lowest ergot severities were observed in eastern region although the northern region had relatively high severities above 47%. Rust severity differed in all the four districts (p=0.03) but higher in eastern region (37.56 to 58.93%) than in northern region (16.92 to 19.73%). Kumi district had the highest rust severity of 58.93% although the same district had the lowest severity score for the other diseases. Smut severity (14.18%) was generally low compared with rust, blast, and ergot severity; but significantly differed at district level (9.71 to 19.50%). Still Kumi district had the lowest smut severity and Lamwo district the highest (Table 1). On the contrary, the cercospora and exserhilum severities were lowest of all the diseases with no significant variation in all the districts.

Grain yield did not differ significantly (p=0.13) in all the districts although the lowest and the highest were observed in the northern region. Katakwi and Kitgum districts had relatively low grain yields when compared with Kumi and Lamwo districts. The average yield of 467.87 Kg ha^{-1} observed in the study is very low compared with the potential grain yield of 3000 Kg ha^{-1} realized from research experiments.

The low yield observed was partly due to the combined effect of the observed diseases as shown by the significant regression of yield against disease severity (Table 2) and the negative correlation of yield against the disease severity and incidence (Table 3). The null hypothesis of diseases having no significant effect on yield was tested and results (Table 2) indicate a rejection of the null hypothesis; implying that the major diseases had a significant effect on farmers' grain yield. A backward model reduction was done to establish which model parameters significantly contributed to the tested model. Basing on the adjR2 (Table 2) it was observed that percentage smut incidence, percentage rust incidence, percentage ergot severity, percentage blast severity, and percentage rust severity were the most important parameters in reducing farmers' pearl millet grain yield. The reduced model further shows that generally disease severity was more important than incidence in explaining the low

Table 2. Regression variance of severities and incidences of major diseases on yield.

Source of variation	Sum of Squares	df	Fvalue	Pvalue	%R^2	%adjR^2	Stderror
			Full model				
Regression	3.585	8	2.863	**0.006***	15.70	10.20	0.39563
Residual	19.253	123					
Total	22.838	131					
			Reduced model				
Regression	3.565	6	3.853	**0.001***	15.30	**12.00**	0.39178
Residual	19.273	125					
Total	22.838	131					

*significant at p=0.05. Reduced model parameters; %smut incidence, %rust incidence, %ergot severity, %blast severity, %rust severity.

Table 3. Severity correlations of the common diseases and grain yield.

Variable	Yield	smut severity	blast severity	ergot severity	rust severity	p-value
smut severity	-0.05	1	0.19	0.25	-0.25	0.261
blast severity	-0.11	0.19	1	0.03	0.06	0.104
ergot severity	-0.23	0.25	0.03	1	-0.38	**0.003***
rust severity	-0.06	-0.25	0.06	-0.38	1	**0.045***

*significant at 5%.

grain yield 467.87 Kg ha^{-1} realized by farmers. However, the low adjusted R^2=12.00% accounts for a low percentage of the parameters explaining the model. This may indicate that there may be other factors, not considered in the study, contributing to the observed low grain yield.

DISCUSSION

The major diseases observed in pearl millet were leaf blast, leaf rust, ergot and smut. Except leaf blast, the other three diseases were also reported by Girgi et al. (2006) among the major diseases causing severe damage on pearl millet. Leaf blast has emerged as one of the components of the complex organisms that cause blights on pearl millet (Wilson and Hanna, 1992) and the only blights disease that has gained breeding-for-resistance attention (Hanna et al., 1988). Until recently leaf blast was of economic importance in the southern coastal plains of the USA where it affected green forage and digestible dry matter (Wilson and Gates, 1993). However, it has become a serious disease of pearl millet in India (Lukose et al., 2007; Sharma et al., 2013) which is the world's largest producer of the crop (Gupta et al., 2012). It was a widely distributed foliar disease equally found in eastern and northern Uganda. The incidence range (29.80 to 84.59%) observed in locally adapted materials was almost equal to that (20 to 80%) reported on hybrids in India (Rai et al., 2012). In the current study, pearl millet leaf blast had the highest severity range (43.61 to 67.67%) and a non-significant negative correlation (r= -0.11) with yield. However, Wilson and Gates (1993) reported a severity range of 3 to 35% with a significant negative correlation to dry matter yield; confirming that leaf blast actually has a significant effect in reducing pearl millet yield. The high severity and incidence observed may be a combined result of farmers' materials being susceptible and high plant density; as broadcasting was the sole planting method practiced by farmers resulting in high plant density and dense canopy. Wilson and Gates (1993) noted that dense canopy reduces circulation and sunlight penetration, resulting in high moisture retention, a condition promoting the blast pathogen, *Pyricularia grisea*, survival. The leaf blast pathogen has also been reported to have varying pathotypes, those in the USA being different from those in India (Gupta et al., 2012); indicating that studies should be done to identify whether pathotype variation exists in Uganda in order to develop effective resistant material.

Reports about rust show that the disease is widely distributed in countries that grow pearl millet but of low occurrence in the Sahelian zone. Rust has become one of the major pearl millet diseases (Gupta et al., 2012) affecting forage and fodder quality and substantially reducing grain yield (Lakshmana et al., 2010) through reduction of the photosynthetic area of the infected leaves (Wilson et al., 1996). The high rust incidence (73.58%) observed in the pearl millet growing districts covered in the study shows that the disease is also important in Uganda. There being no significant variation in the high rust incidence (p=0.05) indicates that rust was equally distributed and thus important in all the four districts surveyed. The importance is shown by the relatively high average severity (29.46%) and being in the susceptible range (21 to 30%) (Sharma et al., 2009; Wilson et al., 1996). Rust severity in northern Uganda was within the moderately susceptible range (11 to 20%) while in the east farmers' materials were highly susceptible (>30%) based on the Sharma et al. (2009) description of rust reaction. The variation in severity may be attributed to variation in the environmental factors like time of planting and the variation in resistance level in the germplasm planted by the farmers. Pearl millet being a late planted crop in Uganda and rust also being severe late in the season, the crop growth and development coincides with high level of rust prevalence. This may explain the high severity and incidences in all the pearl millet growing fields surveyed; disease progress being checked only by inherent resistance.

Ergot, also a widely distributed pearl millet disease in Africa, but of no importance in other continents like America, was another common disease with direct negative correlation to yield. The presence of ergot in Uganda was first reported in the early 1980s (Rachie and Majmudar, 1980) and since then no studies about this disease have been reported in Uganda but in Ghana ergot was reported as one of the most important diseases causing considerable pearl millet yield loss (Nutsugah et al., 2006). The wide spread and severity of ergot observed in Uganda calls for immediate action due to the health risk of producing alkaloids that cause ergotism in humans and other animals that consume contaminated grains (Thakur and King, 1988). This study showed that ergot occurred in northern and eastern Uganda with high incidence (62.98%) and severity (43.33%) except Kumi district. Thus, all the three districts can serve as hot spots for screening materials against ergot in Uganda. The high levels in addition to its health hazards make it a dangerous disease for the pearl millet consumers in Uganda.

Smut is also a widely distributed panicle disease which was identified during the current study but information about the disease in Uganda is scanty. Wilson (1995) reported that smut infects pearl millet when sporidia suspended in rain water or dew infiltrates in to the boot. Though smut occurred at low incidence and severity in the farmers' fields compared with other diseases, the rate was generally above the 10% severity level described for materials as being resistant (Rai and Thakur, 1996). This makes it a potential threat to causing epidemics (Wilson et al., 1990). Thus attention should also be put on smut when screening for resistance to other diseases. Fortunately, screening for smut can be done concurrently with that of ergot as studies done by Rai and Thakur (1995) showed that smut resistant lines were also resistant to ergot.

Other diseases occurring at very low frequencies from the pearl millet were Cercospora leaf spot, and Exserohilum spp. The observed low frequencies of these fungi may be due to the plant growth stage at which the study was done. Wilson (2002) observed a change in the frequencies and type of fungi that infected the pearl millet from boot stage to hard dough stage. Note should be made that downy mildew and striga, some of the most destructive constraints of pearl millet (Kumar and Manga, 2010) reported in the horn of Africa (Esele, 2002) were not observed in any of the 140 fields surveyed.

Conclusion

The study results show that ergot, rust, leaf blast and smut are the major pearl millet diseases in Uganda and thus research should focus on these diseases especially ergot, leaf blast and rust. The results also show that downy mildew and striga spp are not important pearl millet production constraints in Uganda since they were not identified in any of the one hundred and forty pearl millet fields visited. Among the panicle diseases much focus should be on ergot due to its high incidence and severity and the health risk it poses in producing alkaloids that cause ergotism in humans and animals; whereas for the foliar diseases focus should be on rust due to its direct effect on forage and grain yields. Kumi district had very low disease incidence and severity except for rust; making it a hot spot for screening materials against rust. The ergot, blast and smut can be screened in Katakwi, Kitgum and Lamwo districts except Kumi.

Conflict of Interest

The authors have not declared any conflict of interest.

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Morphophysiological characteristics of maize inoculated with *Azospirillum brasilense* and *Herbaspirillum seropedicae* as seed treatment, cultivated in different types of soil

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This work aimed to evaluate the morphological characteristics of maize inoculated with *Azospirillum brasilense* (AbV5) and *Herbaspirillum seropedicae* (SmR1) by seeds treatment, grown in four different types of soil from the Western region of Paraná. The experiment was conducted in a greenhouse at State University of Western Paraná. The used experimental design was a randomized block, in factorial scheme 4x4, with four replications. The first factor is related to the bacteria, with the treatments: without inoculation; AbV5, *A. brasilense;* SmR1, *H. seropedicae*; mix with the two strains. The used soils were from the horizon A, ranked as Dystric Acrisol, Eutric Umbrisol, Eutric Ferralsol and a Eutric Acrisol. The experiment was conducted until the 30 days after emergence (DAE), when plants were collected for the following biometric evaluations: leaf area, root volume and dry mass of culm, leafs and root, calculus of the total dry mass and the quotient between root system and shoot system mass. After, root volume, root density, relative level of chlorophyll in leafs, by SPAD and level of protein in leafs was determined. No significant effect was found from the inoculation of the strains AbV5 and SmR1 for the biometric and biochemical variables evaluated for the 'hybrid corn DKB 390', grown until 30 DAE. The corn plants showed lesser development when cultivated in land from the horizon A of the Eutric Umbrisol. More studies are necessary with the objective of investigating the existing relations between the strains of biological nitrogen fixation (BNF) and genotypes of corn, seeking to decrease the necessity of nitrogen fertilization in corn culture.

Key words: Nitrogen, *Zea mays* L. biological fixation of nitrogen, soil.

INTRODUCTION

The corn (*Zea mays* L.) is an important product in the global market. In Brazil, the productivity in 2011/2012 crop was estimated in 4,400 kg ha^{-1} (Conab, 2012). However, projections point out a significant increment in the use of nitrogen fertilizers (Hungria, 2011). But, high costs associated with the dependence of these fertilizers do not allow the obtaining of higher productions, because a subtle reduction can limit the production, once that it act directly in the vegetal metabolism as the biosynthesis of organic compounds (Taiz and Zeiger, 2010).

Beyond of nitrogen, other limiting factor is the quality of the soil, comprehended with the balance between geological, hydrological, chemical, physical and biological conditions (Zilli et al., 2003). Between these factors of soil formation, it can be placed in evidence: origin material, clime, topography, time of microorganisms biological activity (Bertoni and Neto, 1996). According to Silva et al. (1999), the brazilian soils in the most, present a higher degree of weathering, higher acidity and low nutritional availability, what is directly related to the interaction between plant and microorganisms. Ashraf et al. (2013) highlight the promotion of plant growth and sustainability provided with the use of rhizobacteria.

The Paraná state stands out for presenting a large diversity of soils (Embrapa, 2006). However, are basically few comparative investigations about the real performance of a culture with respect to the interaction of the different classes of soil with the presence of microorganisms. Many diastrophic bacteria which live in the roots of some plants, also denominated as rhizobacteria, are promoters of the vegetal grow (RBPC) (Olivares et al, 1996). This process was observed in some maize plants, where an increment was verified not only by biological nitrogen fixation (BNF) (Hungria, 2011), but also by phytoregulator (Kuss et al., 2007). These bacteria can stimulate or produce phytoregulators (Baldani and Baldani, 2005). Between many RBPC isolated in corn, the species *Azospirillum brasilense* and *Herbaspirillum seropedicae* (Radwan et al., 2004; Mendonça et al., 2006; Pedrinho et al., 2010) can be highlighted. Patil (2014) emphasizes increased productivity in grasses when using *Azospirillum.* The distribution of the bacteria from the gender *Azospirillum* is very large, being found in different ecosystems (Marin et al., 1999; Hungria, 2011). Their population density varies depending on its interaction with the genotype of plant or with environmental factors (Cardoso et al., 2010). These bacteria can be categorized as facultative endophytes, propagating in the hosts or surviving in the soil in the cist form (Bashan and Holguin, 1997).

Distinctly, the bacteria from the gender *H. seropedicae* are considered obligatory endophytes, presenting very low survival taxes in soil (Olivares et al., 1996). Also present low specificity with hosts, being their association with the biological nitrogen fixation (BNF) more frequent with gramineous (Baldani et al., 1992). According to Pedrosa et al. (2011), these bacteria have the capacity of colonize the interior of tissues in very important cultures like corn. These microorganisms also present a larger capacity of tolerate drastic alterations of the environment pH (5.3 to 8.0), being also the enzyme nitrogenize is less affected by the presence of oxygen when compared with other bacteria. In this way, this work aimed to evaluate the morphophysiological characteristics of corn inoculated with *A. brasilense* (AbV5) and *H. seropedicae* (SmR1) by seeds treatment, cultivated in vases with soil from horizon A from four different classes, common in the western Paraná region.

MATERIALS AND METHODS

The experiment was performed in November of 2009, in a greenhouse, in the Horticulture Station and Biological Control of the State University of Western Paraná, *Campus* Marechal Cândido Rondon, Brazil. The station is located in the coordinates of 54° 22' W, 24° 46' S with mean altitude of 420 m. The vegetal material used was the hybrid single cross DKB 390, considered precocious, requiring 870 thermal units for the female flowering. The soils used were characterized as Dystric Acrisol, Eutric Umbrisol, Eutric Ferralsol and Eutric Acrisol (Table 1). Samples were collected in the layers of 0-20 and 20-40 cm for the chemical characterization (Embrapa, 1999). The physical characterization involved the particle size analysis by the volumetric flask method (Blake and Hartge, 1986).

The experiment had the duration of 30 days after emergence (DAE), being adopted the experiment design of randomized blocks in factorial scheme 4x4, with four replications. The first factor was the four classes of soil (Dystric Acrisol, Eutric Umbrisol, Eutric Ferralsol and Eutric Acrisol), and the second factor was the inoculation of corn seeds with the strains (*A. brasilense* (AbV5), and *H. seropedicae* (SmR1)), association with the two species and control with no inoculation). The fertilization was without nitrogen and was the same for all treatments, with the fertilizer dose calculated by bases saturation method (Álvares et al., 1999).

The inoculation of the seeds was performed with a concentration of 2.0 x 10^8 colony-forming unit (CFU) by seed. Regarding the strains of *A. brasilense* and *H. seropedicae*, these were provided by the laboratory of Biochemistry and Molecular Biology, UFPR of Curitiba. After the inoculation the seeds were maintained in the shadow for two hours. The sowing was performed manually, six units per vase, 5.0 cm of deep, keeping two plants per vase after germination. Each experiment parcel was constituted by a vase (8 L of volume), containing two corn plants, totalizing 64 vases. The insects control and the irrigation were performed according to the culture necessity. For the evaluation of the number of leafs (NL), SPAD index (SPAD), length of culm (LC), culm diameter (CD), total leaf area (LA) root volume (RV), root density (RD), dry mass of shoot system (DMSS) and dry mass of root system (DMRS), at the end of 30 days after emergence, the two plants of each experimental unit were harvested. The NL was defined as the total number of leafs with the blade fully expanded.

The SPAD index was obtained using mobile SPAD (SPAD-502 Minolta, Osaka, Japan). The CD was determine with a graduated ruler in mm, from the base of the plant until the last node of the plant stem, measured with a digital caliper rule in the plant base. For the obtaining of LA a portable area meter was used (LI-3000, Li-Cor, Lincoln, USA). After the washing of the plant parts, the RV and the RD were obtained in a graduated cylinder of 100 ml. After that, for the obtaining of the DMSS and DMRS, the part plants were

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Table 1. Class, origin material, location, physicochemical analysis of different soils from the Western Region of Paraná State.

Class	Location [1]	GG [2]	GF [3]	Lithology
Eutric Ferralsol	Marechal Cândido Rondon	São Bento	Serra Geral	Basatl
Dystric Acrisol	Palotina	Bauru	Caiuá	Sandstome
Eutric Acrisol	Marechal Cândido Rondon	São Bento	Serra Geral	Basatl
Eutric Umbrisol	Marechal Cândido Rondon	São Bento	Serra Geral	Basatl

Class	pH [4]	P	K^+	Ca^{2+}	Mg^{2+}	Al^{+3}	CTC [5]	V [6]	MO [7]	Sand	Silt	Clay
		---mg dm^{-3}---	-------------cmol$_c$ dm^{-3}----------					----%---	-----------------g kg^{-1}-----------------			
Eutric Ferralsol	4.73	20.44	0.20	2.99	1.77	0.40	10.38	50.78	15.04	88.4	9.2	902.4
Dystric Acrisol	5.85	69.91	0.19	1.87	0.86	0.00	5.43	48.71	10.25	893.6	20.0	86.4
Eutric Acrisol	4.87	11.90	0.61	4.37	1.98	0.30	12.31	56.54	25.97	155.0	142.6	702.4
Eutric Umbrisol	5.44	13.29	0.22	6.19	2.67	0.00	14.30	63.50	21.19	181.8	182.8	635.4

[1] City which was collected; [2] Geological Group; [3] Geological Formation; [4] pH in $CaCl_2$ 0,01 mol L^{-1}; P e K^+ (Mehlich-1), Ca^{2+}, Mg^{2+} e Al^{3+} (KCl 1 mol L^{-1}); [5] CEC a pH 7,0; [6] V % (bases saturation); [7] Organic matter (Walkley and Black method).

Table 2. Variance analysis for SAPD, Proteins (PROT), Length of Culm (LC), Culm Diameter (CD), Number of Leafs (NL), Root Volume (RV), Root Density (RD), Dry Mass of Root System (DMRS), Dry Mass of Culm (DMC), Dry Mass of Leafs (DML), Total Dry Mass (TDM), Quotient of Root system / Shoot system (QRS) of corn cultivated in different classes of soil and inoculated with *Azospirillum brasilense* and *Herbaspirillum seropedicae*.

FV	MS						
	DF	SPAD	PROT	LC	CD	NL	RV
Block	3	89.29	0.0003	146.39	17.84	4.18	1870.10
Soils (S)	3	100.16*	0.0001	16.20	45.29**	7.22	20945.20**
Strains (ST)	3	4.17	0.0002	3.72	7.64	9.77	9.28.50
S x ST	9	25.88	0.0001	61.58	8.60	5.99	1838.50
Residue	45	33.04	0.0001	69.84	10.67	6.32	2330.70
CV (%)		22.24	40.95	20.94	31.33	22.79	38.50

FV	MS						
	DF	RD	DMRS	DMC	DML	TDM	QRS
Block	3	0.001	83.77	19.58	13.99	58.97	0.127
Soils (S)	3	0.021	2626.39**	63.71	60.76	243.02**	4.058**
Strains (ST)	3	0.002	120.62	10.41	1.22	18.60	0.288
S x ST	9	0.001	67.37	4.59	5.63	18.75	0.122
Residue	45	0.003	248.25	11.91	10.86	43.52	0.346
CV (%)		42.79	77.76	34.21	32.32	32.519	43.30

** Significant at 1% e * Significant at 5%.

placed in paper bags and inside a drier of forced circulation air at 60°C for 72 h. Thereafter it was calculated the quotient between DMRS and DMSS. The protein and nitrogen level was determined by Watt and Merril (1975). All the data were submitted to variance analysis, using the F test (P≤ 0.05). The statistical analyses were performed using the computer program Sisvar (Ferreira, 2010).

RESULTS AND DISCUSSION

There were not found significant interactions (P> 0.05) between soil types and strains in corn hybrid DKB 390 grown in vases until 30 days after seeding (DAS), in the absence of fertilization for the studied variables (Table 2). In the same way, the decomposition of the interaction in soil classes in function of the strains did not presented significant differences (P> 0.05) for none of the evaluated variables to strains. Araújo et al. (2014) conducted under controlled conditions of greenhouse were measured at 35 days after plant emergence and obtained the biometric variables were higher with inoculation of *H. seropedicae* in seeds of corn hybrids cultivated in Oxisoil with 650 g kg^{-1} of clay with different results in stem diameter and

Table 3. Culm Diameter (CD), Root Volume (RV), Dry Mass of Root System (DMRS), Root Density (RD), Quotient of Shoot system / Root system (QRS), Dry Mass of Culm (DMC), Dry Mass of Leafs (DML), Total Dry Mass (TDM) and SPAD of corn plants inoculated with the strains *A. brasilense* and H. *seropedicae* by seeds treatment, and cultivated in different classes of soil. Unioeste, Marechal Candido Rondon – PR, Brazil, 2010.

Soils	CD	RV	DMRS	RD	QRS	DMC	DML	TDM	SPAD
	(mm)	(cm^3)	(g)	(g cm^{-3})	(g g^{-1})	--------------	(g)	---------------	
Eutric Ferralsol	15.81 [ab]	106.88 [b]	15.05 [b]	0.13 [b]	1.61 [ab]	10.54 [a]	9.77 [ab]	20.32 [ab]	25.50 [ab]
Dystric Acrisol	17.13 [a]	112.19 [b]	12.85 [b]	0.11 [b]	1.92 [a]	11.29 [a]	11.44 [a]	22.73 [a]	28.06 [a]
Eutric Acrisol	15.20 [ab]	179.38 [a]	39.43 [a]	0.19 [a]	0.74 [c]	11.37 [a]	11.93 [a]	23.30 [a]	27.36 [ab]
Eutric Umbrisol	13.09 [b]	103.13 [b]	13.70 [b]	0.12 [b]	1.28 [bc]	7.14 [b]	7.62 [b]	14.76 [b]	22.46 [b]
Strains									
Control	17.13	123.75	19.94	0.13	1.32	10.15	10.19	20.35	25.96
AbV5 [(1)]	13.09	118.44	19.46	0.13	1.58	10.21	10.32	20.54	25.10
SmR1[(2)]	15.81	136.25	24.08	0.15	1.27	10.96	10.44	21.41	26.24
(1 + 2)	15.20	123.13	17.56	0.12	1.38	9.01	9.80	18.82	26.07
CV (%)	21.33	22.79	77.76	42.79	42.30	34.21	32.32	32.51	22.24

Means followed by the same letter don not differ statistically by Tukey Test ($P<0.05$); AbV5 = *A. brasilense;* SmR1= *H. seropedicae.*

shoot nitrogen content in simple hybrid P3646H, triple hybrid BRS3035 and double hybrid Maximus. Quadros et al. (2014) detected different responses to test *Azospirillum* in corn hybrids, low interference was observed in the biometric variables at the beginning of crop development, especially increased dry matter yield for AS 1575 and SH5050 hybrid; higher thousand grain weight with P32R48; greater plant height with AS 1575.

The obtained results demonstrate that the presence of these microorganisms in the tested conditions did not affect the initial development of the plants during the evaluation period, independent of the soil class used. This response indicates that the two strains do not have effectiveness in the inoculation of corn plants of hybrid DKB 390. The microorganisms showed a great potential *in vitro*, however, the expression of its benefits in the field is still unpredictable and many times disappointing (Hungia, 2011). According to the same author, many are the factors that can interfere in the activity of the interaction between bacterial-soil-plant as biotic and abiotic factors. What is one of the primary factors for the success of the inoculation with these bacteria, acting constantly in the selection of strains in different habitats (Baldani and Baldani, 2005). However, in Brazil, there are not many studies which give emphasis the interactions between the genotypes of corn, nitrogen and bacteria which promote the growing (Moreira et al., 2010) and in different soils.

For Ikeda (2010), the plant response time to the inoculation, independently of the strain, may or not contribute for a better development of the plants. Other important aspect to be considered is the survival percentage of the bacteria after the inoculation, because this is a main question that still need to be solved in future studies relating the association of bacteria which promote growing and gramineous species.

By the biometrical variables analysis for the effect of soil classes, it was observed that, a significant increase ($P> 0.05$), in the culm diameter of the plants cultivated in the Dystric Acrisol, when compared to those plants cultivated in the Eutric Umbrisol at 30 DAS (Table 2). These results corroborate with the one obtained by Murtadha et al. (1989), which concluded that the culm diameter of the corn plants can be influenced by the class of soil.

Corn plants cultivated in the Eutric Acrisol, regardless of the inoculation presented a higher development of the root system (volume of roots, dry mass of root and root density), in relation to the other treatments (Table 3). It is possible that the chemical condition of the soil may have been favorable to the radicular development, favoring the expression of the bacteria potential, since that the Eutric Acrisol presented higher levels of V%, just as higher CTC, as seen in Table 1. The inferior means obtained for the other treatments can be related to the higher level of sand in the Dystric Acrisol, to the lower deep and to the limiting physical characteristics in the Eutric Umbrisol, such as the higher level of clay (90%) in the Eutric Ferralsol (Table 1). Obtaining plants with a better initial development is fundamental, because this better development provides a more developed root system, mainly in the maturation stage, which can provide a better water and nutrient absorption and contribute for a higher final production (Taiz and Zeiger, 2010). In this way, Pereira et al. (2003) relate that corn plants which were maintained without hydric restriction have remained with a higher level of water in the leafs, providing higher photosynthetic rates and higher production of photoassimilates by the plant. Different results were obtained by Cavallet et al. (2000), when inoculating *A. brasilense* spp in seeds of corn G-159 S.

Meanwhile the development of the shoot system (dry mass of culm, dry mass of leaf, quotient “root system/shot system”), of the corn plants cultivated in the Dystric Acrisol showed significantly superior from those cultivated in the soil Eutric Umbrisol (Table 3). In the same way, the total dry mass of plants cultivated in the Dystric Acrisol and Eutric Acrisol were superior from those cultivated in the soil Eutric Umbrisol.

The SPAD in the plants cultivated in the Eutric Umbrisol were lower to those obtained in the soil Dystric Acrisol (Table 3). The obtained results in relation to the quotient between “root system/shoot system”, show that plants cultivated in the Dystric Acrisol were higher than those cultivated in the Eutric Umbrisol and Eutric Acrisol. The obtained values for this variable can indicate a better radicular development when compared to the shoot system of the plant, indicating, according to Bassoi et al. (1994), that the growing of the root system of corn is conditioned by chemical, physical and biological factors of the soil.

Meanwhile the SAPD rates can reflect the relative rates of chlorophyll in the leafs, which allow inferences about the plant potential in producing photoassimilates in function of the variation of the photosynthetic rate of the leafs, which tends to be superior in leafs with higher levels of chlorophyll.

In general, it is worth mentioning the lack of response in this test inoculation of diastrophic bacteria in corn seed (DKB 390) and the different responses for the development of plants due to the soil class. Although, other studies must be proposed seeking to investigate the interaction between genotypes of corn and strains, taking in consideration the possibility of the partial substitution of the nitrogen fertilization, what would be very useful for a more sustainable and economic agriculture.

Conclusions

By the obtained results and the experimental conditions of this study it can be concluded that the inoculation of corn seeds (DKB 390) with the diastrophic bacteria *A. brasilense* AbV5 and *H. seropedicae* SmR1 in the absence of nitrogen fertilization did not presented higher development hybrid DKB 390 of corn plants cultivated in vases until 30 days after sowing. Corn plants (hybrid DKB 390), presented lower development when cultivated in vase conditions with soil from horizon A, from a Eutric Umbrisol. More studies are necessary with the objective of investigating the existing relations between the strains of biological nitrogen fixation (BNF) and genotypes of corn, seeking to decrease the necessity of nitrogen fertilization in corn culture.

Conflict of Interest

The authors have not declared any conflict of interest.

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Study on diversity of *Phaseolus* spp. landraces with reference to global climate change

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The purpose of this study was to investigate the differences between *Phaseolus vulgaris* landraces and to determine their adaptation to local climatic conditions to enrich the genetic diversity of the collection of the Institute of Plant Genetic Resources (IPGR), Sadovo with original plant material better adapted to current climatic changes. The study was performed in four different geographical regions of Bulgaria (Troyan, Smilyan, Velingrad and Sadovo) with six traditional *P. vulgaris* landraces. It was demonstrated that genotype was a more dominant influence on morphological characteristics of landraces than climatic factors or genotype/environment interaction. Differences in the reaction of separate genotypes to fluctuations in meteorological conditions were established based on agro-climatic indices. Tolerance of the studied genotypes to drought was assessed using physiological indices. Accession A9E1270 had the best indices and high adaptability. The influence of meteorological conditions on its growth rate during all interphase periods, even under drought conditions, was insignificant, and its biological specifications had a determining role. A9E1206, A9E1211 and A9E1259 were identified as potential candidates; the quantity of rainfall had a strong influence on their development rate, but they developed more quickly under drought conditions.

Key words: Common bean, phenology, morphology, climatic factors, photosynthesis, leaf water potential, drought.

INTRODUCTION

Climate change, connected with global warming, was forecast 20 years ago (IPCC, 2007). It affects all spheres of the economy, particularly agriculture (Schneider et al., 2007). According to Adams et al. (1998), the effect of climate change on agricultural yield varies by crop and by region. Climate change includes higher temperatures, changes in precipitation, and higher atmospheric CO_2 concentrations. Increased temperature leads to reduced yields and quality of many crops. Change in precipitation may benefit different areas by increasing soil moisture, while the reduction of rainfall could have the opposite effect. Higher concentration of CO_2 would result in higher net photosynthetic rates (Cure and Acock, 1986; Allen et al., 1987). The net change in crop yields is determined by

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the balance between these negative and positive direct effects on plant growth and development, and by indirect effects on crop production (Adams et al., 1998). These factors undoubtedly will result in new criteria for crops and regional distribution of cultivars. Flowering, fruit setting and maturity cycle of grain legumes were affected by different stress factors, as well as higher temperature and solar radiation (Munoz-Perea et al., 2006). Singh et al. (2009) reported on the severest and negative adverse effect of the most stressful conditions on seed weight and other seed characteristics of common beans such as seed shape, color, and coat brilliance or shininess. Cultivars not possessing good drought tolerance and better plasticity reduced their reproductive organs (pods and seeds) and other useful associated agronomic traits, thus substantially affecting yield production and quality (Suarez et al., 2008; Vallejo and Kelly, 1998).

P. vulgaris L. were introduced as a crop into Europe by the Spaniards after the discovery of Americas during the 15th century (Westphal, 1974). Common beans are the world's second most important legume crop after soybean, and it is well known that bean pods and seeds are an affordable and inexpensive source of protein, carbohydrates, dietary fiber, starch, minerals and vitamins. The use of common beans declined until a few decades ago, when their use began to be reevaluated for dietary reasons (Sathe, 2002; Mitchell et al., 2009; Zhu et al., 2012). FAO (www.faostat.fao.org 2011) statistics show that world production was approximately 23,250 million tons harvested from 29,211,491 ha. Europe's top common bean producing countries are Poland (34,896 tons), Greece (22,744 tons), Romania (21,351 tons), and Spain (12,952 tons). In Bulgaria the crop occupied an area of 954 ha, from which 1011 tons were produced.

In Europe the diversity of *P. vulgaris* germplasm is the result of adaptation to different agro-climatic and edaphic conditions as well as multiple inputs of material from Andean and Mesoamerican domestication centers (Araya, 2003). People still carry seeds from neighboring and far away regions into Europe and other continents; such unrecorded seed exchange has been occurring since the first visit of Europeans to the Americas (Zeven, 1997). Much unrecorded seed exchange between plant collectors, gardeners, and farmers must have taken place since the first arrival of common bean in Europe.

Common beans are very popular in Bulgaria; they are the most widely used legume in local cuisine, and beans are connected with local traditions and habits, usually based on production (Stoilova and Sabeva , 2006). Due to the good adaptation of common beans to soil types and climatic conditions, and their aesthetic and organoleptic traits, a large number of landraces were differentiated by type of plant, flower, form and size of seeds, as well as economic qualities (Gradinarov, 1939; Genchev and Kiryakov, 2005). Today common beans are widely cultivated in intensive agricultural systems and commercialized mainly in the Dobrudzha plateau, where new varieties displaced the old varieties and landraces. However, throughout the entire country Bulgarian farmers still grow old varieties and traditional landraces in low input agricultural systems, not only for personal consumption but also for sale as niche products or specialties in local markets. Unfortunately, the cultivation of these old varieties and landraces is generally practiced by older farmers, and as a result a large fraction of common bean landraces are endangered by the risk of extinction. Many authors have reported that landraces of many crops are the most threatened category of genetic resources, and are also the primary object of demands for compensation (Hawkes, 1983; Fowler and Mooney, 1990).

The climate in Bulgaria is formed under the influence of complex factors: Geographic (location, altitude and relief), radiation (solar radiation) and circulation (atmospheric circulation and cyclonic activity). Areas with an altitude above 1000 m are characterized by a mountain climate. The mean annual air temperature for the lowland parts of the country is 10 to 12°C. The highest mean monthly air temperatures are 21 to 24°C in July and August. Precipitation is unevenly distributed in the country and changes widely from 500 to 550 mm in the lowlands to 1000 to 1400 mm in places with a mountain climate.

Over the last three to four decades Bulgaria's climate has been changing, which is in accordance with global trends (Kouzmova, 1999; Peev et al., 2000; Peev and Kouzmova, 2001). In the 1990s and 2000s, drought in Southern Bulgaria was very severe, and included the years with the minimum precipitation of the century. With a few exceptions, the mean monthly air temperature deviated positively from the climatic norm and the rainfall-negative deviations in the direction of this reduction. 1994 and 2007 proved to be the warmest years of the 20th century, and 2000 the driest one of the 21st century to date.

All these peculiarities in the climate of Bulgaria have an impact on crop productivity and require more detailed study of historical and current agro-climatic conditions and global trends to correctly select appropriate varieties for a specific area.

To evaluate crop candidates for distribution, it is necessary to assess crop structure and cultivar composition based on their reaction to abiotic stress factors. The Institute of Plant Genetic Resources (IPGR) in Sadovo preserves a collection of about 2000 accessions of *P. vulgaris* from different geographical origins. During the last decade an effort was made to collect local landraces and old varieties to characterize, evaluate and preserve them at the IPGR National Genebank.

The objectives of this study were: (i) to study the differences between landraces using morphological and physiological techniques; and (ii) to determine their adaptation to local climatic conditions to enrich the

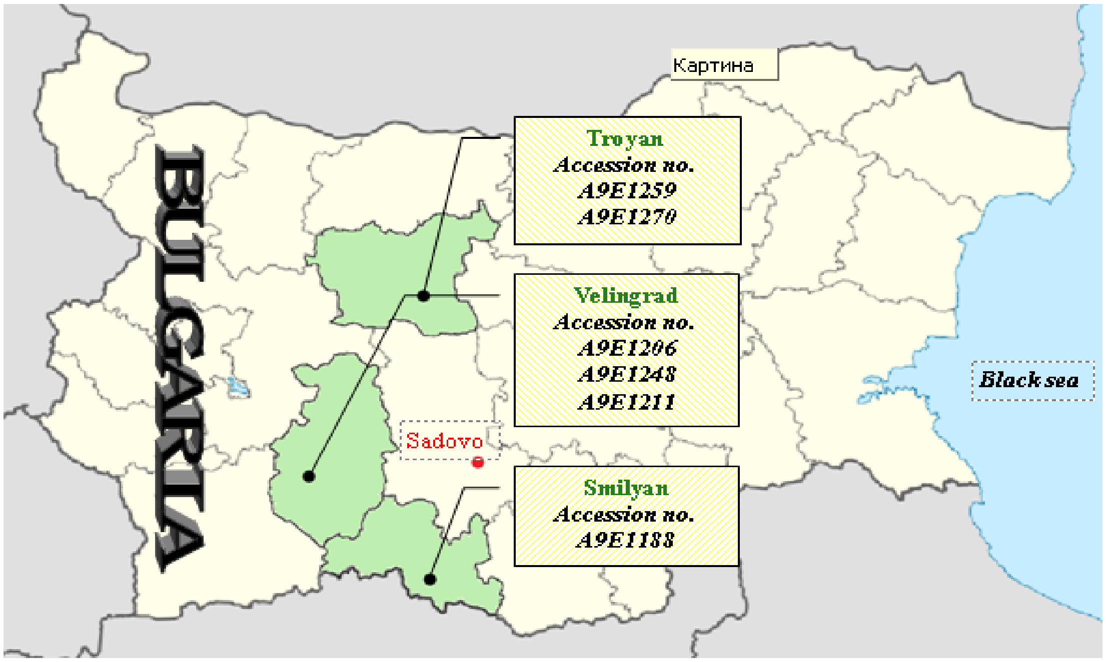

Figure 1. Geographical regions of Bulgaria included in the present study on the diversity of *Phaseolus* spp. landraces with reference to global climate change.

genetic diversity of the *P. vulgaris* collection with plant material, landraces, or primitive varieties of local origin that are better adapted to current climatic changes.

MATERIALS AND METHODS

Plant material

The study was performed in four different geographical regions (Troyan, Smilyan, Velingrad and Sadovo) with different householders and six traditional *P. vulgaris* landraces. These regions were located in the Rhodope and Balkan Mountains at different elevations, as follows: Troyan, 395 m/asl; Smilyan, 1010 m/asl; Velingrad, 745 m/asl and Sadovo, 153 m/asl (Figure 1).
The studied landraces were selected according to their importance, popularity and use in each region. The most traditionally grown bean landraces, still grown by older householders, were chosen. Six accessions were analyzed in this study (Table 1). The selection of the regions was based on previous collecting missions and knowledge that many farmers still used and maintained typical landraces on-farm to meet local market demand for high quality products. A complex morphological characterization was done during three vegetative cycles (2010-2012) (Table 1).

Field trials design

To trace the adaptive capacity of the studied landraces to agro-climatic conditions (especially to drought) two field trials at IPGR were carried out with irrigation and non-irrigated. The irrigated field trial was performed with irrigation once per week with 25 L m^{-3} water. The trials were a randomized complete block design with three replications. Each accession was grown in two row plots; each plot was 3 m^2 in size. In each plot 10 plants and 20 seeds per replication were randomly chosen for biometrics. Complex evaluation and characterization was done according to the International Board for Plant Genetic Resources (IBPGR) Descriptors of *Phaseolus* (1982).

Morphological and physiological evaluation

Observations were made on 11 different agro-biological and morphological characters (Table 2). Physiological analyses (the parameters of the leaf gas exchange - net photosynthesis /P_N/, transpiration intensity /E/, stomatal conductance /g_s/) were performed with a portable photosynthetic system LCA-4 (ADC, Hoddesdon, England). The measurements were conducted in natural environmental conditions. The measurements were made from 10:00 to 14:00, under approximate photosynthetic photon flux density (PPFD) of 1200 to 1900 µmol m^{-2} s^{-1}. Fully developed leaves of the same physiological age (from the middle portion of the shoot) were used for the analyses. The measurements were carried out on ten intact plants of each landrace. Leaf water potential /Ψ_l/ was measured on the same plants as gas exchange using a pressure chamber EL 540-305 (ELE-International Ltd., Hemel Hempstead, England), according to Turner (1988).

Climatic factors

The agro-meteorological conditions were traced in the studied regions by interphase periods. The air temperature and the quantity of rainfall have been taken as main factors, on the basis of which the main agro-climatic indices determining the development rate of the studied bean genotypes were outlined. The hydrothermal coefficient (HTC) was used for assessment of drought and dry conditions (Selyaninov, according to Kouzmova, 2003).

Physiological and climatic adaptation investigations were carried out for a period of two years, 2010 to 2011. During this period

Table 1. Number of accessions included in this study.

No.	Accession No	Status of sample	Geographical Origin	Local name
1	A9E1211	Landraces	Draginovo-Velingrad region	Elenski roga
2	A9E1248	Landraces	Grashevo-Velingrad region	Kadanka
3	A9E1206	Landraces	Kamenitsa-Velingrad region	Maslen bob
4	A9E1259	Landraces	Vrabevo-Troyn region	Byal bob
5	A9E1270	Landraces	Cherni Osam-Troyan region	Naplatar
6	A9E1188	Landraces	Smilyan region	Smilynski bob

Table 2. Quantitative descriptors used in the characterization of common bean landraces.

Morphological characters	Abbreviations	Morphological characters	Abbreviations
Beginning of flowering	BFL	Number of seeds per plant	Ns/s/pl
Flowering duration	FLD	Number of seeds per pod	Ns/s/pod
Days to maturity	DM	100 seed weight	100sw
Plant height	PH	Weight of seeds per plant	w/s/pl
Number of pods per plant	Ns/pod/pl	Yield (g/m^2)	$Y/g/m^2$
Pod length	Pl		

Table 3. Phenological observations of *Phaseolus vulgaris* accessions in Troyan, Velingrad and Smilyan regions with irrigation.

P. vulgaris **accession number**	**BFL ($days^{-1}$)**	**FLD ($days^{-1)}$)**	**DM ($days^{-1}$)**
A9E1211[1]	32.7	40.7	94.3
A9E1248[1]	32.3	39.3	95
A9E1206[1]	32.0	35.7	88.7
A9E1259[2]	32.0	34.3	79.3*
A9E1270[2]	32.7	34.0	82.7*
A9E1188[3]	33.3	42.0	113.3*
Mean Standard	32.5	37.7	92.2
Genotype x Environment %	0.01	28.21	10.6
Genotype's influence %	9.45	37.96	72.1
Environment %	90.53	33.83	17.3
LSD (0.05)	2.79	4.54	9.39

[1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

similar results were observed, thus average data from two reporting years is presented in this paper.

Statistical analyses were carried out by the SPSS-9 program for Windows. The correlation and regression analysis was used for meteorological data processing, with the help of a specially developed Excel program for processing of phenological data (Kouzmova, 2002).

RESULTS

The accessions from different trials needed a different number of days after emergence to enter into the next phase, the beginning of flowering (BFL) (Table 3 to 5). The results obtained showed differences in phenological observations and morphological traits among all accessions from the regional trial and the other two trials carried out at IPGR with and without irrigation (Tables 3 to 8). The longest period from emergence to beginning of flowering was shown by accessions from the experimental field of IPGR without irrigation, as follows: Accession A9E1248 (41 days), A9E1188 (38 days), and A9E1211 (37 days) (Table 5). The duration of the flowering period from the trial without irrigation was the shortest, ranging from 27 to 34.7 days, compared with the other two trials grown with irrigation (Tables 3 and 4). Accessions from the three locations in Troyan, Velingrad and Smilyan regions started the first phenological phase (BFL) after the least number of days, counting from

Table 4. Phenological observations of *P. vulgaris* accessions irrigated trials in Sadovo.

Accession No.	BFL (days^{-1})	FLD (days^{-1})	DM (days^{-1})
A9E1211[1]	33.0	33.2	81.3
A9E1248[1]	33.0	33.2	81.3
A9E1206[1]	30.0	33.0	77.3
A9E1259[2]	32.7	29.5	75.4
A9E1270[2]	39.7*	31.0	89.3
A9E1188[3]	34.7	29.7	81.3
Mean Standard	33.8	31.6	81.0
Genotype x Environment %	0.1	25.1	12.0
Genotype's influence %	7.1	37.5	69.1
Environment %	92.8	37.5	18.9
LSD (0.05)	5.8	3.03	15.45

Seeds from: [1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

Table 5. Phenological observations of *P. vulgaris* accessions in non-irrigated trials in Sadovo.

Accession No	BFL (days^{-1})	FLD (days^{-1})	DM (days^{-1})
A9E1211[1]	37.0	29.0	78.3
A9E1248[1]	41.0*	29.3	77.0
A9E1206[1]	36.7	29.0	77.3
A9E1259[2]	33.0*	29.0	73.3
A9E1270[2]	36.0	34.7	74.3
A9E1188[3]	38.0	27.0	71.3
Mean Standard	37.0	29.7	77.3
Genotype x Environment %	0.013	26.2	9.5
Genotype's influence %	9.5	38.9	70.2
Environment %	90.5	34.9	20.3
LSD (0.05)	2.32	5.35	6.19

Seeds from: [1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

emergence until 50% of flowering plants; the duration of flowering period was the longest, ranging from 34 to 42 days (Table 3).

Results with a significant difference compared with the mean trial value (accepted as a mean standard) were shown only at the beginning of flowering (BFL) by two accessions: A9E1259 and A9E1248 (LSD 0.05) from the non-irrigated trial carried out at IPGR (Table 5). Duration of the flowering stage did not show any significant difference between all accessions in each trial (Tables 3 to 5). The longest period of vegetation and maturity was obtained by landraces in the regional trial, ranging from 79.3 to 113.3 days (Table 3). Accessions A9E1259 and A9E1270 from Troyan reached maturity over the shortest period of time, and A9E1188 from Smilyan had the longest vegetation cycle. These three accessions showed significant differences at the 0.05 level, compared with the mean standard value.

Morphological characters collected from accessions of these three trials showed big differences (Tables 6 to 8). The highest value of plant height was shown by accessions from the regional trial and the tallest accessions were A9E1248 from Velingrad, at 2.2 m with significant difference to the mean value, followed by A9E1188 at 2.0 m from Smilyan (Table 6).

Accessions of the other two trials at IPGR showed different results. The plants' height was shorter, with values between 1.2 and 1.7 m with mean standard value of 1.4 m from the trial with IS, and between 1.1 to 1.3 m with mean standard value of 1.2 m from the trial with NIS (Tables 7 and 8).

The degree of genotype influence on plant height (expressed by percentage) was higher than the other two factors of genotype x environment and environment (Tables 6 to 8). Similar results were obtained for the remaining morphological characters (number of pods per plant, number of seeds per plant, weight of seeds per plant and 100 seed weight). The biggest number of pods per plant were produced by accessions in the regional trial with mean standard of 14.8 pods/plant (Table 6),

Table 6. Morphological characteristics of *P. vulgaris* accessions obtained from Troyan, Velingrad and Smilyan regions with irrigation.

Ph. vulgaris/acc. No	PH (m)	Ns/pod/pl	PL (cm)	Ns/s/pl	Ns/s/pod	100sw (g)	W/s/pl (g)	Y (g m^{-2})
A9E1211[1]	1.9	13.6	13.6	52.5	5.5	67.3	45.7*	196.0*
A9E1248[1]	2.2*	21.2*	15.9	72.1*	5.4	69.3	40.9	207.3*
A9E1206[1]	1.9	10.8	16.8	47.0	5.6	71.4	29.2	158.3
A9E1259[2]	1.6	10.5*	13.5	45.9	5.2	34.4*	20.9*	133.3*
A9E1270[2]	1.8	10.1*	16.5	53.9	5.3	45.5*	28.4	119.7*
A9E1188[3]	2.0	22.7*	13.1	55.7	5.3	76.3*	34.9	176.7
Mean Standard	1.9	14.8	14.0	54.5	5.4	60.69	33.35	165.2
Genotype x Environment %	32.76	0.93	0.64	8.8	0.8	38.24	28.32	13
Genotype's influence %	47.26	76.2	41.1	61.1	30.06	47.45	53.35	77.1
Environment %	18.78	12.9	58.3	30.2	69.14	14.31	18.33	9.9
LSD (0.05)	0.15	4	3.6	11.15	1.49	12.09	7.61	25.75

Seeds from: [1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

Table 7. Morphological characteristics of *P. vulgaris* accessions from irrigated trials in Sadovo.

Ph. vulgaris/acc. No	PH (m)	Ns/pod/pl	PL (cm)	Ns/s/pl.	Ns/s/pod	100sw (g)	W/s/pl (g)	Y (g m^{-2})
A9E1211[1]	1.5	11.3	11.2	37	4.8	49.8	27.5	143.7*
A9E1248[1]	1.5	11.3	11.2	37	4.8	49.8	27.5	143.7*
A9E1206[1]	1.7	9.5	10	23	4.8	38.8	13.4	82.7*
A9E1259[2]	1.2	13.1	10.8	42.2	4.3	36	15.6	145*
A9E1270[2]	1.2	9.8	11	23.2*	5.3	43.8	24.8	94*
A9E1188[3]	1.5	16.7*	12.6	88*	4.9	42.2	24.2	114.6
Mean Standard	1.4	11.9	11.2	41.7	4.8	43.3	22.2	120.2
Genotype x Environment %	27.1	16.7	1.3	15	5.5	31.9	20.2	25.3
Genotype's influence %	51.2	70.1	48.7	50.1	5.6	53.1	42.8	65
Environment %	21.7	13.2	50	34.9	88.9	15	37	9.7
LSD (0.05)	0.38	4.59	2.25	17.38	1.28	7.46	10.68	23.44

Seeds from: [1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

followed by accessions from the IS trial with mean standard of 11.9 pods/plant (Table 7) and the lowest value was recorded with accessions in the NIS trial, with mean standard value of 5.1 pods/plant (Table 8). The same results can be observed by the next important character, number of seeds per plant, with mean standard value of 54.5, 41.7 and 15.1 seeds per plant, respectively. The genotype influence was higher than the environment factor on these two characters, number of pods per plant and number of seeds per plant. The next morphological characters were related to seed size. The weight of seeds per plant, 100 seed weight, as well as seed yield depended mostly on the genotype influence. One hundred seed weight (100 sw) had different mean values, from different irrigated and non-irrigated trials (Tables 6 to 8). Genotype influence in all three trials was 47.45% (Table 6), 53.1% (Table 7) and 45.3% (Table 8) followed by genotype x environment interaction coefficients with values of 38.24, 31.9 and 43.3%, respectively. The highest seed yield production was obtained by A9E1248 with 207.3 g/m^{-2} from a regional trial (Table 6). Four accessions (AE1211, A9E1248, A9E1259 and A9E1270) showed a significant difference at 0.05 level with mean standard value of 165.2 g/m^{-2} (Table 6). The results from the IPGR trials showed higher production from the irrigated trial with mean value of 120.2 g m^{-2} compared with the non-irrigated trial, with a mean standard value of 36.4 g m^{-2} (Tables 7 and 8). The significantly positive difference in seed yield from the irrigated trial was shown by three accessions: A9E1211, A9E1248 and A9E1259 and the significantly lower seed yield by two of them, A9E1206 and A9E1270 (Table 7). The influence of genotype on this character was more dominant than environment factor or genotype x environment interaction in two trials with and without irrigation as shown by related coefficients 77.1, 65.0 and 70.6% (Tables 6 to 8). The correlation and regression dependencies between the development rate in the studied bean samples and the main agro-meteorological factors are shown in Table 9.

Table 8. Morphological characteristics of *P. vulgaris* accessions in non-irrigated trials in Sadovo.

Ph. vulgaris/acc. No	PH (m)	Ns/pod/pl	PL (cm)	Ns/s/pl	Ns/s/pod	100sw (g)	W/s/pl (g)	Y (g/m^{-2})
A9E1211[1]	1.1	6*	10	14.3	4.7	44	4.7	49.5*
A9E1248[1]	1.3	1.5*	8.6	5.0*	2.6	38.6	1.3	25.0
A9E1206[1]	1.2	6.6*	9.0	19.2*	3.6	40.2	8.6	40.3
A9E1259[2]	1.1	9.1*	9.6	27.7*	4.3	33.8*	8.0	37.5
A9E1270[2]	1.2	4.3	8.9	15.9	4.1	44*	5.1	46.5
A9E1188[3]	1.2	3.1	8.4	8.3*	3.4	37.4	2.6	19.5*
Mean Standard	1.2	5.1	9.1	15.1	3.8	39.6	5.0	36.4
Genotype x Environment %	30.8	12.1	0.52	10.2	0.8	43.3	25.6	17.3
Genotype's influence %	48.9	76.5	42	57.8	3.5	45.3	50.1	70.6
Environment %	20.5	11.4	57.5	32.1	95.7	12.2	4.3	12.1
LSD (0.05)	0.29	0.89	1.08	10.83	0.86	1.20	3.09	11.72

Seeds from: [1]Velingrad, [2]Troyan, [3]Smilyan, *the mean difference is significant at the 0.05 level.

Table 9. Correlation and regression relationships on the influence of the main agro-meteorological factors on the rate of development of the studied bean genotypes.

Genotypes	Germination - flowering		Flowering – pod formation		Pod formation - maturing	
	Regression equation of the type y=ax+b	Correlation coefficient (r)	Regression equation of the type y=ax+b	Correlation coefficient (r)	Regression equation of the type y=ax+b	Correlation coefficient (r)
Mean air temperature (t, °C)						
A9E1211	y=0.9806t+13.622	0.2933	y=1.446t-18.872	0.8188	y=-10.401t+303.45	-0.8561
A9E1248	y=-4.3943t+127.25	-0.6602	y=-2.531t+73.71	-0.7851	y=-15.978t+430.43	-0.9447
A9E1206	y=-0.5407t+44.489	-0.2773	y=-2.176t+70.61	-0.3932	y=-10.120t+287.84	-0.8281
A9E1259	y=-2.6129t+92.578	-0.5284	y=0.9096t+4.237	0.2855	y=-8.084t+231.86	-0.6247
A9E1270	y=-0.9905t+57.592	-0.1568	y=-0.028t+16.80	-0.0141	y=-8.8092t+256.38	-0.9341
A9E1188	y=0.5281t+28.48	0.3672	y=-1.475t+43.92	-0.8359	y=-3.0584t+110.24	-0.9786
Sum of precipitations (R, mm)						
A9E1211	y=0.0788R+30.919	0.2674	y=-0.004R+13.1	-0.0224	y=0.2362R+14.103	0.9110
A9E1248	y=-0.069R+41.791	0.1319	y=0.2341R+3.75	0.8769	y=-0.4715R+117.1	-0.3886
A9E1206	y=0.0642R+30.671	0.4420	y=0.1043R+16.6	0.6466	y=0.1063R+26.47	0.3105
A9E1259	y=0.0752R+34.779	0.5796	y=0.107R+11.28	0.4977	y=0.0977R+25.204	0.2482
A9E1270	y=0.0361R+35.3	0.1661	y=0.0413R+14.9	0.2285	y=0.1218R+23.383	0.4352
A9E1188	y=-0.0232R+39.636	0.2263	y=0.2043R+8.97	0.9301	y=0.2436R+8.479	0.8906
Hydrothermal coefficient (H)						
A9E1211	y=-1.8713H+34.634	-0.0906	y=-6.5H+17.21	-0.6406	y=10.822H+32.526	0.2784
A9E1248	y=-23.415H+56.73	-0.7053	y=6.8596H+5.78	0.6896	y=-34.502H+95.756	-0.9606
A9E1206	y=3.1899H+31.399	0.3270	y=5.0828H+16.8	0.5334	y=-7.8744H+49.368	-0.3015
A9E1259	y=4.8236H+35.634	0.4580	y=1.2422H+14.3	0.1855	y=-10.618H+48.339	-0.3718
A9E1270	y=-2.0287H+38.27	-0.1378	y=0.3587H+15.9	0.0616	y=-0.473H+36.213	-0.0173
A9E1188	y=-1.3614H+40.147	-0.3972	y=9.0702H+6.28	0.9418	y=26.097H+2.1505	0.8884

У, Duration of the interphase periods (days); t, average air temperature (°C); R, sum of precipitations (mm); H,Hydrothermal coefficient (HTC); r, correlation coefficient.

During the period from sowing to germination there were no cultivar differences between the separate genotypes (unpublished data). However, in the remaining interphase periods differences in the reaction of the separate genotypes to the fluctuation of meteorological conditions were found. In the period from germination to flowering the air temperature was decisive for the growth rate only in A9E1248, where a strong negative correlation was

Table 10. Gas exchange and water potential (Ψ) in the leaves of common bean (*P. vulgaris*).

Variable	P_N	g_s	E	Ψ_l	P_N/E
A9E1211					
Velingrad (irrigated)	13.55^a	0.11^b	4.30^b	-3.3^a	3.11^a
Exp. field - Sadovo (irrigated)	16.69^b	0.15^b	2.14^{ab}	-3.1^a	7.79^b
Exp. field - Sadovo (non-irrigated)	11.95^a	0.07^a	1.16^a	-3.9^{ab}	10.30^c
A9E1248					
Velingrad (irrigated)	11.45^b	0.14^b	2.11^{ab}	-2.9^a	5.43^{ab}
Exp. field - Sadovo (irrigated)	18.49^c	0.12^b	2.95^{ab}	-3.1^a	6.27^{ab}
Exp. field - Sadovo (non-irrigated)	7.33^a	0.04^a	1.74^a	-5.0^b	4.21^a
A9E1206					
Velingrad (irrigated)	10.91^a	0.14^b	1.51^a	-3.3^a	7.23^{ab}
Exp. field - Sadovo (irrigated)	11.69^{ab}	0.16^b	2.28^{ab}	-3.1^a	5.13^a
Exp. field - Sadovo (non-irrigated)	10.94^a	0.06^a	1.39^a	-4.2^{ab}	7.87^{ab}
A9E1259					
Troyan (irrigated)	14.99^b	0.12^b	1.83^b	-3.0^a	8.19^a
Exp. field - Sadovo (irrigated)	14.52^b	0.15^b	1.87^b	-3.0^a	7.76^a
Exp. field - Sadovo (non-irrigated)	10.28^a	0.04^a	0.94^a	-3.6^{ab}	10.94^b
A9E1270					
Troyan (irrigated)	12.54^b	0.21^b	3.56^b	-3.1^a	3.52^a
Exp. field - Sadovo (irrigated)	10.33^{ab}	0.19^b	3.23^b	-3.6^a	3.20^a
Exp. field - Sadovo (non-irrigated)	9.55^a	0.07^a	1.67^a	-4.2^{ab}	$5,72^b$
A9E1188					
Smilyan (irrigated)	10.22^b	0.11^a	3.40^{ab}	-2.7^a	3.00^b
Exp. field - Sadovo (irrigated)	16.81^c	0.17^a	2.90^a	-3.1^a	5.79^c
Exp. field - Sadovo (non-irrigated)	7.69^a	0.13^a	3.95^{ab}	-4.3^b	1.95^a

P_N, Net photosynthesis (μmol $m^{-2}s^{-1}$); E, transpiration intensity (mmol $m^{-2}s^{-1}$); g_s, stomatal conductance (mol $m^{-2}s$)); P_N/E, water use efficiency; Ψ_l, leaf water potential (MPa)* Within the same column (for each genotype) values flanked by different letters (a, b, c) are significantly different for p=0.05. The results for each experimental field were statistically analyzed using Student's *t*-test then, the fields were compared by One-Way ANOVA using Tukey's test.

established. In A9E1259 both the air temperature and the quantity of rainfall influenced the growth rate, but the accessions developed faster under conditions of drought (Table 9).

In all remaining samples no correlation dependencies between the studied parameters were established. In the period from flowering to bean formation the air temperature and the quantity of rainfall were determining factors on the growth rate of A9E1248 and A9E1188, in which a very close correlation dependency was reported. However, the influence of rainfall on the growth rate of the beans during that period was completely different. A very close correlation dependency was reported in A9E1188 and A9E1211 (Table 9).

The assessment of the tolerance of different genotypes to drought under field conditions is connected with tracing changes in the plants' physiological status in the course of stress impact. The gasometric parameters (photosynthesis and transpiration rate, stomatal conductance) were used as indicators, as well as water regime parameters (predawn water potential) (Blum et al., 1998; Blum, 1999; Vassilev et al., 2010). The effect of drought on the different stages of plant development is reflected in inhibition of photosynthesis and growth, and is associated with changes in carbon and nitrogen metabolism and water exchange (Yordanov et al., 2000; Boutra and Sanders, 2001; Zlatev and Lidon, 2005).

Where dehydration is gradual, the initial decrease in the net photo-assimilation is due to stomatal limitations and at a later stage it is mostly due to mesophilic limitations and structural disturbances of the thylacoid membranes (Lawlor and Cornic, 2000). The applied methodology allows measurement of leaf gas exchange of the landraces traditionally grown in different areas and under controlled conditions at IPGR, Sadovo (Table 10).

Under irrigation the photosynthesis rate (P_N) is higher in landraces grown at Sadovo. The highest values were found in A9E1211, A9E1248 and A9E1188. The intensity of photosynthesis increased by 79.9% on average. The differences between landraces grown in different regions and in Sadovo under irrigation were probably due to different climatic factors and farming practices in the relevant areas. Without irrigation P_N decreased in all tested landraces. The most pronounced inhibition was demonstrated in A9E1188 and A9E1248. The indicated changes in P_N are comparable with those in the intensity of transpiration and stomatal conductivity (with exception of A9E1188). In A9E1211, A9E1259 and A9E1270 the water use efficiency in photosynthesis, expressed through the ratio P_N/E, increased as a result of the stronger inhibition of transpiration, compared with photosynthesis under irrigated conditions. The nature of changes in the parameters of the leaf gas exchange in A9E1248 and A9E1188 determined the decrease in the ratio P_N/E. The results showed that the leaf water potential, which is the main thermodynamic value of water exchange, decreased under non-irrigated conditions. Changes in leaf potential were most probably caused by some structural and functional modifications ensuring the plant's adaptation to drought.

DISCUSSION

The accessions used in this study were representative of observed field trials from each region with different local names and plant habits, pod and seed traits. We were able to select six landraces among 39 observed accessions with great morphological variability as well as different response to stress factors. These results are consistent with Rodino et al. (2006) and Freitas et al. (2011), who studied the morphology of common bean diversity on Madeira Island. They concluded that the accessions showed a high variability of the analyzed morphological characters and this reflects a wide range of environments in which crops evolved.

Plant systems, and hence crop yields, are influenced by many environmental factors, and these factors, such as precipitation and temperature, may act positively or negatively together with other factors in determining yield (Waggoner, 1983).

The results obtained from these samples had a great phenotypic stability and were well adapted to the agro-ecological conditions of the relevant region: Velingrad, Smilyan or Troyan. This adaptation is likely one reason why farmers still prefer to grow traditional landraces and continue to use traditional knowledge and practices. According to Blum (1988), physiological, morphological and phenological criteria could be used to select for improved adaptation to dry environment.

Mean days to maturity for all studied genotypes of the three different trials were similar in the whole experimental period of three years. The mean value of DM for regional field trials was 92.22 days and the longest vegetation period was registered for A9E1188 with 113.3 days (Table 3). There is a chance of mild to severe frost at the beginning of May (start of the growing season) and beginning of October (toward the end of growing season). Therefore, cultivars/landraces with more than 110 to 115 days maturity are under risk of frost during these months. Short-season cultivars/landraces with 95 to 100 days maturity with wide adaptation capacity would be more reliable for bean producers, especially in the Rhodope and Balkan Mountains. The results published by Singh et al. (2009) confirmed the strong emphasis on developing earlier maturing common bean cultivars because of a shorter growing season and less risk of frost at higher altitudes. Large differences for seed yield among six landraces of three different field trials during the studied period were observed. The highest value of mean grain yield was obtained by accessions from regional trials grown under the most favorable edapho-climatic conditions (temperature, precipitation and soil type) using IS with an average yield of production 163.22 g m^{-2} (Table 6). The landraces from regional trials with IS reached a 100 seed weight of 69.69 g, on average. Temperature increases lead to higher transpiration rates, shorter period of seed formation and consequently low production. Similar results can be observed from our research (Tables 7 and 8). The two field trials carried out at IPGR under unfavorable growing conditions with higher temperature and low air humidity during the whole vegetation cycle had lower values for reproductive traits including seed yield production, weight of seeds per plant and 100 seed weight. The plants from IPGR's trial with IS produced 120.2 g m^{-2} and 36.4 g m^{-2} seed yield, much less than the regional trial with IS (Tables 7 and 8). The same trend was registered on weight of number of seeds per plant and 100 seed weight (Tables 6, 7 and 8). The values of 100 seed weight at IPGR's trials with IS and NIS were much less than the first regional trial, at 43.3 and 39.6 g, respectively.

In the separate interphase periods, considerable differences in the reaction of the genotypes to the fluctuations of the meteorological conditions were reported. The air temperature and the quantity of rainfall were decisive for the growth rate, mostly for A9E1248 and A9E1188.

Following the physiological indices it is worth noting that the plants differ in terms of their stomatal role for the maintenance of the functional activity of their photosynthetic apparatus during the periods of drought (Ort et al., 1994). In some plants the stomatal control has a dominant share in the restriction of photosynthesis and they are characterized by increased efficiency of water use in the photosynthesis (P_N/E). In other plants maintaining their stomata "relatively" open due to the fact that they are able to compensate for the loss of water or due to loss of stomatal control, the water use efficiency may remain unchanged or may considerably decrease. Our research places A9E1211, A9E1259 and A9E1270 91-089 in the first group and A9E1188 in the second group.

Conclusions

A9E1270 proved to have the best indices and the highest level of adaptability, since the influence of climatic conditions on the growth rate in all interphase periods was insignificant, even under drought conditions. A9E1206, A9E1211 and A9E1259 also could be potential candidates; the quantity of rainfall had a strong impact on their growth rate, but they developed at an accelerated rate under drought conditions. The worst adaptability to drought and the strongest influence of climatic conditions were attributed to A9E1188 and A9E1248, in which the influence of climatic conditions on the growth rate was very strong, but the growth rate accelerated with the increase in the rainfall and was strongly maintained under drought conditions.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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Impacts of wetland cultivation on plant diversity and soil fertility in South-Bench District, Southwest Ethiopia

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Wetlands provide enormous socioeconomic and environmental values. However, wetlands are threatened by conversion for agricultural land in southwestern Ethiopia. The study aims to assess the impact of wetland cultivation on plant species richness, composition and soil fertility. Plant species richness and composition was investigated for 30 plots in each site of adjacent uncultivated and cultivated wetlands sites and total of 60 sampling plots were used. Soil samples were collected from 18 sample plots (9 in each site) selected using simple random method from plots used for plant survey. The results showed that cultivated sites have significantly higher (P<0.05) species richness, diversity and evenness indices than uncultivated wetlands. Though, this seems positive biological integrity in cultivated site, some ecologically and socioeconomically valuable wetland plant species were lost. Similarity of species (index 30.51%) between two sites was low. Moisture content, clay, organic carbon, total nitrogen, available phosphorous, cation exchange capacity (CEC), exchangeable K^+ and Na^+ were significantly (P<0.05) lower while silt, pH and electric conductivity (EC) were significantly (P<0.05) higher for cultivated site respect to uncultivated site. However, bulk density, sand, exchangeable Mg^{2+} and Ca^{2+} were not significantly (P>0.05) affected. Hence, planning wise use strategy for sustainable management of wetlands is essential.

Key words: Wetland cultivation, species composition, soil physico-chemical properties, South-Bench District.

INTRODUCTION

Wetlands are diverse in types and hence defined differently across the world. The most commonly used definition is that of Ramsar Convention which defines wetlands as ‘areas of marsh, fen, peatlands or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters’ (Ramsar Convention Secretariat, 2011). Wetlands contribute in diverse ways to the livelihoods of millions of people (Rebelo et al., 2010) and providing fundamental ecological services such as food, water, and recreational benefits for the larger catchment population (Ayalew, 2010; McCartney et al., 2010). In recent decades, agricultural use of wetlands has increased significantly in many developing countries, particularly in Africa (McCartney et al., 2010). This

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increase is driven partly by increasing number of population, deterioration of upland soil, economic and financial motivation (Schuyt, 2005) and increasing issues of food security in developing countries (Taiwo, 2013). It also supplements the upland soils where soil productivity and crop yields have declined due to improper land use and management, soil erosion and degradation (Ogban et al., 2011). Though, the continuous use of wetlands for cultivation has the potential to degrade their fragile ecosystems and undermine their capacity to provide ecological services (Morardet et al., 2010).

In Ethiopia, wetlands cover about 2% the total area (13,699 km^2) of the country (Ayalew, 2010). Like other developing countries most of Ethiopian wetlands are under the risk of degradation and loss due to drainage for cultivation, overstocking, offsite and underlying causes related to policy issues (Afework, 2007). Some researchers indicated that, farmers in the country were encouraged and often enforced to drain and convert available wetlands into agricultural land because they are considered as underutilized potential agricultural lands. During the past decade, this trend of wetland conversion during the past decade in the country shows faster increase than ever. For instance, Legesse (2007) reported that in Illu Abba Bora zone the percentage of wetlands converted to agricultural land was 12.7% in 1996 and 65.6% in 2006, which is more than five times within ten years. Besides, many wetland ecosystems are regarded as unproductive and unhealthy ‘wastelands’ with no useful purpose to society or as a source of disease and a threat to public health and they continue to be depleted at an alarming rate throughout the country (Yilma, 2003; Legesse 2007). Dixon and Wood (2003) also showed that many small wetland areas in eastern Africa have been drained for agriculture and now pose a real threat to their continued existence.

Wetland drainage and cultivation have resulted in major impacts on wetland hydrology (Dixon, 2002) which is one of the strongest determinants for wetland vegetative and composition, diversity and for soil (Collins, 2005). Disturbance to wetlands especially from agricultural activity was the causes for elimination of native species and introduction of weedy species due to hydro-period regime shift (Zedler and Kercher 2004; Handa et al., 2012) which generally reduces the value of the wetland for wetland dependent species (Collins, 2005). Besides, an alteration to water regimes has notably affect on wetland dependant species composition and contributed to a loss of wetland biodiversity (Legesse, 2007). Anthropogenic activities such as cultivation also affect self-organization in wetlands and affecting spatial patterns of soil pH, nutrient concentrations and soil organic matter (SOM) content (Cohen et al., 2008). Cultivation also impacted on soil structure, hence lowering the clay content by promoting the disintegration of soil and leading to precipitation of clay particles into lower horizons and increased accumulation of the fine silt particles on surface (Belay and Hunt, 2000; Igué, 2004; Fungai, 2006; Rezaei et al., 2012). Moreover, the loss of biological diversity, changes in soil characteristics and associated impact on ecological services had serious socio-economic impacts (Legesse, 2007).

In southwestern Ethiopia, cultivation of wetlands is increasingly needed due to growing population associated to shortage agricultural land and decline in crop productivity of the uplands. Although understanding the impact of wetland cultivation on plant diversity and soil properties will be the basis for designing strategies and implementation of a sustainable utilization of wetland resources. However, the study on wetlands degradation has not been conducted and the information on southwest Ethiopia is still lacking particularly in the South-Bench district. Therefore, the objective of this study was to assess the impact of wetland cultivation on plant species richness and composition and on some selected soil physico-chemical properties as fertility indicators.

MATERIALS AND METHODS

Descriptions of the Study Site

The study area is located in southwest of Ethiopia and nearly 586 km away from Addis Ababa, the federal capital of Ethiopia. The geographic location of the study area is between 29°23' 13.401" and 29° 41' 37.004" east latitude and between 6° 43' 55.916" and 6°59' 42.775" north longitude. The altitudes range from 1,000 to 2,200 m above sea level with undulating plains and mountains. The area receives annual rainfall of nearly from 1,000 to 1,452 mm and much of it falling during March to November. The mean annual minimum and maximum temperature is18 and 25°C, respectively.

A study wetland, according to Collins (2005), is valley bottom wetlands. The wetland is seasonally flooded and fed by ground water, as well as spring flow around it. A wetland was stratified into two adjacent land uses: Cultivated and uncultivated (pristine wetland). Cultivated site has been used for cultivation of taro (*Colocasia esculenta*) for about nine years. Clearing of native vegetation, burning of vegetation and crop residues, drainage and soil manipulation through hoe was the common farming activities in cultivated wetland site. Agrochemicals (chemical fertilizers, herbicides, etc) were not used by farmers’ for cultivation. Both sites of the wetland have similar slope of almost flat surfaces with gradients of about zero to 2.6%.

Plant sampling and identification

A plant survey was conducted from December 2012 to mid-January 2013. This period was selected because most species was expected to reach at their full growing stage during end of the rainy season in the area. Seven transects intervals were determined systematically at fixed intervals of 160 m across the direction of water flow in each cultivated and uncultivated wetland sites. Along each transect, sample plots were laid systematically at fixed intervals of 15 m. The plot size of 1m×2m (2 m^2) was used for herbaceous and grass while the plot size of 4×4 m (16 m^2) was used for shrubs (Jefferies et al., 2008). Plots were laid after estimating the boundaries of wetland in each site from the upland. For comparison of change in wetland plant composition due to cultivation, sampling plots were entirely placed inside the wetland. Thus, a total of 60 sample plots (30 sampling plots from each site) were used. In each sample plot, all plant species (excluding agronomic species) were recorded and plant specimens were collected for identification. Identification, assignment and nomenclature of the plant species were performed according to the Flora of Ethiopia (Hedberg and Edwards, 1989; Edwards et al., 1995, 1997; Phillips, 1995).

Determination of species diversity and evenness

Shannon and Wiener Diversity index (H') was used to calculate the species diversity to compare the diversity between cultivated and uncultivated wetland sites using the formula (Help et al., 1998):

$$H' = -\sum_{i=1}^{s} Pi \operatorname{Ln} Pi$$

Where: H' = Shannon-Wiener diversity index, s = number of plant species encountered, Pi = n_i/N = relative abundance of each species, n_i = number of individual of a species, N = total number of all individuals of all species. The evenness (E) component of H´ was computed as follows:

$$E = \frac{H'}{\operatorname{Ln}(S)} = \frac{H'}{H'max}$$

Where: E = Evenness; H'max = Ln(S), S= total number of species in the sample. Jaccard coefficient of similarity index (JCS) was used to assess the similarity of plant species composition between cultivated and uncultivated wetland sites using the formula (Kent and Coker, 1992):

$$JCS = \frac{C}{A + B + C} \times 100$$

Where: C = the number of species in common between sites (cultivated and uncultivated site), A = the number of unique species at uncultivated site, B = the number of unique species at cultivated site. The Jaccard coefficient of similarity index value was converted to percentage to show the percentage similarity between two sites (cultivated and uncultivated wetlands)

Soil sampling and laboratory analysis

Eighteen plots (that is, 9 samples from each site) were used for soil sampling. Soil samples were collected using a soil augur from 0 to 30 cm depth. The samples were collected at five points after removing aside vegetation and litter and pulled into one sample. The soil sampling plots were chosen among the plots used for plant sampling using a simple random method. From 7 transects and 30 sample plots used for vegetation survey in each sites, three transects from each site and 3 plots along selected transect were randomly selected for soil sampling (3 transect*3plot*2site=for a total of 18 samples as a whole).

Particle size distribution was determined by the hydrometer method after destroying OM and dispersing the soil. Soil moisture content was determined using Gravimetric method as the ratio of weight of water to weight of oven dry soil (Sahlemedhin and Taye, 2000). Soil bulk density was determined by core method (FAO, 2007) using core sampler and drying it to constant weight in an oven at a temperature of 105°C for 24 h. Soil pH was measured in 1:2.5 pH-H_2O (soil: distilled water) using the glasscalomel combination electrode whereas electric conductivity (EC) by conductivity meter using suspension of 1:2.5 soil: water ratio.

Organic carbon (%OC) was determined using wet combustion methods of Walkley-Black as described by Nelson and Sommers (1982). Total nitrogen (%TN) was measured by using the Kjeldahl method and available phosphorus was determined by Bray method. Total exchangeable bases were determined after leaching soils with ammonium acetate. The exchangeable Ca^{2+} and Mg^{2+} in the extracts was measured using atomic absorption spectrophotometer (AAS) while Na^+ and K^+ by flame photometer. Cation exchange capacity (CEC) of the soil was estimated from ammonium-saturated samples that were subsequently replaced by sodium (Na^+) from by a percolating sodium chloride solution. The excess salt was removed by washing with alcohol and the ammonium that was displaced by sodium was measured by Kjeldahl method (Chapman, 1965).

Data analysis

To know the statistical difference in plant diversity indices and soil physico-chemical properties among plots from cultivated and uncultivated wetlands sites, calculated plant diversity indices and soil physico-chemical properties were analyzed using SPSS version 16.0 software. Independent two sample t-test was used to test whether significance ($P \leq 0.05$) difference in these parameters between cultivated and uncultivated wetland sites exist. Relative change (RC) in soil parameter was computed to compare the change in soil properties due to cultivation as:

$$RC(\%) = \frac{Puc - Pc}{Puc} \times 100$$

Where Puc is the mean value of soil property in uncultivated site and P*c* is the mean of a soil property in cultivated site. Pearson correlation analysis was carried out to determine the relationship between soil parameters. Moreover, Principal Components Analysis (PCA) was used explore the relationship between and within plant species and soil variables.

RESULTS AND DISCUSSION

Species composition

A total of 59 different plant species belonging to 20 families were identified in both cultivated and uncultivated wetland study sites. Higher numbers of species were found in cultivated site (Table 1). In cultivated wetlands 48 species classified as in 19 families and in uncultivated site 29 species belonging to 15 families were identified. From 29 plant species observed in uncultivated site, 28 species were identified as wetland plants and 11 species were exclusively observed in uncultivated site. On other hand, of the 48 species observed in cultivated site, 18 plant species were wetland plant species while 30 species were upland plant species or weedy species. About 80% of the plant communities were solely found in cultivated site.

In the uncultivated site, Cyperaceae was the family with the highest number of plant species (5), followed by the family of Gramineae and Lamiaceae each with 4 species. Besides, Fabaceae and Polygonaceae each of them had with 3 species while the remaining 10 families each had

Table 1. Plants species recorded at uncultivated and cultivated wetland sites with their relative distribution.

Family	Species	Study sites		Species category
		Cultivated	Uncultivated	
Acanthaceae	*Hygrophila schulli* (Hamilt)Almeda v Almeda	+	+	w
Amaranthaceae	*Amaranthus spinosa* L.	+	-	nw
	Achyranthes aspera L.	++	++	w
Apiaceae	*Cenetella asiatica* (L.) Urb	++	+	w
	Hydrocotyle sibthorpioides Lam.	+	-	nw
Balsaminaceaeae	*Impatiens ethiopica*	+	-	nw
Caryophyllaceae	*Cerastium octandrum* Hochst. ex A. Rich.	+	-	nw
	Drymaria cordata (L.) Willd	+	-	nw
Commelinaceae	*Floscopa glomerata* (Willd. ex Schult. & Schult. f.) Hassk	+	+	w
	Commelina lantifolia A.Rich	+	-	nw
	Commelina forskalaei Vahl.	++	-	nw
Compositae	*Galinsoga parviflora* Cav.	+	-	nw
	Sonchus asper(l.) hill	+	-	nw
	Galinsoga quadriradiata Ruiz & Pav	+	-	nw
	Bidens pilosa L.	+	-	nw
	Aqeratum conyzoidesL.	+	-	nw
Convolvulaceae	*Jacquemontia paniculata* (Burm. f.) Hall f.	+	-	nw
	Ipomea cordofana R. Br.	+	-	nw
	Convolvulus arvensis L.	+	-	nw
	Ipomea eroiocarpa R. Br.	+	-	nw
Cyperaceae	*Pycreus elegantulus (Steud.) C.B. Clarke*	-	+	w
	Cyperus flavescent L.	-	+	w
	Cyperus mundtii (Nees)Kunth.	-	+	w
	Fimbrist*ylis dichotoma (L.) Vahl.* ssp. *Sieberiana*	-	+	w
	Mariscus syperoides L.	+	-	nw
	Cyperus latifolius poir	+	++	w
	Cyperus assimilis Steud.	++	-	
Euphorbiaceae	*Phyllanthus boehmii* Pax. var. boehmii	++	++	w
Fabaceae	*Aeschynomene schimperi* Hochst. Ex A.Rich	-	+	w
	Sesbania dummeri E. Phillips &Hutch.	-	+	w
	Aeschynomene abyssinica (A.Rich.)Vatke	+	+	w
Gramineae	*Sacciolepis rigens* (Mez) A. Chev.	-	+	w
	Panicum sp.	+	+	n
	Cynodom dactylon (L.)pers	+	-	nw
	Sacciolepis africana C.E.Hubb. and Snowden	+	+	w
	Echinocloa colona(L.)Link	+	-	nw
	Snowdenia polystachya (Fresen.) Pilg	++	-	nw
	Eragrostis ciliaris(L.) R. Br.	++	-	nw
	Digitaria ternate (A.Rich.) Stapf	++	-	nw
	Oplismenus spp.	++	-	nw
	Digitaria sanguinalis (L.) Scop.	++	-	nw
	Leersia hexandra SW.	++	++	w
Lamiaceae	*Leucas deflexa* Hook f.	-	+	w

Table 1. Contd.

	Plectranthus argentatus (S.T.Blake)	-	+	nw
	Plectranthus punctatus (L.)L Her	+	+	w
	Ajuga remota Benth.	+	+	w
Melastomataceae	*Dissotis canescens* (Graham) Hook. F.	+	++	w
	Antherotoma naudinii Hook.	+	-	nw
Onragraceae	*Luddwigia abyssinica* A.Rich.	+	+	w
	Ludwigia stolonifera *(Guill. & al.) Raven*	+	-	nw
Polygonaceae	*Persicaria glabra* (Wild.) M.Gomez	+	++	w
	Persicaria senegalensis (Meisn.) Sojak	+	+	w
	Polygala petitiana Meisn.	++	+	w
	Rumex abyssinicus Jasq.	++	-	nw
Rubiaceae	*Oldenlandia lancifolia* (Schumach) DC var. scabridula	+	+	w
Solanaceae	*Solanum anguivi* Lam	+	-	nw
Thelypteridaceae	*Thelypteris confluens* (Thunb.) Morton	-	++	w
Tiliaceae	*Triumfetta spp*	-	+	w
	Triumfetta pilosa Roth	+	-	nw

+Represent species with abundance <2% while ++ represent ≥2%; (-): absence, (+): present, (++) dominant, w= wetland plant, nw =non wetland plant (upland plant), n=habitat not identified.

one species (Table 1). In the cultivated site, Gramineae was the family with highest number of plant species which is 10 species followed by Compositae with 5 species, Convolvulaceae and Polygonaceae each with 4 species, Apiaceae and Cyperaceae each with 3 species, Caryophyllaceae, Amaranthaceae, Commelinaceae, Melastomataceae, Onragraceae and Lamiaceae each with 2 species while the rest 7 families each had one species (Table 1). Family Thelypteridaceae was not observed in cultivated site. Furthermore, in cultivated wetlands, the species in family Cyperaceae, Fabaceae and Lamiaceae were decreased because of draining the land for agricultural use while species in families Amaranthaceae, Apiaceae, Balsaminaceaeae, Caryophyllaceae, Commelinaceae, Compositae, Convolvulaceae, Gramineae, Melastomataceae, Onragraceae, Polygonaceae and Solanaceae was increased because of drainage and cultivation created conducive environment for their invasion.

Among plant species in uncultivated site, 7 plant species dominant the plant community with relative abundance more than two percent. These plant species were *Leersia hexandra* (46.35%), *Cyperus latifolius* (23.79%), *Thelypteris confluens* (3.96%), *Phyllanthus boehmii* (3.73%), *Persicaria glabra* (2.71%), *Dissotis canescens* (2.58%) and *Achyranthes aspera* (2.09%). These 7 plant species were accounted for 85.21% of the community while rest 22 species had relative abundance less than 2% which accounted for 14.79%. From 48 plant species, 13 species such as *Commelina forskalaei* (15.6%), *Leersia hexandra* (12.96%), *Digitaria sanguinalis* (12%), *Oplismenus* spp. (9.71%), Digitaria ternate (8.02%), *Cyperus assimilis* (3.54%), *Phyllanthus boehmii* (3.3%), *Rumex abyssinicus* (2.89%), Cenetella asiatica (2.6%), *Eragrostis ciliaris* (2.59%), *Achyranthes aspera* (2.44%), *Snowdenia polystachya* (2.16%) and *Polygala petitiana* (2.11%) with relative abundance more than two percent were accounted for 79.92% of the plant community in cultivated sites of which 56.61% them were upland plant species.

On other hand, wetland plant species such as *Thelypteris confluens, Cyperus mundtii, Leucas deflexa, Cyperus flavescens, Cyperus elegantulus, Sesbania dummeri, Fimbristylis dichotoma, Plectranthus argentatus, Aeschynomene schimperi, Sacciolepis rigens* and *Triumfetta* spp were not observed in cultivated site. The result revealed that other important species such as *Leersia hexandra* and *Cyperus latifolius* were decreased significantly due to cultivation. The local community is using *Cyperus latifolius* for thatching; *Leersia hexandra* for thatching, fodder and plastering; *Aeschynomene abyssinica* and *Sesbania dummeri* for construction and fuel wood; *Triumfetta spp*. for fodder and rope making. Due to conversion of wetland into agricultural lands some of these species are declining and hence the socioeconomic benefits obtained by local community from these plants were significantly reduced. A research report by Dixon (2002) indicated that conversion of natural wetland by drainage and cultivation may be causes for loss of wetland vegetation which area

Table 2. Species diversity measured using transects in uncultivated and cultivated wetland sites.

Parameter	Study wetland sites	
	Uncultivated	Cultivated
Species richness(S)	29	48
Shannon-Wiener diversity(H')	1.90	2.99
Evenness(E)	0.58	0.78
Jaccard's coefficient of similarity (JCS) (%)	30.51	

Table 3. T-test for diversity measured using plot based in uncultivated and cultivated wetland sites.

Parameter	Mean ± Std. deviation		t-test	P-value
	Uncultivated	Cultivated		
Species richness(S)	7.3±1.44	10.33±2.06	-6.61	0.000***
Shannon-Wiener diversity(H')	1.24±0.20	1.85±0.22	-11.45	0.000***
Evenness(E)	0.59±0.09	0.80±0.08	-9.41	0.000***

*** Very highly significant P<0.001.

important to local communities livelihoods.

The Jaccard coefficient of similarity index (30.51%) showed low similarity in plant species composition between cultivated and uncultivated wetland sites. This confirms the change in wetland plant composition and invasion of the wetlands by upland plants species due to wetland drainage and cultivation. Fungai (2006) also observed that cultivation influences community structure and species composition. According to Dixon (2001), disappearance of natural wetland vegetation and invasion of non wetland (upland) vegetation or weedy species is the sign of environmental degradation in wetlands. This is because of the fact that each plant species has a limited tolerance to their habitat requirement. Thus change in composition and loss wetland plant in cultivated site could be change in habitat condition of the wetland or alteration of water regimes by wetland drainage for cultivation (Zerihun and Kumlachew, 2003; Barakagira and Kateyo, 2008; Dube and Chitiga, 2010). Besides, drainage cultivation could cause undesirable environments to the wetland plants and resulted in their disappearance. In line with this, Collins (2005) also reported that the degree of harshness decreased as wetlands were drained for cultivation which could create conducive environments for increasing diversity of upland species in cultivated site and loss/degradation of wetland plants. Temporary the evading species use the opportunity that is why the diversity of cultivated site increased. However, as time goes this situation will change results in decreasing species diversity in cultivated site.

Species diversity and evenness

High species diversity (H') (2.99) and species evenness (E) (0.78) were measured at cultivated site than uncultivated site (H' = 1.9 and E = 0.58) which showed that cultivated site had more number of species and more even distribution of plant species than uncultivated site (Table 2).

The diversity result indicated that cultivated site had significantly higher (P<0.001) mean species richness (10.33) than uncultivated site (7.3) (Table 3). Similarly, cultivated site had also significantly higher (P<0.001) mean species diversity (1.85) than uncultivated (1.24) site. The result of this study is in agreement with Zerihun and Kumlachew (2003) and Handa et al. (2012) where they reported that drainage and the disruption of vegetation creates an increased number of ecological niches or conditions which suit a wider range of plants or favorable environments for the survival of upland plants species to invade the disturbed area. Fungai (2006) also reported that, shortened hydroperiods, the use of fire in land preparation can induce the domination of weedy species in cultivated site. Cultivated site also significantly higher (P<0.001) mean species evenness (0.80) than uncultivated site (0.59). This indicates little dominance but more number of species with few individual per plot in cultivated site. It also showed that cultivated site has more species diversity than uncultivated site (Table 3).

Soil physico-chemical properties

Conversion of wetland into agricultural land may cause the alternation of soils physico-chemical properties which in turn can influence the soil fertility status of a given area. Hence, soil samples collected from the study site at the depth of 0 to 30 cm were analyzed for some selected soil properties. The soil of uncultivated and cultivated site were clayey and clay loamy respectively. The soil contained

Table 4. Soil physical properties of cultivated and uncultivated wetland sites.

Parameter	Mean ± Std. deviation		t-test	P-value	Relative change (%)
	Uncultivated	Cultivated			
%Sand	34.22±5.83	36.11±5.90	-0.68	0.504^{ns}	-5.52
%Clay	49.44±5.50	34.78±8.86	4.22	0.001**	+29.7
%Silt	16.33±3.81	29.11±7.29	-4.66	0.001**	-78.23
Bulk density(g/cm^3)	0.20± 0.043	0.22±0.02	-1.12	0.287^{ns}	-8.84
%soil moisture content (SMC)	15.54±0.24	11.05±0.25	10.08	0.000***	+28.85

***very highly significant P<0.001; **highly significant at P<0.01; * significant at P<0.05; ns = not significant at P>0.05 whereas (-) decrease in soil properties; (+) increase in soil properties from cultivated to uncultivated site.

Table 5. Soil chemical properties of cultivated and uncultivated wetland sites.

Parameter	Mean ± Std. deviation		t-test	P-value	Relative change (%)
	Uncultivated	Cultivated			
pH-H_2O	4.26±0.18	4.49±0.13	-3.17	0.006**	-5.48
Available P(ppm)	3.62±0.46	3.03±0.42	2.81	0.013*	+16.22
%TN	2.31±0.73	1.06±0.23	4.9	0.000***	+54.02
%OC	28.19±5.8	12.33±2.68	7.45	0.000***	+56.26
CEC(meq/100gm)	41.31±11.78	28.19±9.72	2.58	0.021*	+31.77
Mg^{2+}(cmol(+)/kg soil)	3.31±1.66	3.96±1.11	-0.98	0.342^{ns}	-19.67
Ca^{2+} (cmol(+)/kg soil)	26.83±11.28	26.17±9.89	0.13	0.899^{ns}	+2.41
K^+(cmol(+)/kg soil)	0.714±0.17	0.56±0.028	2.58	0.020*	+21.1
Na^+(cmol(+)/kg soil)	0.057±0.03	0.025±0.003	2.91	0.019*	+56.38
EC (dS/m)	0.10±0.01	0.22±0.14	-2.58	0.032*	-120.29

***very highly significant P<0.001; **highly significant at P<0.01; *significant at P<0.05; ns = not significant at P>0.05 (-) decrease in soil properties; (+) increase in soil properties from cultivated to uncultivated site.

acidic in reaction with a pH value ranged from 4.26 to 4.49, and high organic carbon varied from 12 to 28%. The cation exchange capacity (CEC) of the soil also ranged from 28 to 41 meq/100 g in which the dominant cation being Ca^{2+} followed by Mg^{2+} and K^+ was the dominant exchangeable cation (Table 5)

Soil physical properties

Clay and silt content of the soil samples analyzed from uncultivated and cultivated wetland sites were significantly different (P<0.001) while the sand content was not significantly different (P>0.05) (Table 4). Uncultivated site had higher mean value of clay (49.44) than cultivated site (34.78). On the contrary, cultivated site had high mean value of silt (29.11) and sand (36.11) than uncultivated site (silt 16.33, and sand 34.22). The relative change result indicated that clay content of the soil decreased by 29.7% while silt and sand was increased by 78.23 and 5.52% respectively due to change of wetland into cultivated land. The possible reason for this lower content of clay in cultivated site could probably due to the removal of clay soil from surface by erosion and translocation of clay fraction down to a lower horizon. This result are in agreement with the findings of Lgué (2004), Fungai (2006) and Rezaei et al. (2012), in which they reported that cultivation of land cause accumulation of silt and sand particles in upper horizon and high clay content in lower horizon due to translocation of clay fraction from surface layer to subsurface layer. Besides, Igué (2004) and Wakene and Heluf (2004) reported that the removal of clay by accelerated soil erosion (sheet erosion) in rainy season as cultivated site was less vegetation cover and bare during rainy season could be the cause for lower clay content in cultivated site. Similarly, Wakene and Heluf (2004) indicated that clay content can be decreased by land use change as the management practices that may contributed indirectly to the changes in particle size distribution particularly in the surface layers by removal of soil by sheet erosion and mixing up of the surface and the subsurface layers during continuous cultivation.

The mean bulk density of the soil of study sites ranged from 0.20 g/cm^3 (uncultivated wetland) to 0.22 g/cm^3 which is less than the bulk density of mineral soils (fine silt:

1.0 to 1.3 g/cm^3, and sandy soil: 1.3 to 1.7 g/cm^3) (FAO, 2007). This wetland soil has lower bulk densities than mineral upland soil because it was rich in organic matter (OM) and water-saturated. Similar bulk densities were reported, for instance; 0.11 to 0.23 g/cm^3 by Bruland et al. (2003), as low as 0.2 g/cm^3 in the very organic rich soils by Powell (2008). Moreover, Mitsch and Gooselink (2000) indicated that, organic soils (Organic carbon >12-20%) have low bulk density due to high porosity and usually had bulk density of ranging between 0.2 and 0.3 g/cm^3. Otabbong and Fristedt (2005) reported the bulk density lower than 0.12 g/cm^3 in almost entirely not decomposed wetlands soil and 0.27 to 0.35 g/cm^3 in highly decomposed peat soil. This indicated that the level of decomposition of OM had effect on bulk density of wetlands soils.

The t-statistics revealed that bulk densities were not significantly different (P>0.05) in the two sites. The change of organic matter from cultivated to uncultivated wetland was high, though the soil bulk density not changes. This might be due to the variation of bulk density by contribution of tillage practices is higher that organic matter. Farmers in the study wetland used hoes for soil preparation could have insignificant impact on risk of increasing bulk density of the soil in cultivated site. Fungai (2006) and Collins (2005) also reported that tillage by hand had less risk of soil compaction in wetlands soils.

Soil moisture content (SMC) between the cultivated and uncultivated site was significantly different (P<0.001). The mean SMC of uncultivated site was higher (15.54) than cultivated (11.05) site. Relative change in SMC indicated that it was decreased by 28.85% by to cultivation. The higher SMC in the uncultivated sites may be due to the presence of high vegetation cover and high OM of the soil. Correlation result showed there was positive and significant correlation between OC and SMC (r=0.81**). On the other hand, clearing vegetation cover, soil tillage and redaction in organic matter of cultivated wetlands could reduce water holding capacity of cultivated soil. This was similar with the findings of Dube and Chitiga (2011); they showed there was a significant correlation between the amount of total organic carbon and moisture content. In addition, high clay content of uncultivated wetland site may leads to have high water holding capacity. There was positively and significantly correlation between clay and SMC(r=0.744**) which explain the direct relationship between clay and SMC. This result agrees with earlier findings of Fungai (2006) and Powell (2008) who reported that soils with high clay content tend to have high water holding capacity.

Soil chemical properties

Soil pH, organic carbon (OC), total nitrogen (TN) and available phosphorous Soil pH level was significantly different (P<0.01) between the cultivated and uncultivated wetland sites. The mean pH value of cultivated site was higher (4.49) than uncultivated (4.28). Cultivation increased the pH of the soil by 5.48%. The removal of vegetation for cultivation and exposure of soils to wind and sunny could increase aeration and temperatures of the soil may facilitate rapid decomposition of OM and prevents the accumulation of acids and increase in pH in cultivated as indicated by Fungai (2006).

On other hand, the lower pH in uncultivated site could be due to the release of organic acids from organic matter decomposition (Collins, 2005; Dube and Chitiga, 2011; Tariku and Abebayehu, 2011).

Organic carbon (OC) content was significantly different (P<0.001) between cultivated and uncultivated site. The mean of OC content of uncultivated sites was higher (28.19) than that of cultivated (12.33) site. The relative change indicated that OC was decreased by 56.26% due to the conversion of wetland to cultivated land. Similarly, Belay and Hunt (2000), Fungai (2006), Dube and Chitiga (2011), Tariku and Abebayehu (2011), measured low amount of OC in cultivated wetlands. Belay and Hunt (2000) and Zoltán (2008) also indicated that the low OM was due to the rapid decomposition of OM that was facilitated by excessive drainage of wetlands, ploughing of soil for cultivation, low coverage and clearing of vegetation in cultivated site. Besides, decreased in OM inputs to the soil due to burning of plants and crop residues for cultivation (Pantami et al., 2010; Verma and Jayakumar, 2012) and removal crop and plant residues as indicated by Jie et al. (2013) could be the causes for the lower OC content in cultivated wetland. On the contrary, high OC levels in the uncultivated sites could be the reduced decomposition rate as a consequence of less soil residue contact, lower aeration and lower soil temperature (Figure 1).

The total nitrogen content (TN) was significantly different (P<0.001) between cultivated and uncultivated wetland site. A cultivated site was lower (1.06) mean levels of TN than uncultivated site (2.31). TN was increased by 54.02% due to wetland uncultivated (Table 6). The TN contents was positively and significantly correlated with the amount of OC(r = 0.74**) (Table 6). This is obvious reason to expect an increase level of nitrogen content in increased OM content of a soil as OM is essentially the main source of nitrogen (Brady and Weil, 2000). The lower level of TN in cultivated site was because of decrease in litter and vegetation cover, soils preparation and wetland drainage in cultivated site. Moreover, nitrogen can be lost due to crop removal and burning of plant and crop remains in cultivated site. Several works (Burdt, 2003; Zoltán, 2008; Liu et al., 2010; Dube and Chitiga, 2011) also reported similar results that cultivation of wetlands increased soil aeration and temperatures which were the causes for rapid decomposition and mineralization of plant materials and this indirectly lower the content of nitrogen in cultivated site.

The available phosphorous (Av.P) concentration was significantly (P<0.05) different between uncultivated and cultivated sites. Cultivated site was lower (3.03) mean levels of available phosphorous than uncultivated site

Figure 1. Ash added by burning of plants and crop residues during cultivation in cultivated wetland site.

(3.62) sites. It was relatively decreased about 16% due to cultivation. The lower concentration of available phosphorus in cultivated site could be the result of continuous loss of phosphorous through crop harvesting, plant and crop residues removal. On other hand, continuous application OM through litter fall and dying of plant in uncultivated site could increase soil phosphorus availability by decomposition and mineralization of organic phosphorous (OP) and reduce phosphate adsorption in the soil colloids (Yusran, 2010).

Exchangeable bases and CEC

There were significant difference (P<0.05) in exchangeable K^+ and Na^+ between cultivated and uncultivated sites. Cultivated sites had lower mean content of exchangeable K^+ (0.57 cmol (+)/kg soil) and Na^+ (0.025 cmol (+)/kg soil) than uncultivated site (K^+ = 0.714 cmol (+)/kg soil and Na^+ = 0.057 cmol (+)/kg soil). The relative change result indicated that K^+ and Na^+ content were decreased by 21.1 and 56.38% respectively due to cultivation. There were no significant difference (P>0.05) in exchangeable Ca^{2+} and Mg^{2+} between uncultivated and cultivated sites. However, the mean exchangeable Ca^{2+} content in cultivated site was slightly lower (26.19 cmol (+)/kg soil) than uncultivated site (26.83cmol (+)/kg). The probable reason for lower contents of exchangeable K^+, Na^+ and Ca^{2+} could be leaching due to clay because of low vegetation cover of cultivated wetlands which expose the soil to direct contact of high amount of rainfall of the area which was similar with the finding of Gebeyaw (2007) and Adamu (2011). Moreover, lower K^+ in cultivated site might be continuous losses though harvested crops and crop residue removal.

The CEC values was significantly different (P<0.05) between uncultivated and cultivated sites. Uncultivated site had higher mean CEC value (41.31 meq/100 g soil) than cultivated site (28.7 meq/100 g soil). The relative change indicated that CEC was decreased by 31.77% by cultivation. High clay and OM might be the reason for high CEC value in uncultivated site. There was general relationship between clay and colloidal OM with CEC value (Raseem and Bhatti, 2000; Brady and Weil, 2001; Gebeyaw, 2007). This is because clay and colloidal OM had high surface area and negative electrical surface charges to absorb and hold positively charged ions. Hence depletion of OM as a result of continuous cultivation could result for reduced CEC under cultivated site. This result was agreed with the observations of Belay and Hunt (2000), which indicated that the capacity of the wetland soils to contain nutrients (CEC) is adversely affected by cultivation.

Species and soil property relationship

Principal Component Analysis (PCA) performed for soil and plant species had extracted more than 32.1% of the variance of data set. PCA 1 provides 19.74% of the variance of data set while PCA 2 takes about 12.38% of

Table 6. Pearson correlation matrix among soil properties.

	Clay	Sand	Silt	BD	OC	TN	%SMC	Av.P	Ca^{2+}	Mg^{2+}	CEC	EC	pH	Na^{+}	K^{+}
Clay	1														
Sand	-0.553*	1													
Silt	-0.830**	-0.003	1												
BD	0.048	-0.441	0.236	1											
OC	0.630**	-0.125	-0.673**	-0.279	1										
TN	0.655**	-0.286	-0.594**	-0.036	0.740**	1									
SMC	0.744**	-0.199	-0.761**	-0.233	0.813**	0.765**	1								
Av.P	0.302	0.181	-0.483*	-0.396	0.485*	0.130	0.553*	1							
Ca^{2+}	0.092	-0.344	0.119	0.377	0.005	0.425	-0.101	-0.466	1						
Mg^{2+}	0.102	-0.147	-0.025	-0.122	-0.194	0.149	-0.111	-0.235	0.067	1					
CEC	0.160	0.406	-0.462	-0.550*	0.538*	0.362	0.478*	0.326	-0.023	-0.166	1				
EC	-0.198	-0.044	0.267	0.272	-0.344	-0.283	-0.522*	-0.714**	0.056	0.206	-0.233	1			
Ph	-0.501*	-0.032	0.624**	0.546*	-0.586*	-0.291	-0.566*	-0.357	0.335	-0.045	-0.644**	0.480*	1		
Na^{+}	0.551*	-0.316	-0.450	0.050	0.575*	0.894**	0.613**	0.134	0.518*	0.328	0.298	-0.291	-0.131	1	
K^{+}	0.502*	-0.309	-0.397	0.062	0.543*	0.879**	0.578*	0.073	0.561*	0.336	0.291	-0.282	-0.089	0.99**	1

* Significant at the 0.05 level; ** significant at the 0.01 level.

the variance. Scatter plot for species and soil parameters indicated three major groups of data set (Figure 2). In first group *A. abyssinica, L. hexandra, C.elegantulus, A. schimperi, C. latifolius, L. deflexa, A. aspera, P. punctatus, P. argentatus, P. senegalensis, T. confluens I. ethiopica, S. dummeri and D. sanguinalis* were associated with available phosphorous, SMC, TN, OC, CEC and Clay. Except *I. ethiopica and D. sanguinalis,* they were wetland plants. Similarly, in second group, *O. forskalaei, S. polystachya, C. assimilis, H. schulli, M. syperoides, I. cordofana, D. ternate, P. boehmii, L. stolonifera and C. dactylon* were associated with sand, bulk density, Ca^{2+}, pH, EC and silt. In this group only *Hygrophila schulli and Phyllanthus boehmii* were wetland species. Furthermore, *C. arvensis, I. eroiocarpa, Sacciolepis Africana, A. conyzoides, E. ciliaris, S. anguivi, D. cordat* and *O.* spp. were associated with Na^{+}, K^{+} and Mg^{2+} in which only *S. Africana* was wetland plant species and the rest were upland species. It also revealed that available phosphorous, SMC, TN, OC, CEC and Clay were associated with each other negatively associated with sand, bulk density, pH, EC and silt. Besides, Shannon-wiener diversity, evenness and species richness were positively associated bulk density, pH, EC and silt. Thus, most wetland plant species were positively associated with clay, SMC, CEC, TN, OC and available phosphorous which measured maximum value in uncultivated wetland site. Similarly, most of upland plant species were positively associated with sand, bulk density, pH and EC measured highest value in cultivated site (Figure 2). This indicated that continuous cultivation can increase EC, pH, silt, bulk density, species diversity and change in the composition wetland plants.

Conclusion

Plant species diversity and evenness were increased in the cultivated site due to wetland drainage and cultivation. Changes in wetland hydrology and wetland cultivation were the most determinant factor for changing in wetland plant composition, diversity and soil characteristics linked to soil fertility. Though this seems positive for biological integrity in cultivated site, cultivation has caused the losses and degradation of wetland plant species vital for ecosystem services and livelihood of local community. Low similarity in species composition between cultivated and wetland sites indicated that changes in environmental conditions of the wetland favor upland plant species. Cultivated and continuous drainage impact on soil phyco-chemical properties such as soil organic matter, water-holding

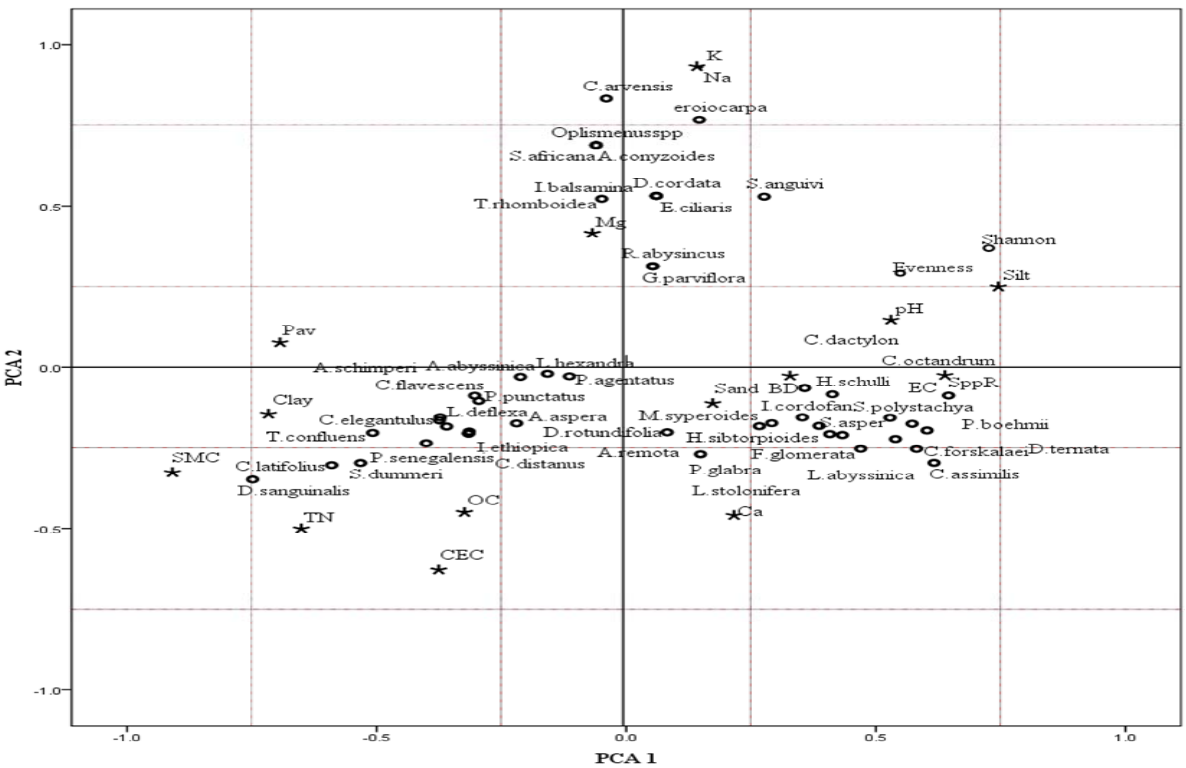

Figure 2. Scatter plot for species and soil parameters relationship in cultivated and uncultivated wetland sites.

capacity of the soils, total nitrogen, available phosphorous and CEC. Thus, the result indicated that in cultivated wetland site there was disturbance of nutrient cycling. Besides, the significant variations in soil physico-chemical properties between

cultivated and uncultivated site the result of this study indicated the risk for the sustainable use of wetlands by cultivation. Hence, planning sustainable use strategy that promotes biodiversity conservation, environmental integrity and enhance community benefits from wetland resources is an urgent research and policy agenda.

Conflict of Interest

The authors have not declared any conflict of interest.

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Assessment of on-farm diversity of wheat varieties and landraces: Evidence from farmer's fields in Ethiopia

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Analysis of spatial diversity, temporal diversity and coefficient of parentage (COP) were carried out along with measurements of agronomic and morphological traits to explain on-farm diversity of modern varieties or landraces of wheat (*Triticum aestivum* L. and *Triticum durum* L.) grown by farmers in Ethiopia. Farm level surveys showed low spatial diversity of wheat where only a few dominant varieties appeared to occupy a large proportion of wheat area. The five top wheat varieties were grown by 56% of the sample farmers and these varieties were planted on 80% of the total wheat area. The weighted average age of wheat varieties was high with an average of 13.8 years for bread wheat showing low temporal diversity or varietal replacement by farmers. The COP analysis showed that average and weighted diversity of bread wheat was 0.76 and 0.66, respectively variance component analysis showed significant variations for agronomic characters such as plant height, grain yield, and yield components (kernels spike^{-1}, thousand seed weight) among modern varieties and/or landraces. The principal component analysis explained better the variation among varieties and landraces. Cluster analysis based on agro-morphological traits grouped modern varieties and landraces into separate clusters. The present study describes the diversity of wheat crop available on the farm using different indicators. The variation among modern varieties and landraces offered opportunities for using genotypes with desired agronomic characters in plant breeding to develop varieties suitable for different agro-ecological zones in the country.

Key words: Ethiopia, wheat, genetic diversity, spatial diversity, temporal diversity, coefficient of parentage, landraces.

INTRODUCTION

Crop genetic diversity refers to variation within a plant, within a crop, between crops of the same species and between different crop species (Almekinders et al., 1995). It is argued, however, that the definition of diversity across disciplines could be problematic because the criteria and scales for measurements and their relationships are weak (Smale et al., 1996). Smale et al. (1996) noted that biological scientists measure diversity using genealogical

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analysis or indicators (coefficient of parentage), analysis of agronomic or morphological characters using G×E interactions, and indices of gene frequencies using biochemical or molecular tools; whereas social scientists use the number of varieties within a given crop species (numerical), proportion of area planted to cultivars (spatial) and the rate of variety replacement over time by farmers (temporal) using both farm level surveys and/or secondary data.

Spatial diversity indicates the number of varieties grown or the proportion of area occupied by each variety per unit farm, area, community or region. Temporal diversity indicates changes in crop varieties (or sequential varietal releases by plant breeders) assessing changes taking place over time through introduction or withdrawal of varieties by individual farmers or farming communities. At present a combination of different approaches and tools are used to analyze the genetic diversity of crops (Duvick, 1984; Brennan and Byerlee, 1991; Smale et al., 1996). According to Duvick (1984) there are at least three kinds of diversity: diversity in space, diversity in time and diversity in reserve (genotypes in breeding pools, breeding materials exchanged, etc.). Moreover, genetic diversity of crops can be measured through examining cultivar morphology (Souza and Sorrells, 1991), molecular markers (Cox et al., 1985) or origin or parentage analysis (Martin et al., 1991) or a combination of these tools (van Beuningen and Busch, 1997a,b; Almanza-Pinzón et al., 2003). The coefficient of parentage (COP) was used to measure genetic diversity in wheat (Souza et al., 1994) and rice in Nepal and India (Witcombe et al., 2001). The weighted average age (WA) of varieties is also a very useful tool for measuring the temporal diversity of the crop (Brennan and Byerlee, 1991; Smale et al., 1996).

Ethiopian highlands are considered the ‘center of diversity’ for wheat (Demissie and Habtemariam, 1991; Tesemma and Belay, 1991). Tesemma et al. (1991) reported the morphological diversity of durum wheat landraces from the central highlands of Ethiopia. Since the establishment of the National Agricultural Research System (NARS) in the mid-1960s (ICARDA et al., 1999), several modern varieties including selections from landraces were released for commercial production in Ethiopia (Geberemaraim, 1991b; Tesemma and Belay, 1991). The extent of adoption and diffusion of modern varieties for wheat has been described in Ethiopia (Bishaw, 2004). To date, there is great concern over the loss of genetic diversity, particularly with the substitution of a diverse set of genetically variable crop landraces with few genetically uniform modern varieties particularly in centers of genetic diversity such as Ethiopia. Although the loss of biodiversity is largely due to replacement of landraces by ‘modern’ varieties, population pressure, urbanization and environmental degradation such as recurrent droughts, overgrazing and desertification are also contributing to the decrease in natural genetic diversity.

Abundant information is available on classical diversity studies for crop genetic resources/core collections (Demissie and Habtemariam, 1991) or for quantifying variation within and between geographic regions and populations (Kebebew et al., 2001a) or for specific agronomic (Belay et al., 1993) or morphological (Tesemma et al., 1991) traits. However, information on the status of varietal diversity at the farm level is rather limited (Witcombe et al., 2001; Souza et al., 1994). Some diversity studies were reported particularly on Ethiopian wheat (Kebebew et al., 2001a) but information is rather limited on on-farm diversity. Benin et al. (2003) reported that using named varieties and ecological indices of spatial diversity (richness, evenness, and inverse dominance), they found that a combination of factors related to agro-ecology of a community, its access to markets, and the characteristics of its households and farms significantly affect both the inter- and infra-specific diversity of cereal crops. The present study, however, aimed at assessing the on-farm wheat diversity using different approaches and tools. Therefore, the main objectives of this study were to: (i) Investigate the spatial and temporal diversity of wheat varieties planted by farmers, and (ii) Investigate the agronomic and morphological traits diversity of wheat varieties used by farmers in Ethiopia using different approaches.

MATERIALS AND METHODS

Field surveys

A total of 304 wheat farmers were interviewed in major wheat growing regions as part of a wheat seed system study (Figure 1). A stratified sampling procedure based on the proportion of wheat area in each region, was followed by random sampling of farmers, as described by Bishaw (2004). Four regions were included covering 81 villages in nine districts in south eastern, central and north western parts of the country. Farmers were asked about wheat varieties or landraces they grew and their perception and source of the varieties and area under each variety. After the interview, a seed sample of about 1 kg was collected from each farmer from the seed lot planted or intended for planting for field experiments.

Field experiments

From 304 wheat seed samples collected from farmers, 50 samples representing 13 bread wheat (7 modern, 6 obsolete or landraces) and 12 durum wheat (1 modern, 11 landraces) were selected and planted for two seasons during the 1998/1999 and 1999/2000 cropping seasons to assess the wheat genetic diversity using agronomic and morphological traits. The study was conducted in a randomized complete block design (RCBD) with three replications. The bread wheat included recommended varieties (Dashen, ET13, HAR1685, HAR1709, HAR710, K6295, Pavon76), obsolete varieties (Batu, Israel, Kenya) and landraces (Goli, Menze, Rash, Zombolel). All durum wheat, except Boohai were landraces (Baghede, Baherseded, Enat sende, Gojam gura, Gotoro, Key sende, Legedadi, Nech shemet, Shemet).

Bread and durum wheat varieties were planted separately to study the genetic diversity among modern varieties and landraces using agro-morphological characteristics. The experiment was planted at an altitude of 2250 masl at the Gonde seed farm (8.0°N and 39.1°E) in southeastern Ethiopia. The soils in Gonde are termed as ignimbrite (consolidated lava flows), volcanic ash and pumice. The soil texture is light clay with clay (44 to 47%), silt (28 to 32%) and sand (23 to 27%)

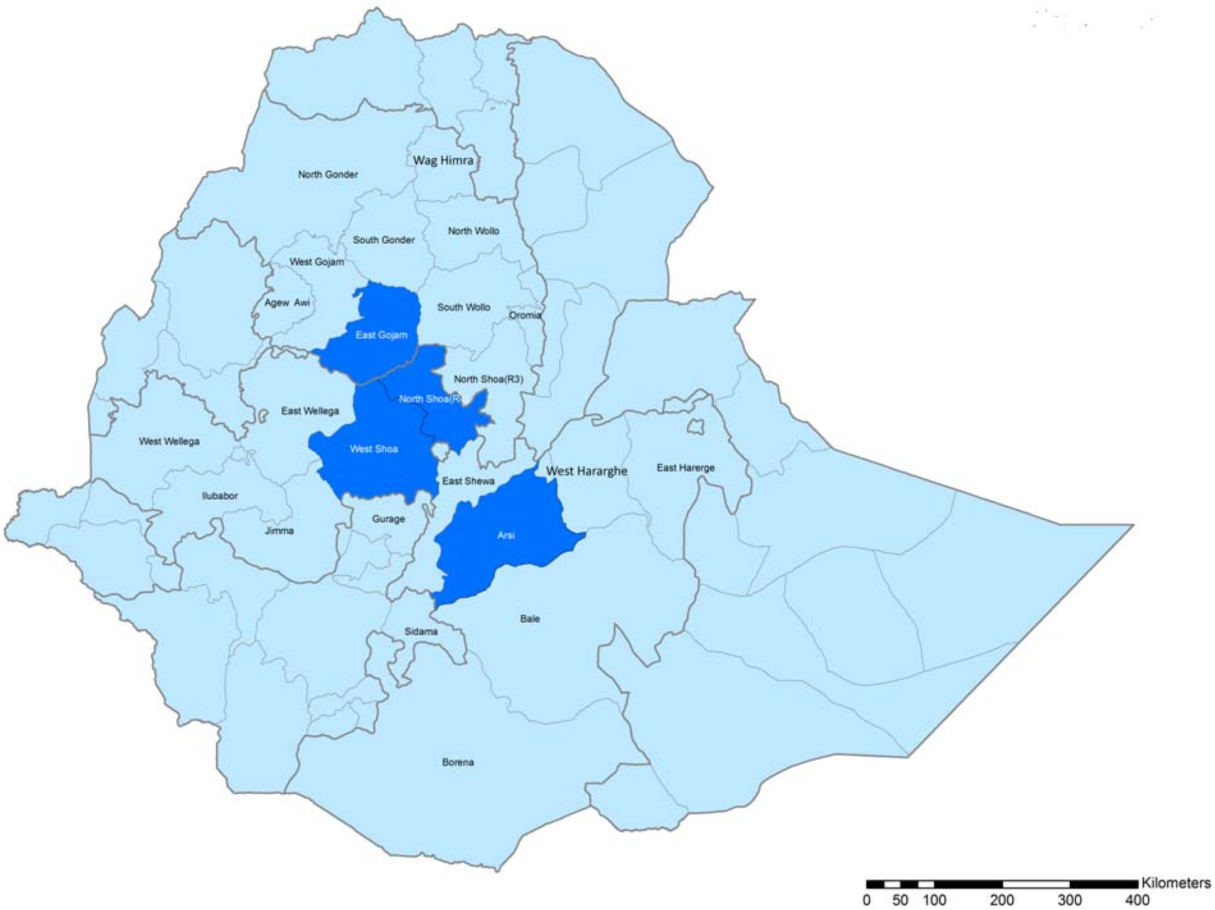

Figure 1. Wheat seed system study areas (shaded) in Ethiopia

(Bishaw, 2004). The agro-morphological characteristics were recorded on a plot basis in the field and after harvest. Agronomic characters measured included days to flowering, days to heading, days to maturity, grain yield, biomass yield, plant height, spike length, number of spikelets spike^{-1}, number of kernels spike^{-1} and thousand seed weight. Morphological characters were measured visually on a plot basis or on a group of plants as described by UPOV (1981 and 1988) defining the methods, scales and crop growth stages for scoring. The following agronomic and morphological characters were recorded during the field experiments:

(i) Agronomic characters (on a plot basis or on 10 randomly selected plants)
Days to heading (days): Number of days (counted from first effective date of rainfall to) when 75% of the plants were heading in the plot;
Days to flowering (days): Number of days (counted from first effective date of rainfall to) when up to 50% of the plants flowering in the plot;
Days to maturity (days): Number of days (counted from first effective date of rainfall to) when 90% of plants reaching physiological maturity in the plot;
Grain filling period (days): Number of days to maturity minus number of days to heading;
Plant height (cm): Length of randomly selected plants measured from the ground (excluding the awns) at maturity;
Number of tillers plant^{-1}: Number of tillers of randomly selected plants counted at maturity;
Grain yield (g): Grain weight of four middle rows harvested at maturity and measured after threshing and cleaning;
Biomass yield (g): Biomass (straw and grain) weight of 4 middle rows harvested and weighed at maturity;
Spike length (cm): Length measured from base of spike to top excluding the awns at maturity;
Number of spikelets spike^{-1}: Number of spikelets on randomly selected plants counted at maturity;
Number of kernels spike^{-1}: Number of kernels counted on randomly selected plants per spike at maturity;
Thousand seed weight (g): Weight of 1000 seeds calculated at 12% moisture content.
(ii) Morphological characters (observed on plot basis or 10 randomly selected plants)
Growth habit: Scored as prostrate, semi-prostrate, intermediate, semi-erect, erect;
Plant characters: Hairiness of uppermost node (HUN), glaucocity of ear neck (GN), zigzagness of neck (ZICN);
Leaf characters: Auricle coloration, glaucocity of leaf sheath and lower leaf blade;
Glume characters: Glume color (GC), beak length (BL), shoulder shape (SHSH), shoulder width (SHW);
Ear characteristics: Ear shape (ES), ear color (EC), awn condition (presence or absence), awn color (AC);
Grain characters: Grain color (GC), grain shape (GS), brush hair (BRH).

Some of the morphological qualitative characters were measured on a scale of 1 to 9. For example, for growth habit the score was erect (1), semi-erect (3), intermediate (5), semi-prostrate (7) and prostrate (9). The qualitative characters were measured on a discontinuous basis such as absent (1) or present (2). For ear shape, it could be scored as tapering (1), parallel (2), semi-clavate (3), clavate (4) or fusiform (5).

Data analysis

Survey data

Farm surveys were conducted as part of a seed system earlier (Bishaw, 2004) in Ethiopia. Farmers were asked about wheat varieties they grew and their perceptions, source of the varieties, area under each variety. The number of varieties grown by each farmer and the proportion of area under each variety was used to measure the spatial diversity on the farm. The weighted average age of varieties was calculated to estimate the temporal diversity of the varieties (Brennan and Byerlee, 1991) grown by sample farmers. Moreover, measuring the varietal diversity also requires information on the genetic relatedness between varieties. The matrix of coefficients of parentage (COP) among released wheat varieties was generated using the International Wheat Information System version 4 computer program (Payne et al., 2002). The COP measures the theoretical genetic relationship between two varieties based on the analysis of their pedigrees. St. Martin (1982) defined the algorithm for calculating COP: (i) the COP of each unique wheat variety with itself is one, and two varieties without common parentage is zero; (ii) each parent contributes equally to the progeny, and any unrelated parents has a relationship of 0.5 with the progeny; and (iii) each variety without a known pedigree is unrelated (COP=0). The average diversity is the average value of the COP among all cultivars (including the COP of a cultivar with itself) grown within each year and region subtracted from 1 (Souza et al., 1994). The weighted diversity is determined from a matrix of the COPs where each cell in the matrix is weighted by the proportion of the area grown to each variety and the weighted mean COP is subtracted from 1 (Witcombe et al., 2001).

Experimental data

The data from field experiments was statistically analyzed using the residual maximum likelihood estimation (REML Genstat 6.1) to test the significance of variation among the genotypes and to estimate variance components. Moreover, the data was pre-standardized to overcome differences in measurement units used for recording data before carrying out the multivariate analysis. Principal component analysis was performed using the correlation matrix to define the patterns of variation among the varieties or landraces or the collection sites based on the mean of agronomic and phenotypic traits measured during the study using the SPSS 11.1 statistical software and the graph plotted with NTSYS pc 2.1 software. Clustering was made using the hierarchical cluster analysis. Euclidean distance was used as cluster distance measure and the clustering method was unweighted pair group using arithmetic average using NTSYS pc 2.1. The actual data matrix was compared with a calculated cophenetic value matrix to evaluate the degree of fitness between the two matrices (r) performing Mantel test (Mantel, 1967).

RESULTS AND DISCUSSION

The average rainfall for 1998/1999 and 1999/2000 were 794 and 682 mm, respectively, showing some variation in the amount and distribution at the experimental site between the two seasons (Table 1). In both years, exceptionally high and extended rainfall during crop maturity and at harvesting period resulted in lodging and loss of grain yield of modern wheat varieties and landraces. In the 1999/2000 crop season, high incidence of yellow rust was observed particularly on landraces leading to substantial yield loss.

Spatial diversity of wheat varieties

Farmers grow different crops and varieties from agro-ecological, agronomic, economic, and socio-cultural context to maximize on-farm productivity and ensure household food security. It was reported that relatively higher speciesdiversity on the farm where most farmers grew a wide range of cereal, legume and oilseed crops in Ethiopia (Bishaw, 2004). Wheat farmers either grew bread wheat (83.2%), durum wheat (7.9%) or a combination of both wheat types (8.9%). Table 2 shows the number of bread and durum wheat varieties grown per farm. The number of wheat varieties grown by an individual farmer was low showing low levels of varietal diversity. If both bread and durum wheat varieties are considered together 72, 24 or 4% of farmers grew one, two or three varieties per farm, respectively. In case the two wheat species considered separately, the number of farmers growing one variety will be 70% for bread wheat (n=280) and 82% for durum wheat (n=51). Similarly, farmers growing two varieties dropped from one-third to one quarter for bread wheat and to 16% for durum wheat.

In Arsi, relatively more farmers had better choice and access to newly released varieties due to proximity to agricultural research stations and seed suppliers and as a result grew more than two varieties. In other regions more farmers grew modern bread wheat varieties as they were newly introduced to the regions along with durum wheat landraces. Lack of availability of varieties with different agronomic characteristics would be one possible cause of growing less number of varieties by farmers. Similar results were also reported where 73% of farmers grew one wheat variety in southeastern Ethiopia (Ferede et al., 2000). However, this is contrary to Negatu et al. (1992) where over 50% of farmers grew more than one variety in the central highlands of Ethiopia (although no distinction between bread and durum wheat) and Stanelle et al. (1984) who found that 32% of farmers planted two varieties and 27% planted three or more wheat varieties in the USA. The latter could be attributed to the availability of many wheat varieties with diverse morphological characteristics to reduce the risk of wheat production. The general assumption that small-scale farmers are growing diverse crop varieties fitting to different niches is not clearly evident both for wheat or other crops grown by farmers. However, at the community level farmers were growing relatively more varieties as in 62 out of 81 villages where sample farmers were growing from 2 to 4 different wheat varieties or landraces. Given the fact that farmers are planting even one variety on different plots in the village one could possibly find a mosaic of fields with different varieties/landraces at a time showing some degree of spatial diversity on the farm. About 40 modern varieties and landraces of bread and durum wheat were grown in the

Table 1. Average monthly minimum and maximum temperature and rainfall in 19998/89 and 1999/00 crop seasons at Gonde basic seed farm, Ethiopia.

Months	1998/1999				1999/2000			
	Rainfall mm	Max ºC	Min ºC	Average ºC	Rainfall mm	Max ºC	Min ºC	Average ºC
January	82	22.18	9.55	15.9	3.5	22.31	7.38	14.8
February	80.4	23.75	11.18	17.5	4.5	25.47	8.65	17.1
March	28.8	25.13	11.4	18.3	27	24.36	10.73	17.5
April	45.8	26.73	12.45	19.6	26.7	26.36	11.31	18.8
May	78.5	25.7	12.4	19.1	60	25.43	11.38	18.4
June	66.2	24.58	11.76	18.2	98.3	24.08	11.18	17.6
July	96.1	20.2	11.3	15.8	96.1	22	12.03	17.0
August	67.8	20	10.9	15.5	148.6	21	11.7	16.4
September	164.5	21.3	11.1	16.2	112.7	na	na	na
October	81.2	21.5	10.7	16.1	104.4	na	na	na
November	2.6	21.88	9.8	15.8	0	na	na	na
December	0	21.71	na	15.6	0	na	na	na
Total/mean	793.9	22.9	11.1	15.6	681.8			

Note: na= data not available because of malfunctioning of the equipment.

Table 2. Number of bread and durum wheat varieties grown by sampled farmers (n=331) in Ethiopia.

Number of varieties	Arsi		West Shoa		North Shoa		East Gojam		Total	
	Farmers	%	Farmers	%	Farmers	%	Farmers	%	Farmers	%
All wheat										
1	75	53	55	77	56	93	53	90	239	72.2
2	55	39	14	20	4	7	6	10	79	23.9
3	11	8	2	3	-	-	-	-	13	3.9
Total	141	100	71	100	60	100	59	100	331	100
Bread wheat										
1	75	53	44	81	30	97	48	89	197	70.4
2	55	39	9	17	1	3	6	11	71	25.4
3	11	8	1	2	-	-	-	-	12	4.3
Total	141	100	54	100	31	100	54	100	280	100
Durum wheat										
1	-	-	11	65	26	90	5	100	42	82.4
2	-	-	5	29	3	10	-	-	8	15.7
3	-	-	1	6	-	-	-	-	1	2.0
Total	-	-	17	100	29	100	5	100	51	100

Note: - = no farmers growing.

survey areas in south eastern, central and northwestern regions of the country (Figure 1) by sampled farmers from 1994/1995 to 1997/1998 crop season. The total number of wheat varieties grown slightly decreased because some landraces were dropped as farmers were adopting new bread wheat varieties instead. The total number of wheat varieties grown by sampled farmers dropped from 40 in 1994 to 31 in 1997 and these included durum landraces such as Atekere, Agere, Bire, Boydo and Wasma. Figure 2 shows the pattern of the top ten wheat varieties grown by farmers over a four-year period from 1994/1995 to 1997/1998 crop season. During the four year period, the five major bread varieties were grown by 44.9% (lowest in 1996) to 66% (the highest in 1997) of wheat farmers. In 1994, the bread wheat varieties Pavon, Enkoy, Dashen, Batu and Israel were planted by 62.1% of farmers. In 1997,

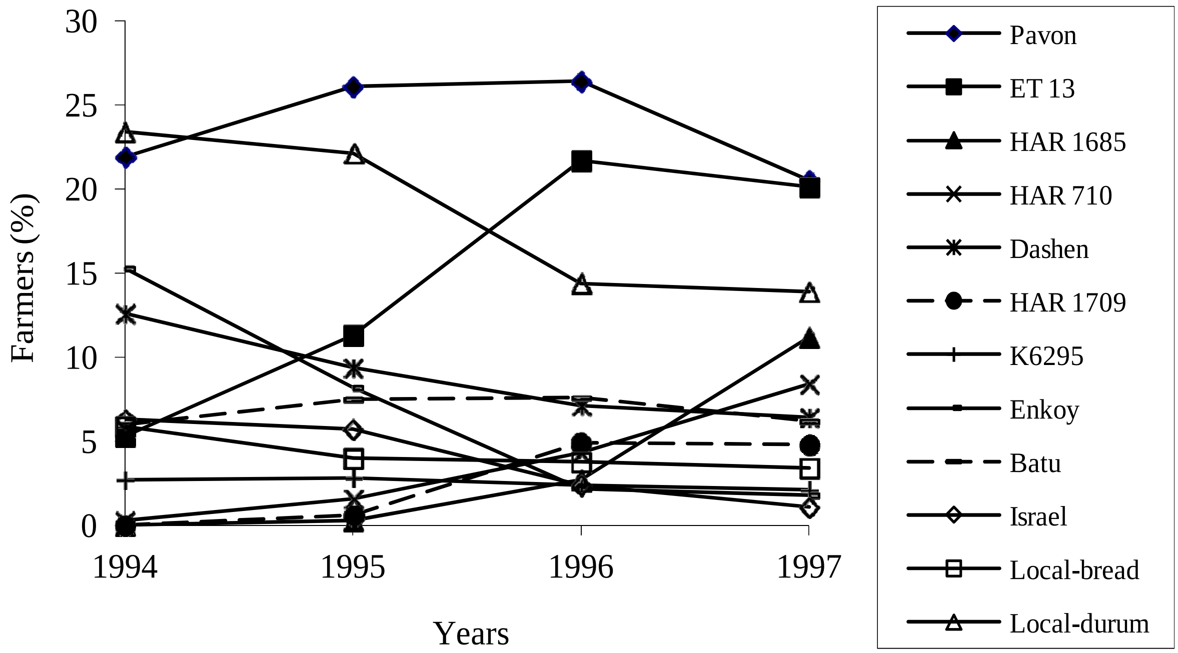

Figure 2. Patterns of bread and durum wheat varieties grown by sample farmers in Ethiopia.

the top five varieties altogether were planted by 66.2% of farmers, among which Pavon and ET13 were grown by 40.6% of the farmers, followed by HAR1685 (11.2%), HAR710 (8.4%) and Batu (6.2%). The average over four year period was 56%. In 1997, about 86% of sampled farmers grew bread wheat varieties whereas the remaining 14% planted durum wheat varieties. The proportion of farmers growing Dashen and Enkoy dropped from nearly one third in 1994 to less than 10% in 1997. On the other hand, the percentage of farmers' growing Pavon and ET13 showed an upward trend increasing from 27.2 to 40.6%, in the same period as the two older varieties Dashen and Enkoy become susceptible to rust and less popular with farmers. Throughout the period Pavon appeared to be a single dominant variety planted by over 20 to 25% of the farmers. Batu also remained among the top five bread wheat grown by sample farmers.

The percentage area of top ten wheat varieties grown by farmers over a four-year period is shown in Figure 3. There was a steady increase of area allocated for wheat production by sampled farmers over the years (almost by 50%). This happened due changes in adoption rates as most of the farmers were introduced to modern varieties and at the same time growing their landraces in decreasing proportion. The five top wheat varieties on average occupied 80% of the wheat area planted during the four year period. In 1994, *Pavon, Enkoy, Dashen, Batu* and *Israel* in decreasing order accounted for nearly 80% of the wheat area planted by farmers. In 1997, *Pavon* and *Batu* still remained at the top whereas the older varieties or landraces such as Dashen, Enkoy and Israel were replaced by the new varieties. The newer 'HAR' varieties accounted for over one fifth of wheat area. Pavon remained dominant occupying 40 to 50% of the wheat area grown by sampled farmers over the four year period. Negatu (1999) also reported that in central Ethiopia three modern wheat varieties were grown on 53% of the wheat area and the most widely grown variety ET13 was planted by 74% of sample farmers on 51% of the wheat area. In another survey it was reported that six dominant varieties covered 92.5% of the total wheat area grown by sample farmers in Arsi region (Ferede et al., 2000). Much higher level cultivar concentration was reported from South Asia where a single wheat variety occupied up to 70% in Pakistan and 75% in Bangladesh (CIMMYT, 2001). The area allocated to bread and durum landraces declined over the years from 18.3 and 14.4%, respectively in 1994 to 12.6 and 7.6% in 1997 in the same order. Kotu et al. (2000) found that wheat farmers in southeastern Ethiopia are decreasing the area of landraces compared to modern varieties.

The important features observed from the survey were: (a) decline in the proportion of bread and durum landraces; (b) decrease in previously most popular varieties such as *Dashen* and *Enkoy* as they became susceptible to diseases; (c) increase in the proportion of previously less popular varieties such as *Pavon* and *ET13*; and (d) a continuous increase of newly released '*HAR*' varieties which was not evident in previous surveys. Negatu et al. (1992) also found that 94% of sampled farmers in predominantly durum wheat production zones in the central highlands grew only few modern bread and durum wheat varieties. About 63% of these farmers were formerly used

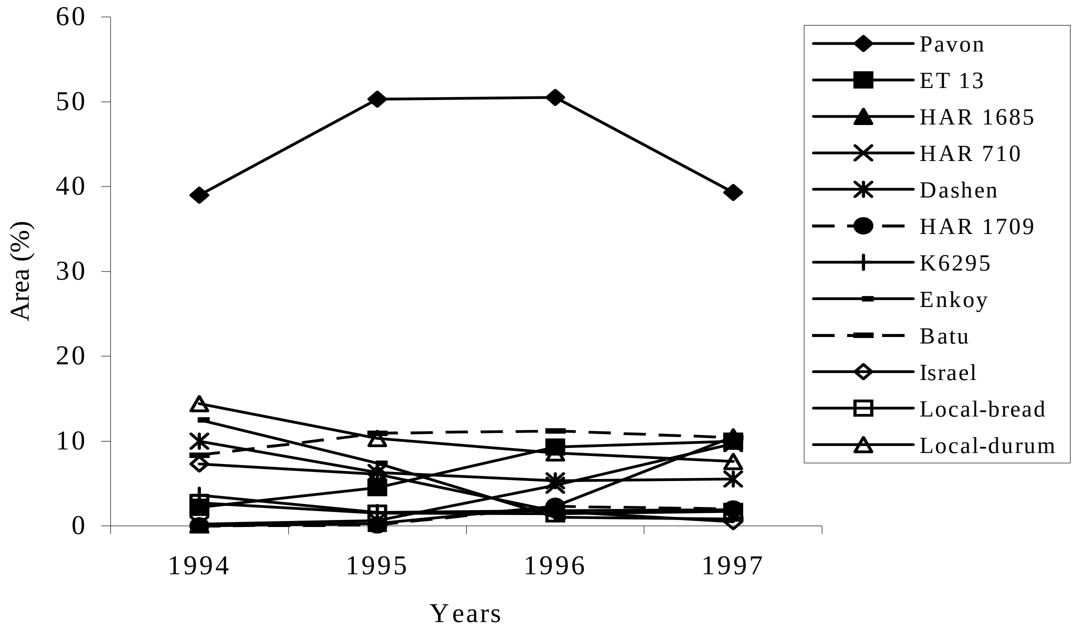

Figure 3. Patterns of area allocation for bread and durum wheat varieties by sample farmers in Ethiopia.

to grow as many as 27 durum landraces, but abandoned them primarily due to lack of seed availability and their susceptibility to plant diseases and insect pests. Hailye et al. (1998) also found that farmers in northwestern Ethiopia had formerly reported mostly growing 13 durum landraces, which were abandoned because of their susceptibility to rusts, moisture stress and low soil fertility.

It should be noted that the number of varieties grown by individual farmers was rather low given the number of released wheat varieties and landraces cultivated in Ethiopia. Moreover, a small number of varieties occupied the highest proportion of area allocated to wheat and they were also grown by a large number of farmers. Varietal concentration indicates the percentage distribution of crop area by cultivar (spatial diversity) and measured by the area planted to a dominant cultivar and the area planted to the top five cultivars. Accordingly, these results indicate high varietal concentration reflecting low on-farm diversity of bread wheat in Ethiopia. On the other hand, there was not a single landrace which substantially dominated the area of wheat production. Different durum landraces were grown quite evenly across the districts.

Temporal diversity of wheat varieties

During the last five decades, several modern bread (49) and durum (16) wheat varieties were recommended or released (Gebremariam, 1991; Tesemma and Belay, 1991; NSIA, 2000) with an average of 13 varieties per decade for the highly diverse agro-ecological regions of Ethiopia (Figure 4). Among these, eleven bread and three durum varieties were released during the survey year. The average wheat varietal release was 1.3 modern varieties per year from 1950 to 2000. There is substantial difference in the average release per year between durum (0.3) and bread wheat (1.0) varieties, indicating more choices for bread varieties. During the wheat seed survey sample farmers grew nine bread wheat varieties on the recommended list compared to one durum variety. Souza et al. (1994) reported an average release of 1.5 varieties per year in the Yaqui valley of Mexico. The performance of the Ethiopian Wheat Research programme appeared satisfactory given the average annual total wheat releases of 80 varieties per year by NARS of developing countries between 1986 and 1990 (Evenson and Gollin, 2003).

The availability of recommended varieties alone would not imply varietal diversity, if they were not available at the farm level and grown by farmers. The weighted average age (WA) of varieties is used to estimate the rate of varietal replacement, based on the average age of varieties grown by farmers in a given year since release, weighted by the area planted to each variety in that year (Brennan and Byerlee, 1991). In 1997, the WA calculated for modern bread wheat showed a low level of varietal turnover of 13.4 years (Table 3) similar to WA of 13 and 11 years reported for bread wheat varieties, respectively in central (Beyene et al., 1998) and northwestern Ethiopia (Hailye et al., 1998). These figures indicate that although Ethiopian farmers are growing modern varieties of bread wheat, they are slow in changing to new varieties released in recent years or having difficulty to get quick access to improved seeds. The present WA was closer to 13 years (Smale et al., 1996), but lower in contrast to 16 years of varietal

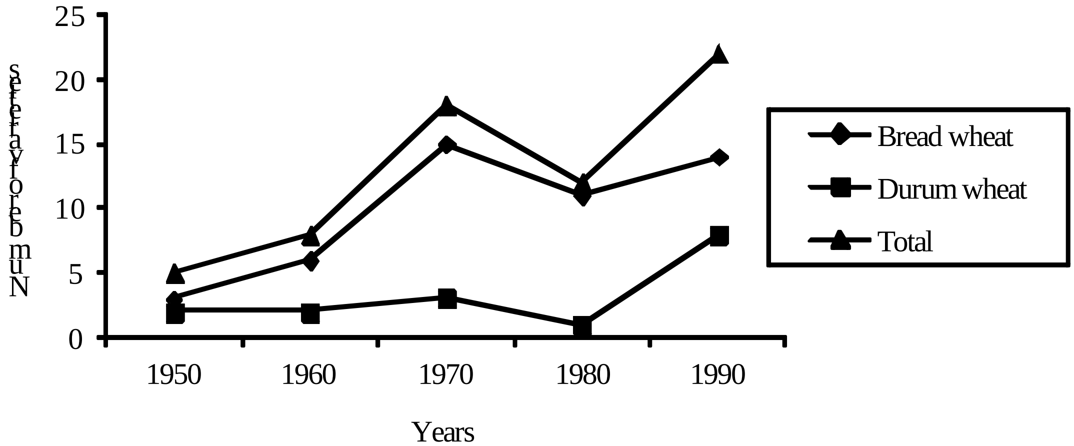

Figure 4. Modern bread and durum wheat varieties released from 1950 to 2000 in Ethiopia.

Table 3. Weighted average age (WA) of bread wheat varieties grown by farmers in Ethiopia.

Variety	Year variety released	Years since release	Mean area (ha) in 1997	WA
Dashen	1984	13	0.80	1.09
Enkoy	1974	23	0.39	0.94
ET13	1981	16	0.46	0.77
HAR 1685	1995	2	0.87	0.18
HAR 1709	1994	3	0.38	0.12
HAR 710	1995	2	1.06	0.22
K6295	1980	17	0.86	1.53
Pavon	1982	15	1.78	2.80
Batu	1984	13	1.57	2.14
HAR 416	1987	10	0.75	0.79
Kenya	1954	43	0.61	2.75
Total				13.35

replacement reported by Moya and Byerlee (1993). Ethiopian farmers had long seed retention period (Bishaw, 2004) which had a negative impact on adoption of new varieties (Gamba et al., 1999) thus increasing the WA of varieties on the farm. The slightly lower WA could be attributed to the release of new varieties and farmers willingness to adopt them replacing most popular 'old' generation wheat varieties such as *Dashen* and *Enkoy* which become susceptible to yellow rust and stem rust, respectively. *Enkoy* variety remains dominant in terms of area coverage for over two decades in major wheat production regions of the country. The breakdown of resistance induced farmers to promoting varietal replacement and increasing the temporal diversity at the farm level similar to what was reported elsewhere (Souza et al., 1994; van Beuningen and Busch, 1997a; Hailye et al., 1998). In general high WA is a combination of many factors reflecting slow rate of variety development by the agricultural research, ineffective variety release and registration system, poor promotion or popularization of new varieties or unavailability or lack of access to seed of new varieties (Bishaw, 2004; Hailye et al., 1998).

Although several modern durum wheat varieties were released by the national agricultural research system none of them were encountered in Arsi region where bread wheat is most popular among farmers because of its high yield potential. Moreover, only a single improved variety was found in traditionally durum wheat growing areas of the country in central and northwestern regions reflecting lower adoption of modern varieties on the farm. This indicates the underlying failure of the crop improvement program in developing modern varieties that meet farmers' adoption criteria or the weakness of national seed system in providing seed of these varieties to farmers. On the other hand, sample farmers were growing a wide range of durum wheat as many as 15 landraces across the regions. It is estimated that over 80% of durum wheat area in Ethiopia is covered by landraces consisting of mixtures

Table 4. Coefficient of parentage matrix of modern bread wheat varieties in Ethiopia.

Variety	Batu	Dashen	Enkoy	ET 13	HAR 416	HAR 710	HAR 1685	HAR 1709	K6295	Pavon 76
W[1]	0.115	0.061	0.009	0.111	0.002	0.107	0.116	0.022	0.021	0.436
Batu	1	0.184	0.007	0	0.147	0.071	0.144	0.073	0	0.152
Dashen		1	0.008	0	0.231	0.096	0.383	0.116	0	0.297
Enkoy			1	0.5	0.009	0.005	0.008	0.005	0	0.01
ET 13				1	0	0	0	0	0	0
HAR 416					1	0.091	0.197	0.281	0	0.274
HAR 710						1	0.083	0.045	0	0.122
HAR 1685							1	0.098	0	0.274
HAR 1709								1	0.5	0.137
K6295									1	0
Pavon										1

Note: W[1] = proportion of area occupied by each variety used for calculating the weighted diversity; COP values for ET 13 and K6295 are assumptions.

that exhibit genetic variation for quantitative and qualitative traits (Tesemma and Bechere, 1998). It is believed that such landrace mixtures constitute the major on-farm diversity of durum wheat in Ethiopia (Belay et al., 1993; Kebebew et al., 2001a) where 20 or more morphotypes (agrotypes) still exist all in one field (Tesemma and Bechere, 1998).

At present a significant proportion of the total wheat area in developing countries is planted to modern varieties, including early generation tall improved varieties and/or second-generation short stature modern varieties (Pingali, 1999). However, the rate of varietal replacement of the old generation improved varieties is slow where farmers could not benefit from investment made in developing new varieties with superior yield potential owing to time lag between the release of the variety and its adoption by farmers. A rapid rate of varietal replacement in farmers' fields not only leads to higher returns to plant breeding research programme by increasing adoption but also increase genetic diversity if varieties are from diverse parentage (Brennan and Byerlee, 1991).

Coefficient of parentage of wheat varieties

During the field survey it was found that the majority of the sampled farmers extensively grew modern bread wheat varieties compared to the landraces. Most of these varieties, however, were introductions from CIMMYT, Kenya or selections from Ethiopian landraces with some common parents or ancestors. Table 4 presents the COP which measures the degree of relatedness among varieties (Payene et al., 2002). The COP values vary from as low as 0.071 (between Batu and Enkoy) to 0.383 (between Dashen and HAR 1685) excluding the non-related varieties (COP values = 0). Most of the recently released wheat varieties not only related to each other, but also to the recommended or 'obsolete' varieties still grown by farmers. Pavon, the most widely grown variety has high COP values of 0.274 each with HAR 416 and HAR 1685 and Dashen (0.297). HAR 1709 has high COP value with HAR 416 (0.281). Dashen also had the highest COP values with HAR 1685 followed by Pavon and HAR 416. The COP data and the proportion of area occupied by each variety were used to measure the average diversity and the weighted diversity of bread wheat varieties deployed in farmers' fields (Souza et al., 1994; Witcombe et al., 2001).

First, the COP data was used to measure the average diversity of bread wheat varieties in farmers' fields. Here bread wheat varieties with unknown association with current varieties (e.g. Kenya) or those considered landraces or the origin could not be traced (e.g. Israel) were excluded, although some of them occupied more than 0.1% of the total wheat area in the 1997/1998 crop season. The most popular bread wheat variety ET13 has Enkoy as one parent and therefore a maximum COP value of 0.5 was assigned between the two varieties assuming they are from unrelated parents. Likewise, K6295 also has Romany Back Cross as one parent similar to HAR1709 and therefore a COP value of 0.5 was assumed between the two varieties. However, these figures appeared high and it is unlikely that the parents of these varieties came from unrelated ancestors. The average wheat diversity among cultivars grown in an area is measured by subtracting the mean coefficient of parentage from 1 (Souza et al., 1994; Witcombe et al., 2001) and higher values indicate higher diversity. Accordingly, the average diversity of wheat varieties of known parentage calculated from the COP matrix would be 0.76, if ET 13 and K6295 were excluded from the matrix. If ET 13 and K6295 are, however, kept in the matrix with COP values of 0.5 with Enkoy and HAR 1709, respectively and unrelated to all other varieties the average diversity of wheat varieties grown by farmers would be 0.81 showing slight increase (6%) in diversity. These results are comparable to similar diversity studies for crops such as barley (Martin et al., 1991).

Table 5. Mean, minimum, maximum and standard error of mean for nine agronomic traits of bread and durum wheat varieties.

Agronomic characters	Bread wheat			Durum wheat		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Number of tillers plant^{-1}	2	10	4.2 ± 0.2	2	10	4.3 ± 0.1
Days to heading (d)	49	97	67 ± 1.0	51	78	67 ± 0.4
Days to maturity (d)	114	147	131 ± 1.1	114	147	132 ± 0.8
Grain filling period (d)	21	82	64 ± 1.4	47	84	66 ± 0.8
Plant height (cm)	72	128	94.3 ± 1.3	65	115	90.9 ± 0.9
Grain yield (kg ha^{-1})	1050	7590	3702 ± 109	250	5550	2381 ±121
Biomass yield (kg ha^{-1})	3750	10000	7343 ± 123	3000	12500	6425 ± 129
Number of grains spike^{-1}	19	53	36.0 ± 0.8	5	57	30.4 ± 0.9
Thousand seed weight (g)	22.8	45.7	33.5 ± 0.5	8	53.09	27.2 ± 0.8

Second, the COP data and the proportion of area occupied by each variety were used to measure the weighted diversity of bread wheat varieties. The weighted diversity measures not only the relatedness but also the area occupied by the varieties; and therefore robust criteria to measure the diversity at the farm level. The bread wheat varieties with known COP values and with the proportion of area of more than 0.1% were included for calculating the weighted diversity. The varieties Batu, Dashen, Enkoy, ET 13, K6295 and the 'HAR' series, altogether accounts for nearly 90% of the total wheat producing area during the 1997/1998 crop season. We calculated the weighted diversity by the formula (d= 1-WRW´) where the COP (R) value in each cell in the matrix is weighted by the proportion of area occupied by each variety (where W is a vector and W′ a transpose). Accordingly, the weighted diversity of bread wheat varieties was 0.66. The weighted diversity is expected to be lower than the average diversity particularly if higher number of varieties is related (because of high average COP values) as seen from the COP values in Table 4. It should be noted that, however, fewer varieties dominated the wheat production area. Pavon is predominantly grown by nearly 40% of the farmers in 1997/1998 crop season and closely followed by ET 13 which is less related to most of the recommended and newly released varieties. Witcombe et al. (2001) found that both the average and weighted diversity increased following participatory variety selection approaches with farmers where previously a single variety predominates the crop area and thus lower the diversity at the farm levels. They also reported that weighted diversity has increased from 0.26 to 0.61 due to releases and adoption of unrelated and diverse varieties following the participatory variety selection in India.

Agro-morphological traits diversity

Table 5 presents the summary of descriptive statistics including the means, minimum and maximum values, standard error of mean of bread and durum wheat varieties. The number of tillers plant^{-1} ranged from 2 to 10 with an average of 4 for both bread wheat varieties. Tillering is the most important yield component of wheat varieties and most liked by farmers because of the potential it offers for better weed control. Although the average number of days to heading appeared to be similar, the bread wheat varieties had a slightly longer period to heading than durum wheat materials. There was a clear distinction in plant height with local bread wheat varieties such as Menze, Zombolel, Goli and ET 13 (selection from Ethiopian germplasm) having the highest plant height (over 100 cm) and modern varieties such as Batu, Dashen, Pavon, Enkoy and 'HAR' showing shorter plant height (< 100 cm). The average grain filling period between bread and durum wheat appears to be similar, but bread wheat varieties had wider range than durum landraces with short gain filling period similar to that reported by Belay et al. (1993). Tarekegne et al. (1996) also found that in bread wheat varieties plant height was reduced significantly, while days to anthesis was significantly increased over the period of varietal releases since 1949.

Among the bread wheat varieties Pavon gave the highest grain yield followed by varieties K6295 and Enkoy whereas Boohai (the modern variety) was the highest yielder among durum wheat close to the expectations farmers gave during field survey (data not shown). The yield at experimental stations ranged from 5 to 7 tonnes ha^{-1} were reported earlier for modern wheat varieties (Tarekegne, 1996). The number of kernels spike^{-1} and the thousand seed weight among bread and durum wheat appeared to be also different. Almost all bread wheat varieties had higher number of kernels spike^{-1} and highest thousand seed weight than durum wheat varieties and therefore widely accepted by farmers because of high yield potential. Alemayehu et al. (1999) reported substantially higher number of grains per spike but similar results with this study for thousand seed weight for recently released bread wheat varieties. In general durum wheat landraces have low thousand seed weight compared to modern varieties (Belay

Table 6. Simple Pearson correlation coefficient of agronomic traits for bread wheat (matrix above diagonal) and durum wheat (matrix below diagonal).

Variables	TIL	DTH	DTM	GFP	PH	GYD	BYD	NKS	TSW
Tillers plant^{-1} (TIL)	1.00	**-0.26**	**0.03**	**0.26**	**-0.18**	**0.03**	**0.13**	**-0.23**	**0.40**
Days to heading (DTH)	0.10	1.00	**0.12**	**-0.99****	**0.26**	**-0.03**	**-0.03**	**0.09**	**-0.63***
Days to maturity (DTM)	0.40	0.28	1.00	**0.44**	**0.24**	**0.11**	**0.28**	**0.03**	**-0.01**
Grain filling period (GFP)	0.09	-0.90**	0.17	1.00	**-0.21**	**0.16**	**0.08**	**-0.09**	**0.64****
Plant height (PH)	-0.16	-0.53	0.07	0.57	1.00	**0.23**	**0.56***	**-0.66****	**-0.03**
Grain yield (GYD)	0.28	-0.86**	0.07	0.91**	0.57	1.00	**0.51**	**-0.11**	**0.16**
Biomass yield (BYD)	0.48	-0.13	0.51	0.37	0.09	0.46	1.00	**-0.51**	**0.37**
Number of kernels spike^{-1} (NKS)	0.12	-0.77**	0.21	0.88**	0.70*	0.89**	0.48	1.00	**-0.45**
Thousand seed weight (TSW)	0.28	-0.77**	0.25	0.90**	0.50	0.94**	0.51	0.91*	1.00

Note: * and ** are significant at P ≤ 0.05 level and P ≤ 0.01, respectively.

et al., 1993).

A wide range in the extreme values of each of the traits studied particularly among the modern varieties will provide farmers an opportunity to make a choice of genotypes that will fit best to their niche environmental conditions. Moreover, the variation that exists among the landraces offers broad opportunities for using the genotypes with desired agronomic characters in the plant breeding program to develop new varieties suitable for different agroecological zones of the country.

Correlation coefficient analysis

The correlation coefficients between agronomic traits are presented in Table 6. In bread wheat correlation among the traits was not only weak but also insignificant with few exceptions. The correlation between days to heading and thousand seed weight was highly significant and negatively correlated (P ≤ 0.01). The longer the days to heading, the lower the thousand seed weight probably due to shorter grain filling period. Grain filling period had a highly significantly negatively correlated with days to heading and a highly significantly positively correlated with thousand seed weight. Similarly, plant height was significantly negatively correlated with number of kernels per spike (P ≤ 0.01) and a significantly positively correlation with biomass yield (P ≤ 0.05). The negative association between plant height and number of kernels was due to the modern bread wheat varieties with short plant height had long spikes and thus more grains as compared to tall landraces with short spike length associated with a low number of kernels spike^{-1}. A positive association is expected between plant height and biomass yield because the taller the plants the more is the biomass yield. Moreover, some of the modern bread wheat varieties had high tillering capacity and therefore produced more biomass yield comparable to the landraces.

In durum wheat, days to heading were significantly negatively correlated with grain yield and yield components such as the number of kernels spike^{-1} and thousand seed weight. Grain filling period had highly significantly positively correlated with grain yield, number of kernels plant^{-1} and thousand seed weight, but highly significantly negatively correlated with days to maturity. However, grain yield was significantly (P ≤ 0.01) correlated with the number of kernels per spike and thousand seed weight. Moreover, the number of kernels spike^{-1} was positively and significantly correlated with thousand seed weight. The findings are similar to what Belay et al. (1993) reported in that days to heading had significantly negatively correlated with grain yield, number of kernels and thousand seed weight; and the grain yield had significant positive correlation with number of kernels and thousand seed weight in durum wheat landraces from central Ethiopia. They also found a highly significant negative association between grain filling period and days to maturity, but a positive association with thousand seed weight which is similar to present findings. The kernel weight was reported as an important yield component in durum wheat landraces (Belay et al., 1993).

Variance component analysis

Variance component analysis revealed little significant differences among the bread and durum wheat varieties for agronomic characteristics except for days to heading for bread wheat and thousand seed weight for durum wheat and qualitative characteristics such as growth habit, grain color and grain shape for both wheat types (data not shown). The estimates of variance components showed the contribution of collection sites towards the patterns of variation that existed among the genotypes which is more pronounced for durum landraces compared to modern bread varieties. This is well understood given the recent introduction of modern varieties to their collection sites and where any variation is expected from the genotypes than the effect of collection sites. Estimates of variance components showed that the patterns of variation among

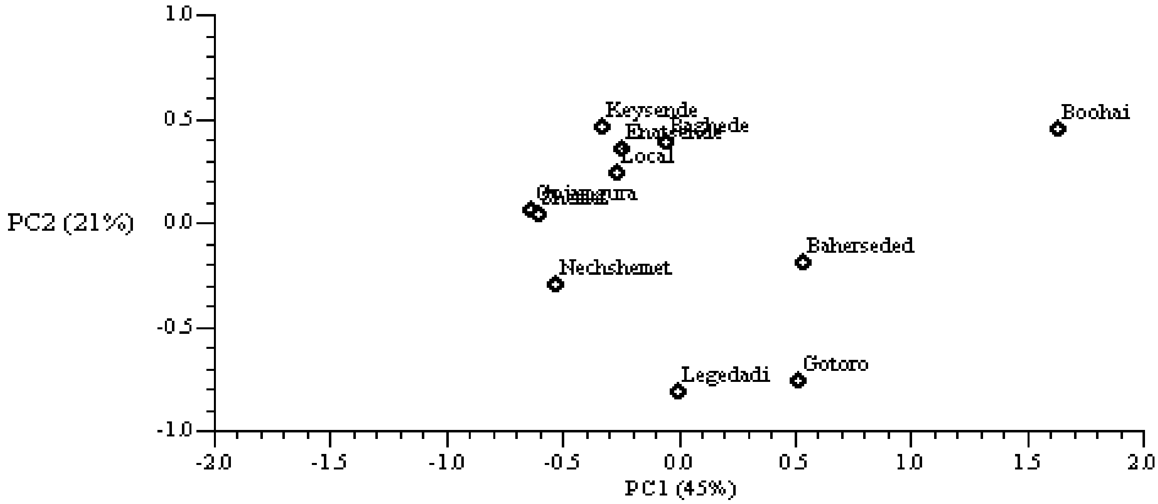

Figure 5. Principal component plot of durum wheat varieties based on 12 agronomic and phenotypic traits.

the genotypes were attributed to the collection sites (provinces and districts) from the lowest of 36% for grain yield to 74% of the variation for plant height among the durum varieties and landraces, although this is not significant in all cases. Tesemma et al*.* (1991) also found that diversity among durum landraces from central Ethiopia was attributed to their collection sites (districts) than variation within the populations. There was no significant difference among all the estimates of mean diversity for the populations and districts except for glume pubescence.

However, by dropping the collection sites from the model, almost all the agronomic characters measured such as plant height, grain yield, biomass yield, number of kernels spike^{-1} and thousand seed weight showed remarkable significant variation among the genotypes. Therefore, there was a significant difference (P<0.001) among bread wheat varieties for tillers plant^{-1}, days to heading, grain yield, number of kernels spike^{-1} and thousand seed weight. Days to maturity and biomass yield were not significant among bread wheat varieties. Likewise, durum wheat varieties showed significant differences (P ≤0.001) for days to heading, grain yield, and thousand seed weight. Number of kernels spike^{-1} was significant at P≤ 0.01. The number of tillers plant^{-1}, days to maturity and biomass yield was not significantly different among the durum wheat varieties. On the contrary significant difference on number of tillers plant^{-1} was observed among landraces of wheat collected from central Ethiopia and suggested as useful agronomic trait for crop improvement programs in the country (Belay et al., 1993).

Principal component analysis

The principal component analysis was made to estimate the relative contribution of the different traits studied towards the overall agro - morphological variations among the local durum landraces. The analysis showed that the first three components with eigenvalues more than unity altogether explained 84% of variation among 11 durum wheat landraces for 12 agronomic and phenotypic characteristics studied (data not shown). The first, second and third components each accounted for 45, 21 and 18% of the variation, respectively. Plant height, grain yield, number of kernels spike^{-1} and thousand seed weight were most important agronomic characters contributing to the first principal component. The qualitative morphological characters such as growth habit, ear shape, grain color and grain shape were important for the second component. According to Demisie and Habtemariam (1991) Ethiopian durum wheat landraces exhibited an enormous variation in spike form, spike density, awn size and glume color and glume hairiness. The third component was associated with days to maturity, tillers plant^{-1} and biomass yield. Ayana and Bekele (1999) also found that plant height and days to 50% flowering as important agronomic characters for classifying sorghum germplasm in Ethiopia.

The distribution of durum wheat landraces along the first two axes of the principal components is presented in Figure 5. The first principal component is more important in separating the durum wheat landraces as compared to the second component. The extreme right of the first component was occupied by Boohai, a modern variety developed from germplasm materials introduced from CIMMYT compared to other landraces which are known to be of Ethiopian origin. The first principal component differentiated the low yielding landraces from high yielding modern variety based on grain yield and yield components such as number of kernels spike^{-1} and thousand seed weight. Belay et al. (1993) reported that landraces were late in days to heading and maturity and had lower kernel

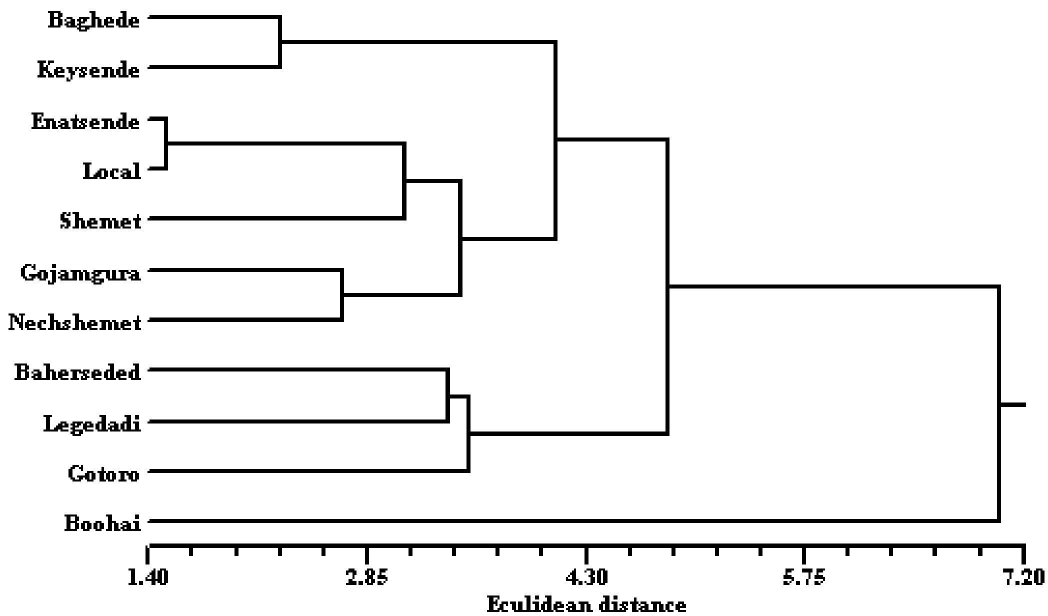

Figure 6. Dendrogram showing clustering of durum wheat landraces collected from farmers in Ethiopia.

weight compared to Boohai, a modern variety. The second component was able to separate early maturing landraces from late maturing genotypes. Gotoro and Legedadi occupied the extreme negative values of the second component and appeared to head earlier compared to other genotypes. Baherseded, Shemet and Nech shemet heads slightly later than other genotypes. Landraces such as Baghede, Enat sende, Gojam gura and Key sende (‘red’ grain) as the name suggests could be separated from others on the basis of seed color. Belay et al. (1995) reported that local landraces exhibited a wide range of colors from white, red/brown to purple colored grains; and the purple-grain landraces have useful agronomic traits such as early maturity, shorter height, higher fertility, tillering capacity and harvest index. However, most of the modern wheat varieties had amber color (Alemayehu et al., 1999) with few exceptions such as Enkoy and K6295 with red kernels.

Cluster analysis

Clustering based on agro – morphological traits revealed three clusters separating the recently introduced modern variety (Boohai) and long established landraces (Figure 6). The correlation between the cophenetic value matrix and actual matrix data was very high (0.91) indicating a very good fit of the cluster analysis performed. The durum wheat landraces were not all clustered along their region of geographic origin based on the morphological traits. Baherseded, Gotoro and Legedai were collected from West Shoa and were clustered together but differently from Bagehede and Key sende which were collected from the same region. Enate sende, Gojam gura and Shemet all from North Shoa were within the same sub-cluster with another unidentified local landrace from the same region. However, Nech shemet was clustered with Gojam gura instead of Shemet. The durum wheat landraces from North Shoa were heading late, had low grain filling period and low grain yield. Kebebew et al. (2001a) also reported that durum landraces collected from central and southeastern Ethiopia were not clustered along their collection sites or geographic origin. Instead, durum landraces with similar vernacular names collected from different sites or geographic regions were clustered together than those landraces from the same collection sites or geographic regions. Ethiopian durum wheat landraces exhibited tremendous diversity for some phenotypic characteristics such as grain color ranging from white to purple. Landraces such as Baghede, Enat sende, Gojam gura and Key sende (‘red’ seeded wheat as the name suggests) were grouped together within the same sub-cluster because of their patterns of grain color mixtures. Tesemma et al. (1991) reported that a high proportion of landraces had purple seed color across different districts. Some landraces such as Tikur sende are used for specific purposes such as for brewing local beer or spirits (Kebebew et al., 2001a) while white colored ones are used for social or religious festivities. The prefixes such as *‘key’* (red), *nech* (white), *tikur* (black), *sergegna* (white and red mixture) are useful folk taxonomy in classifying landraces based on the proportion of grain color mixtures not only in wheat but also in other crops such as barley (Kebebew et al., 2001b) in Ethiopia. Local names could be used to describe the performance or to indicate the original source of landraces. Moreover, farmers may coin new names for modern varieties and some varieties are better known by their adopted name than their release names. For example a bread wheat variety, HAR 1685 is named popularly by farmers as *Qubsa* because of its high yield.

In case of bread wheat the principal component analysis showed that the first four components with eigenvalues more than unity accounted for 74% (22, 21, 18 and 12%, respectively) of the variation among the varieties (data not shown). The first component was associated with plant height and ear shape whereas the second component was with agronomic characteristics such as days to maturity, grain yield, biological yield and phenotypic characteristics such as ear color and grain color. The third component was associated with agronomic traits such as tiller plant^{-1} and thousand seed weight and the fourth with number of kernels spike^{-1}. Clustering separated the varieties into six clusters (data not shown). Israel, one of the 'oldest' popular bread wheat of unknown origin was placed completely distinct from the rest of the group. The local variety had the highest thousand seed weight and unique phenotypic characteristics in terms of ear shape and awn condition compared to other bread wheat varieties. In Cluster 2 Enkoy and K6295 were grouped together because of their unique red grain color as compared to all bread wheat varieties with white to amber color including local bread wheat varieties (Alemayehu et al., 1999). This is in contrast to durum landraces where variable grain color is most common. ET 13 and Goli had the highest plant height and were therefore grouped together in Cluster 3 while Zombolel, another landrace, stood alone in Cluster 5. However, the clusters did not match the clustering constructed from the COP values.

The Ethiopian farmers are growing durum wheat for millennia and the country was recognized as a center of diversity for tetraploid wheats (Demissie and Habtemariam, 1991) while the bread wheat is comparatively of recent introduction (Gebremariam, 1991). The national bread wheat breeding program has benefited substantially from the introduced germplasm from the International Agricultural Research Centers (IARCs). As a result, plant breeders have made good achievement in developing varieties acceptable to farmers at least in favorable production areas. There is substantial increase in bread wheat area and production in traditionally durum wheat growing regions of central and northwestern Ethiopia. At present, the high adoption and diffusion rate of modern varieties coupled with recurrent drought in traditionally durum wheat growing areas of the country are threatening the existence of landraces and leading to loss of such immense diversity (Bishaw, 2004). Moreover, the predominance of a few bread wheat varieties calls for concern in a country where devastating rust epidemics are common features of crop production. There seems to be an urgent desire for appropriate conservation measures to be undertaken for the durum wheat landraces and at the same time diversify the choice of bread wheat varieties available to farmers.

The diverse agro-ecology and long history of association with the wheat crop and its production under a variety of socio-economic and cultural situations led to the evolution of highly diverse forms of landraces which could be of practical benefit for crop improvement. Several workers reported the diversity of quantitative and qualitative characters of the Ethiopian wheats (Demissie and Habtemariam, 1991; Belay et al., 1993, Tesemma et al., 1991). Durum wheat landraces such as Enat sende and Nech shemet from North Shoa identified by farmers as having frost tolerance (Kebebew et al., 2001a). Moreover, purple seeded wheat matures earlier and has higher tillering capacity than other color types and a good adaptation to water-logged soil conditions in high-altitude areas (Kebebew et al., 2001b). Monomorphism for awn condition (presence or absence) was also reported for landraces which is similar to our findings, a useful trait for tolerance to plant diseases (Tesemma et al., 1991). It was suggested, however, that durum wheat crop improvement would be possible through indirect selection for tiller numbers plant^{-1} and thousand seed weight or direct selection for yield *per se* (Belay et al., 1993). Moreover, alternative breeding strategies led to the development of 'composites' with up to 20 to 25% more yield than local landraces and 10 to 15% more than modern varieties (Tesemma and Bechere, 1998). The study has shown that the few wheat varieties, particularly the durum wheat landraces collected from farmers, were diverse in agronomical and phenotypic characteristics offering greater opportunities for developing germplasm adapted to the varied agroecology and diverse end uses and consumer preferences. This would contribute towards the maintenance of genetic diversity on the farm and counter balance the ensuing genetic erosion.

Conclusion

The Ethiopian highlands are considered the centers of diversity of tetraploid wheats where a considerable wealth of genetic variability and diversity still exists on the farm. The diverse agro-ecology of Ethiopia coupled with a long history of association with the crop under a variety of socio-economic and cultural situations led to the evolution of highly diverse forms of these crops. Until recently this wealth of genetic diversity has been maintained by generation of farmers. However, the introduction of modern agriculture brought a dramatic shift in wheat production practices. There was a remarkable increase in the adoption of modern bread wheat varieties in predominantly durum wheat growing regions of the country as farmers are striving to maximize production and achieve food security from diminishing and meager land resources. The wide spread adoption and diffusion of modern bread wheat varieties could lead to the replacement or displacement of these valuable genetic resources - the loss of durum landraces. The loss of landraces also leads to loss of traditional knowledge in crop improvement and maintenance. It is important to design an innovative and integrated genetic resources conservation, maintenance, enhancement and utilization strategies and approaches that could meet the food security and livelihoods of farmers dependent on these crops. It is desirable that the participation of national governments and all stakeholders in formulating and targeting the interventions required.

The national agricultural research systems made a spectacular progress and achievement in developing modern varieties of bread wheat that meet farmers' preferences. In contrast, there is little headway in crops like durum wheat where landraces still dominate the agricultural landscape. Not only was there a lack of success in developing modern varieties, but farmers also rejected those varieties released by the national programs and the area under improved varieties is negligible. The Ethiopian durum wheat production areas are characterized by highly varied microenvironments such as topography, soil type, soil moisture (water-logging), temperature and frost. In apparent effort to circumvent the failure of conventional crop improvement program alternative breeding strategy is suggested for durum wheat in Ethiopia. Therefore, the national agricultural research systems should introduce and institutionalize participatory approaches as a means of identifying new varieties that farmers prefer and link this with formal plant breeding and seed production activities. Adoption of such varieties by farmers not only enhances productivity, but also maintains and improves on-farm varietal diversity of durum wheat.

The agro - morphological studies revealed a wide range of variation for each of the traits studied particularly among the modern bread wheat varieties that will provide farmers an opportunity to make a choice of genotypes that will fit best to their niche environments. Moreover, the variation that exists among the landraces offers broad opportunities for using the genotypes with desired agronomic characters in the plant breeding program to develop varieties suitable for different agro ecological zones of the country. In Ethiopia, past effort to use exotic germplasm in developing durum wheat varieties with wider adaptation to the local conditions met with little success and the locally adapted germplasm remains under-exploited in the national breeding program. Therefore, the national agricultural research system should incorporate the local landraces into their breeding program and develop location specific varieties that meet farmers' requirements and also increase on-farm diversity.

Spatial diversity, temporal diversity, coefficient of parentage analysis and measurements of agronomic and morphological traits were employed to explain the diversity of wheat varieties or landraces grown by farmers in Ethiopia. While the spatial diversity and temporal diversity indicates the domination of few selected varieties in terms of area coverage, the agronomic and phenotypic measurements showed remarkable variation that existed both among modern varieties and local landraces that would provide broader opportunities for use in crop improvement and production. Since different measurements and scales were used to define diversity it would be difficult to ascertain a set of common indicators and their interrelationships that would satisfy both the biological scientists and social scientists concerned with biodiversity issues. It is imperative that a multidisciplinary approach is undertaken to address the problem and develop a common framework for assessing genetic diversity that would enable policy changes required to enhance the conservation and utilization of these resources to the benefit of farmers and the society at large.

This study was not meant to measure wheat diversity *per se* or intended to investigate the patterns of diversity from the geographic or agroecological context. It was rather an attempt to look into the agronomic and morphological traits diversity of sets of varieties currently used by farmers and any specific traits that are associated with farmers' considerations or preferences for particular group of varieties or landraces.

Conflict of Interest

The authors have not declared any conflict of interest.

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The effect of harvest conditions and drying temperature on drying kinetics of two popcorn genotypes

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The present work aimed to assess the effect of the initial moisture content of grains (at harvest), velocity of the harvester cylinder and air temperature on the diffusion coefficient, as well as to achieve the activation energy of the drying process of two popcorn cultivars. Grains of popcorn from the cultivars Zélia and CMS 43 were mechanically and manually harvested and thrashed. The rotations of the threshing cylinder were fixed at 500, 600 and 700 rpm, with initial moisture contents of 0.235 and 0.175 db. They were dried with drying air temperatures of 40, 50 and 60ºC, until reaching the final moisture content of 0.137 db. The diffusion coefficient increased with increased air temperature, presenting average values from 6.345 × 10^{-11} to 3.075 × 10^{-13} m^2s^{-1} for the temperature range studied, depending on the initial moisture content, cultivar and level of mechanical damage. The cultivar CMS 43 (C2) is more resistant to the mechanical damage caused by the threshing cylinder, and the structural changes caused by it increased the diffusion coefficient. The relation between diffusion coefficient and temperature can be described by the Arrhenius expression, which presents activation energy for liquid diffusion in the grains of popcorn from 1.50 to 45.92 kJ mol^{-1}.

Key words: Mechanical damage, initial moisture content, diffusion coefficient.

INTRODUCTION

Popcorn cultivation is increasing throughout the years in several countries, including Brazil, due to the consumption increment of popcorn, especially after microwave use. Furthermore, this culture has some favorable aspects when compared to conventional corn grain, such as: High mechanization potential at all production processes; lower susceptibility to plague and diseases during plant development. Besides, its commercial value is, at least, two times superior to traditional corn grain.

Moisture content reduction is essential in order to diminish the material biological activity. In addition, chemical and physical occurs due to drying procedure, which consequently affects storage of the product. The moisture content reduction involves heat and mass transfer processes, which can substantially change the grain's quality.

Water transport in agricultural products demands a

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Table 1. Harvesting machine characteristics for each cultivar.

Characteristics	Dimension
Cylinder diameter	0.35 m
Cylinder width	0.80 m
Concave length	0.31 m
Entrance opening between cylinder and concave (cultivar Zélia)	14.90 mm
Exit opening between cylinder and concave (cultivar Zélia)	7.65 mm
Entrance opening between cylinder and concave (cultivar CMS 43)	17.08 mm
Exit opening between cylinder and concave (cultivar CMS 43)	8.89 mm

driving force, either by adsorption or desorption, that is, a concentration gradient between their surface and the inner part (Botelho, 2009). Although many mechanisms have been proposed in the available literature, the primary means of water transportation is liquid diffusion (Fortes and Okos, 1980; Geankoplis, 1983). Diffusion occurs in solids with thin structure and in capillaries, pores and small holes full of steam. However, the diffusion theory disregards shrinkage, hardening of the shell and sorption isotherms (Barbosa-Cánovas and Veja-Mercado, 2000).

The liquid diffusion mechanism is very complex due to the diversity of the chemical composition and physical structure of products. The data available in literature presented very different values, due to the complexity of the products, and the function of the different estimation methods, type of material, moisture content, drying process and methodology used.

The effective diffusion coefficient is an important property in the transportation of water. Its dependence on temperature is frequently reported in classical literature (Gely and Giner, 2007; Addo et al., 2006; Goneli et al., 2007). According to Giner and Mascheroni (2002), the value of this coefficient also depends on the initial moisture content. Besides, Botelho (2009) considers that the physical integrity of a product is another fact that significantly affects this value.

Mechanical damage in grains and seeds during harvest, thrashing and processing are extremely harmful to their quality, causing breakage, cracks, cuts and abrasion, which may reduce their physiological quality (Araújo et al., 2002). In addition, Goneli et al. (2005) found that the effect of mechanical damage on the physiological quality of seeds of popcorn during storage depends on the level of damage caused by mechanical impact.

The present work aims to aid the producers and companies related to popcorn agribusiness to perform harvest decision due to the impact of different procedures during harvest and the consequences for popcorn quality. Therefore, investigation of the effect of the initial moisture contents of the grains (at harvest), velocity of the harvester cylinder and drying air temperature on the diffusion coefficient, as well the activation energy of the drying process in two popcorn cultivars were accomplished.

MATERIALS AND METHODS

Grains of popcorn from the cultivars Zélia and CMS 43 were used in this work. The planting was performed in the experimental field of the EMBRAPA-Centro Nacional de Pesquisa de Milho e Sorgo, located in Sete Lagoas-MG. The harvest was carried out when maize reached the moisture contents of 0.235 and 0.175 db. The hot air drying method at 105 ± 3ºC for 24 h was employed to determine the moisture content (Brazil, 1992).

Harvest and thrashing were performed in two ways: Manually and with the aid of a harvester machine (pull-type harvester, model "Double Master", axial flow system), with harvester cylinder rotations fixed at 500, 600 and 700 rpm. Internal characteristics of harvesting machine are presented at Table 1.

After thrashing, the samples were manually cleaned and then placed into two low-density polyethylene bags, properly sealed and identified, which were put into a refrigerator at 4ºC for 24 h, to maintain the initial moisture content of the harvest. Then, they were transferred in styrofoam boxes to the Laboratory of Pre-Processing of Agricultural Products of the Department of Agricultural Engineering of the Universidade Federal de Viçosa, located in Viçosa-MG, where they were stored in a refrigerator at 4ºC and 80 ± 5% of RH, until the beginning of the experiment.

Drying was carried out with the aid of a laboratory dryer (Ethik Technology, model 440/DE), in thin layer, with controlled temperature and air flow. Drying air velocity was maintained constant at 1 $m\,s^{-1}$ and monitored by a digital anemometer with rotating blades. The air flow was provided by an axial fan that conducted the air to the plenum and from there to three individualized chambers with removable trays with screened bottom. Drying air temperatures of 40, 50 and 60ºC were used and measured by a mercury thermometer installed just below the layer of grains. The temperature and air relative humidity were recorded, with the use of a thermohygrograph (RENE GRAF). It was determined that drying would finish when the samples reached the pre-established moisture content of 0.137 db. A semi-analytical balance (Gehaka, model BK 400, Brazil) with precision of ± 0.01 g was used to monitor drying, and the samples were weighed at every five-minute interval by retrieving the drying trays from the dryer. Weighting procedure lasted about 30 s.

Thin layer drying is defined as the one with thickness of only one grain. The thin layer drying equation, added to representative equations of other physical properties specific to the product under study, forms a set of mathematical relations that help in the calculations and understanding of the thick layer drying process. It is considered that a thick layer of grains is composed of successive overlapped thin layers. For Chittenden and Hustrulid (1966), the theory used to describe the drying phenomenon may be based on the principle that resistance to moisture transport is concentrated in the surface of grains, according to the following differential equation:

$$\frac{dU}{dt} = -k(U - U_e) \quad (1)$$

Where U and U_e are the moisture content of the product for a certain time and the equilibrium moisture content (kg/kg), respectively; K is the drying constant (s^{-1}); t is the drying time (s).

By integrating this equation between the U_0 limits in the beginning of the process, and U_t at any time of drying, t, we have:

$$\frac{U_t - U_e}{U_0 - U_e} = RU = \exp(-kt) \quad (2)$$

Where RU is the humidity ratio, dimensionless; U_0 is the moisture content of the product at time zero (kg/kg); t is the drying time (s).

The equilibrium moisture content of popcorn, for the conditions of temperature and drying air relative humidity, was calculated by the Sigma-Copace equation (Corrêa et al., 1998).

$$U_e = \exp(a - bT + c\exp(UR)) \quad (3)$$

Where T is the drying air temperature, ºC; UR is the drying air relative humidity, decimal; a, b and c are the specific parameter of the product (a = 1.2658, b = 0.0053 and c = 0.7879).

According to Brooker et al. (1992), in the liquid diffusion theory, the second Law of Fick has been used to establish water diffusion according to the concentration gradient.

$$\frac{\partial U}{\partial t} = \frac{\partial}{\partial x}\left(D_{ef}\frac{\partial U}{\partial x}\right) \quad (4)$$

Where D_{ef} is the liquid diffusion coefficient, $m^2 s^{-1}$; x is the distance from a reference point, m.

The variation of the moisture content according to the time of drying, for homogenous materials with constant diffusion coefficients, is represented by the following equation:

$$\frac{\partial U}{\partial t} = D_{ef}\left(\frac{\partial^2 U}{\partial r^2} + \frac{c}{r}\frac{\partial U}{\partial r}\right) \quad (5)$$

Where r is the radial distance or thickness, m; c is 0 for plane bodies, 1 for cylindrical bodies and 2 for spherical bodies.

Brooker et al. (1992) present the following analytical solution for the spherical geometric shape:

$$RU = \frac{U_t - U_e}{U_0 - U_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left[-\frac{n^2\pi^2 D_{ef} t}{9}\left(\frac{3^2}{R}\right)\right] \quad (6)$$

Where n is the number of terms; R is the equivalent radius, m.

The diffusion coefficient was achieved by the Equation (6). The analytical solution of this equation is presented as an infinite series and the finite number of terms (n) in the truncation can determine the accuracy of the results.

The equivalent radius, used in the liquid diffusion model, is defined as the radius of a sphere with the same volume as the grain. It is determined by the measurement of the three orthogonal axes (length, width and thickness), as proposed by Mohsenin (1986), in fifteen grains, with the aid of a digital caliper. The volume of each grain, considered a spheroid, was achieved by the expression:

$$V_g = \frac{\pi(abc)}{6} \quad (7)$$

Where a is the largest grain axis, mm; b is the average grain axis, mm; c is the smallest grain axis.

The dependence of effective moisture diffusivity (D_{ef}) on drying temperature has been shown to follow an Arrhenius relationship (Bai et al., 2013; Xiao et al., 2012) as shown in Equation (8).

$$D_{ef} = D_0 \exp\left(-\frac{E_a}{RT_{abs}}\right) \quad (8)$$

Where D_0 is the pre-exponential factor, $m^2 s^{-1}$; E_a is the activation energy, kJ mol^{-1}; R is the universal gas constant, kJ $mol^{-1} K^{-1}$; T_{abs} is the absolute temperature, K.

RESULTS AND DISCUSSION

Table 2 shows the values of the diffusion coefficient, using the initial equivalent radius of popcorn, related to the cultivars, initial moisture contents of the product at harvest, velocity of the harvester cylinder and drying air temperature.

The analysis of the results demonstrates that the diffusion coefficient increased with increased drying air temperature. It agrees with several researchers (Goneli et al., 2007; Côrrea et al., 2006a; Campos et al., 2009) and suggests that, for lower temperatures, popcorn grains offer more internal resistance to water transport, which leads to lower diffusion coefficients. Thus, increased drying air temperature indicates higher intensity of the phenomenon of water transport from the inner part to the periphery of the grain. Campos et al. (2009) affirm that water viscosity decreases with increased temperature. Since it is a measure of resistance of the fluid to flow, variations of this property result in changes in water diffusion in the capillaries of grains, thus favoring the movement of this fluid in the product. Similarly, the level of molecular vibrations of water molecules is also intensified, which contributes for a more efficient diffusion.

The values of diffusion coefficient ranged from 0.30756 to 63.45711 × 10^{-12} $m^2 s^{-1}$. Xiao et al. (2010a) found this parameter values from 1.82 to 5.84 × 10^{-10} m s^{-2} for grapes whilst Xiao et al. (2010b) reported values from 0.265 to 1.052 × 10^{-9} $m^2 s^{-1}$ for carrot cubes. These different values can be explained by differences in the chemical composition, physical structure, and geometry of the products, in addition of different drying methods.

It can be observed that, for the initial moisture content

Table 2. Diffusion coefficient using the initial equivalent radius of two popcorn cultivars, Zélia and CMS 43, moisture content of the product at harvest, velocity of the harvester cylinder and drying air temperature.

Combinations*	Diffusion coefficient ×10^{-12}(m^2 s^{-1})	Combinations*	Diffusion coefficient ×10^{-12}(m^2 s^{-1})
C1U1MT1	0.55217	C2U1MT1	61.28197
C1U1MT2	0.71859	C2U1MT2	61.60351
C1U1MT3	1.02783	C2U1MT3	63.45711
C1U1V1T1	0.73437	C2U1V1T1	0.71990
C1U1V1T2	0.90948	C2U1V1T2	0.91302
C1U1V1T3	1.31225	C2U1V1T3	1.31119
C1U1V2T1	0.64649	C2U1V2T1	0.69295
C1U1V2T2	0.83726	C2U1V2T2	0.95145
C1U1V2T3	1.10687	C2U1V2T3	1.36117
C1U1V3T1	0.44876	C2U1V3T1	0.78911
C1U1V3T2	0.94171	C2U1V3T2	1.03465
C1U1V3T3	1.28857	C2U1V3T3	1.35387
C1U2MT1	0.30756	C2U2MT1	0.38353
C1U2MT2	0.44608	C2U2MT2	0.49308
C1U2MT3	0.60189	C2U2MT3	0.72197
C1U2V1T1	0.37389	C2U2V1T1	0.51966
C1U2V1T2	0.44885	C2U2V1T2	0.72273
C1U2V1T3	0.63210	C2U2V1T3	1.05531
C1U2V2T1	0.33539	C2U2V2T1	0.47191
C1U2V2T2	0.49218	C2U2V2T2	0.68524
C1U2V2T3	0.55343	C2U2V2T3	0.97063
C1U2V3T1	0.44876	C2U2V3T1	0.53754
C1U2V3T2	0.59906	C2U2V3T2	0.81223
C1U2V3T3	0.80104	C2U2V3T3	1.04777

* C1 and C2: Cultivars Zélia and CMS 43, respectively; U1 and U2: Initial moisture content of the product at harvest, 0.235 and 0.175 (d.b.), respectively; M: Manual harvest and thrashing; V1, V2 and V3: Mechanical harvest and thrashing with velocity of the harvester cylinder of 500, 600 and 700 rpm, respectively; T1, T2, T3: drying air temperature (40, 50 and 60°C), respectively.

(U1), the diffusion was higher than (U2), since the higher the water concentration gradient between the surface and the inner part of a product, the higher the diffusion. This fact was also observed by Giner and Mascheroni (2002), who reported increased diffusion coefficient for initial moisture content values of 0.2694; 0.2396; 0.2133 and 0.1891 db for wheat grains. Besides, on average, the cultivar CMS 43 (C2) is the most resistant to the mechanical damage of the cylinder, because it presented lower values for diffusion coefficient.

Higher values of diffusion coefficient were found for elevated thrashing velocity (higher mechanical damage), on average, when compared to the values of this parameter for grains with lower thrashing velocity (lower mechanical damage). The same phenomenon was observed by Botelho (2009), while studying water absorption by maize with different levels of mechanical damage, and by Campos et al. (2009), when they assessed coffee grain drying at different stages of wet processing. However, it did not occur for the combination C2U1M because a preferential way for gas exchange with the environment may have been formed, while mechanical damage caused changes in the intracellular configuration, bringing together the cells previously apart from each other.

As an example, Figure 1 presents the graphic of correspondence among the values observed and estimated according to humidity for the combination C1U1V1. This figure shows the appropriate adjustment of the moisture diffusion model for the kinetic description of popcorn grain drying.

The dependence of the diffusion coefficient on drying air temperature has been satisfactorily described by the Arrhenius equation. Figure 2 shows the Arrhenius representation for the diffusion coefficients according to the drying air temperatures for the combination C1U1V1.

The slope of the curve of the Arrhenius representation provides the E_a/R relation, while its intersection with the Y-axis indicates the value of D_0. According to Sharma and Prasad (2004), thermodynamically, the activation energy represents the energy necessary for the disruption of the barrier that the water molecules face during the drying process, when they migrate from the interior to the surface of the product, and the lower it is, the higher the water diffusivity in the product. Reduced activation energy of a process causes increased average energy of the

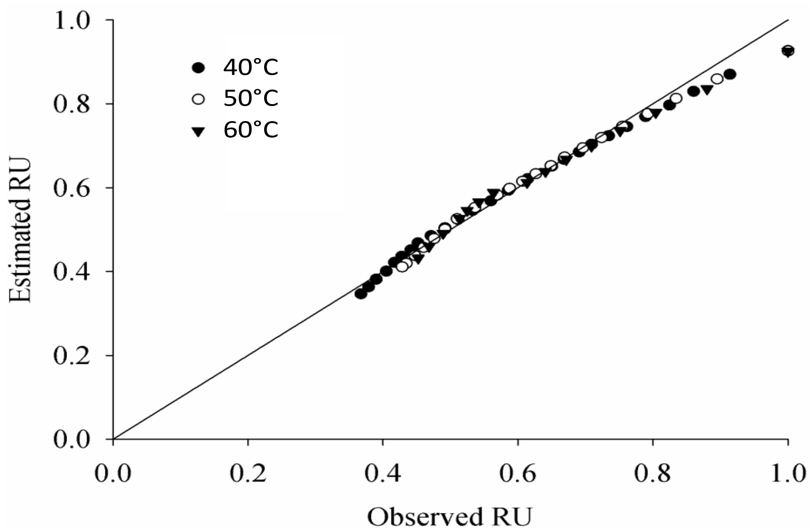

Figure 1. Observed and estimated values of humidity for the combination C1U1V1.

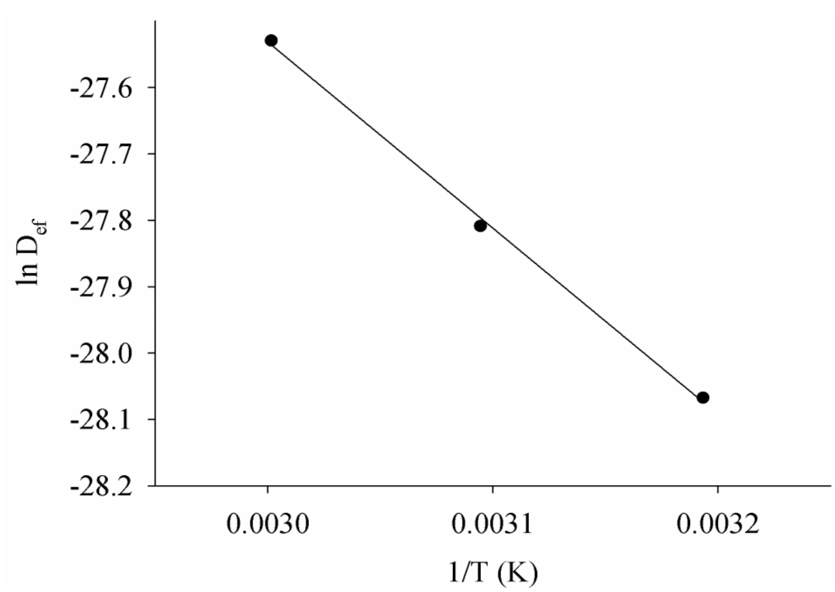

Figure 2. Arrhenius representation for the diffusion coefficients according to the drying air temperatures for the combination C1U1V1.

molecules that compose it. The values of activation energy and pre-exponential factor found in this work (Table 3) corroborate those found in literature (Campos et al., 2009).

It is observed that, on average, for the cultivar Zélia (C1), the higher the moisture content, the lower the activation energy needed, as found by Xiao et al. (2012). However, for the cultivar CMS 43 (C2), the same trend is not observed, since it presents higher resistance to the impacts and abrasive mechanical efforts that generate fissures and cracks, caused by the thrasher cylinder, which overlaps the moisture content factor.

Values of activation energy ranged from 1.50 to 45.92 kJ mol^{-1} with median value of 26.79 kJ mol^{-1}. Researchers reported different values of activation energy, such as 67.29 and 20.17 kJ mol^{-1}, respectively by Xiao et al. (2010a) and Xiao et al. (2010b). This trend indicates the need of the study of different agricultural products, due to variety of physical and chemical properties, which interferes at the drying process.

Table 3. Calculated values of the activation energy and pre-exponential factor of water diffusion in popcorn grains for the temperature range under study.

Combinations*	Activation energy (kJ mol^{-1})	Pre-exponential factor ($m^2 s^{-1}$)
C1U1M	26.90	2.88
C1U1V1	26.00	2.91
C1U1V2	23.31	2.95
C1U1V3	45.92	2.37
C1U2M	29.14	2.87
C1U2V1	26.69	2.99
C1U2V2	21.83	3.01
C1U2V3	25.12	2.93
C2U1M	1.50	3.13
C2U1V1	25.94	2.89
C2U1V2	29.25	2.82
C2U1V3	23.41	2.94
C2U2M	27.37	2.90
C2U2V1	30.69	2.80
C2U2V2	31.28	2.79
C2U2V3	29.00	2.84

*C1 and C2: Cultivars Zélia and CMS 43, respectively; U1 and U2: Initial moisture content of the product at harvest, 0.235 and 0.175 (d.b.), respectively; M: Manual harvest and thrashing; V1, V2 and V3: Mechanical harvest and thrashing with thrasher cylinder velocity of 500, 600 and 700 rpm, respectively.

Conclusions

1. The liquid diffusion model satisfactorily represents the kinetics of the drying of popcorn grains, for the experimental conditions.
2. The diffusion coefficient increases with increased air temperature, presenting average values from 6.345×10^{-11} to 3.075×10^{-13} $m^2 s^{-1}$ for the temperature range studied, and it depended on the initial moisture content, cultivar and level of mechanical damage.
3. The cultivar CMS 43 (C2) is more resistant than the cultivar Zélia to the mechanical damage caused by the thrasher cylinder.
4. The structural changes caused by the thrasher cylinder led to increased diffusion coefficient, mainly due to the formation of fissures and cracks which are preferential paths to water diffusion.
5. The relation between diffusion coefficient and temperature can be described by the Arrhenius expression, which presents activation energy for liquid diffusion of 1.50 to 45.92 kJ mol^{-1} in popcorn grains.

Conflict of Interest

The authors have not declared any conflict of interest.

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