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Full Length Research Paper

Cinnamon and citronella essential oils in the *in vitro* control of the fungi *Aspergillus* sp. and *Sclerotinia sclerotiorum*

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Among the fungi that cause damage and/or are spread by seeds, *Aspergillus* sp. and *Sclerotinia sclerotiorum* stand out, which have a worldwide distribution and a wide range of hosts. A viable and safer option than chemicals would be to use natural compounds for plant disease management. The objective of this study was to evaluate cinnamon (*Cinnamomum cassia*) and citronella (*Cymbopogon winterianus*) essential oils in the in vitro control of fungi *Aspergilus* sp. and *S. sclerotiorum*. The experimental design was completely randomized in a 2x4 + 2 factorial scheme [essential oils x concentrations + (fungicide + standard control)]. Cinnamon and citronella essential oils were used in doses of 0.2, 0.4, 0.8 and 1.6 mL L^{-1} (+Tween 80 to 1%) and the Captana (480 g L^{-1}) and thiophanate-methyl + chlorothalonil (200.0 g kg^{-1} + 500.0 g kg^{-1}) fungicides, at doses of 3 g L^{-1} and 2 g L^{-1}, for the fungi *Aspergilus* sp. and *S. sclerotiorum*, respectively. The products were diluted in potato dextrose agar (PDA) medium in Petri dishes, and mycelium discs with 5 mm diameter were placed and incubated in a Biochemical Oxygen Demand (BOD) incubator at 25 ± 1°C and photoperiod of 12 h. There was significant interaction between treatments. The dose of 1.6 mL L^{-1} of both oils showed greater inhibition of the mycelial growth of fungi *Aspergilus* sp. and *S. sclerotiorum*, and the greater inhibition of sporulation of the fungus *Aspergilus* sp. It is concluded that cinnamon and citronella essential oils control the fungi *Aspergilus* sp. and *S. sclerotiorum*.

Key words: Alternative control, pathogens, *Cymbopogon winterianus*, *Cinnamomum cassia*, seed pathology.

INTRODUCTION

With the increase in the world's population, there is a growing concern about food security, regarding production and food storage. Among the major challenges of modern agriculture, the decrease in the usage of agrochemicals in disease, pest and weed management stand out, which aim at sustainable agriculture (Farooq et al., 2013; Javaid and Shoaib, 2013; Ootani et al., 2013). Plant pathogens, which cause disease, are responsible for large yield damages in many economically important crops. The use of agrochemicals in soil fumigation, foliar application or seed treatment is the most common strategy for plant disease management (Javaid and Shoaib, 2013). However, due to the adverse effects of pesticides on human health and the environment, consumers are increasingly demanding products that are free of chemical residues (Farooq et al., 2013; Javaid and Shoaib, 2013; Ootani et al., 2013).

The natural compounds from plants are safer than synthetic chemicals, which are an option for plant disease management (Javaid and Shoaib, 2013; Abreu et al., 2016). Among these natural compounds, cinnamon (*Cinnamomum* sp.) and citronella (*Cymbopogon* sp.) essential oils are used as a viable option for fungal disease management in plants, mainly due to their antifungal properties (Pawar and Thaker, 2006; Negrelle and Gomes, 2007).

Among the fungi that cause damage and/or are spread by seeds, the fungi *Aspergillus* sp. and *Sclerotinia sclerotiorum* (Lib.) de Bary, which present world distribution and a wide range of hosts (Boland and Hall, 1994; Perrone et al., 2007). The main symptoms observed in seeds infected by the genus *Aspergillus* are rotting, a decrease in germination, abnormal seedlings development and damping-off in plants. Some species of this genus may produce during storage secondary metabolites called aflatoxins, which are highly toxic, mutagenic and carcinogenic to human and animals (Perron et al., 2007).

The fungi *S. sclerotiorum* causes considerable decreases in several agricultural crops production worldwide, especially in soybeans, beans, potatoes and sunflowers, causing stem, pods and leaves to rot (Boland and Hall, 1994). The ability of this fungi to survive in the seeds, cultural remains and soil, associated with the gradual resistance to the fungicides used for their control, makes them difficult to manage (Mueller et al., 2002; Jiang et al., 2013).

In order to find efficient alternatives for disease management caused by these pathogens, the objective of this study was to analyze cinnamon and citronella essential oils in the in vitro control of fungi *Aspergillus* sp. and *S. sclerotiorum*.

MATERIALS AND METHODS

The experiment was a completely randomized design, in a 2x4+2 factorial scheme [essential oils x concentrations + (fungicide + standard control)], both for the fungi *Aspergillus* sp. and *S. sclerotiorum*. Five replicates were used for each treatment, and each Petri dish (90 × 15 mm) was considered one repetition.
Cinnamon (*Cinnamomum cassia*) and citronella (*Cymbopogon winterianus*) essential oils were used in doses of 0.2, 0.4, 0.8 and 1.6 mL L^{-1} (+ 1 Tween 80 to 1%) and the Captana (480 g L^{-1}) and thiophanate-methyl + chlorothalonil (200.0 g kg^{-1} + 500.0 g kg^{-1}) fungicides at doses of 3 and 2 g L^{-1}, for fungi *Aspergillus* sp. and *S. sclerotiorum*, respectively. The employed essential oils which are of commercial origin and obtained through hydrodistillation were diluted in potato dextrose agar (PDA) medium in Petri dishes, and mycelium discs with 5 mm diameter, except for the control treatment (standard control), which was maintained only in the PDA culture medium. Subsequently, the plates were incubated in a Biochemical Oxygen Demand (BOD) incubator at 25 ± 1°C and photoperiod of 12 h.

The analyzes were done daily and consisted of: (1) The diameter of the fungus colonies were measured in orthogonal position (mean of the two opposite measurements), being closed only after filling the control plate with the fungus *Aspergillus* sp. and/or *S. sclerotiorum*, respectively; (2) sporulation of fungus: *Aspergillus* sp., a spore suspension was prepared for each treatment by adding 20 mL of sterile distilled water to the Petri dishes followed by light friction of the fungus colony so that the fungal reproductive structures of the culture medium were released with the aid of a Drigalski loop. The solution formed was filtered in a beaker, using a glass funnel with a gauze layer, allowing the passage of water suspension containing spores and retention of other materials, such as hyphae. The suspension was homogenized and conidia were counted in the Neubauer chamber (hemocytometer). Sporulation analysis was not performed for S. *sclerotiorum* because this fungus does not produce spores.

In order to calculate the percentage inhibition of mycelial growth (PIMG) and sporulation (PIS) (Edgington et al., 1971), the following equation were used:

$$\text{PIMG OR PIS} = \left(1 - \frac{\text{TREATMENT}}{\text{CONTROL}}\right) * 100$$

Where, PIMG is percentage inhibition of mycelial growth; PIS is percentage inhibition of sporulation; CONTROL is value of mycelial growth or control sporulation (control); and TREATMENT to value of mycelial growth or sporulation of each treatment.

The values of the calculation of PIMG or PIS were used to determine the effective dose to inhibit the mycelial growth and/or sporulation of the pathogen by 50% (DE_{50}) and 100% (DE_{100}) by adjusting the regression equations.

The data obtained on the mycelial growth and sporulation were compiled in a database using spreadsheet, in Microsoft Excel 2013 and submitted to the analysis of variance, and the means, grouped by the Scott-Knott test, in level of 5% using the R® program version 64.1 (R CORE TEAM, 2017).

RESULTS AND DICUSSION

There was a significant interaction between the treatments, which differed from the control according to the doses and oil tested (Tables 1 to 4).

For the fungi *Aspergillus* sp. (Table 1), the use of the

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Table 1. Mycelial growth (cm) and number of spores (x10^4 spores mL^{-1}) of fungi *Aspergillus* sp., due to the essential oil of cinnamon and citronella essential oil.

			***Aspergillus* sp.**			
Treatment	**Description**	**Dose ($mL\ L^{-1}$)**	**Cinnamon (cm)**	**Citronella (cm)**	**Cinnamon (×10^4sporesmL^{-1})**	**Citronella (×10^4sporesmL^{-1})**
T1	Control (standard)	-	8.34^{a*}	8.34^{a}	188.80^{a}	188.80^{a}
T2	Essential oil	0.2	8.22^{a}	7.56^{a}	232.15^{a}	184.35^{a}
T3	Essential oil	0.4	3.46^{b}	2.66^{b}	107.00^{b}	160.65^{a}
T4	Essential oil	0.8	2.96^{b}	2.26^{b}	68.50^{c}	141.15^{a}
T5	Essential oil	1.6	1.24^{c}	0.80^{c}	26.40^{c}	46.10^{b}
T6	Captana (480 gL^{-1})	3 g kg^{-1} seed	1.86^{c}	1.86^{b}	135.60^{b}	135.60^{a}

*Averages followed by the same letter in the column do not differ from each other at a 5% probability level by the Scott-Knott test.

Table 2. Mycelial growth (cm) of fungi *S sclerotiorum* as a function of the application of cinnamon and citronella essential.

		Sclerotinia sclerotiorum		
Treatment	**Description**	**Dose ($mL\ L^{-1}$)**	**Cinnamon (cm)**	**Citronella (cm)**
T1	Standard control	-	8.02^{a*}	8.34^{a}
T2	Essential oil	0.2	7.38^{a}	7.68^{a}
T3	Essential oil	0.4	4.14^{a}	6.04^{b}
T4	Essential oil	0.8	2.74^{b}	3.80^{c}
T5	Essential oil	1.6	1.20^{c}	1.12^{d}
T6	Thiophanate-methyl + chlorothalonil (200 g kg^{-1}+500g kg^{-1})	2 g kg^{-1} seed	1.78^{bc}	1.86^{d}

*Averages followed by the same letter in the column do not differ from each other at a 5% probability level by the Scott-Knott test.

cinnamon essential oil at the dose of 1.6 mL L^{-1} inhibited the mycelial growth similar to the treatment with Captana commercial fungicide (480 g L^{-1}). On the other hand, citronella essential oil at the dose of 1.6 mL L^{-1} had a greater inhibition when compared to the application of the commercial fungicide. Considering the sporulation, there was an inhibition with the use of the doses of 0.8 and 1.6 mL L^{-1} of cinnamon essential oil, and the dose of 1.6 mL L^{-1} of citronella essential oil.

The doses of 0.8 and 1.6 mL L^{-1} (Table 2) of cinnamon essential oil determined lower mycelial growth of the fungi *S. sclerotiorum*, differing from the other doses used, but did not differ significantly from thiophanate-methyl + chlorothalonil (200 + 500 g kg^{-1}) commercial fungicide. However, citronella essential oil at the dose of 1.6 mL L^{-1} proportioned mycelial growth statistically equal to the commercial fungicide, differing from the other doses used.

Losses related to cereals, legume grains such as beans, soybeans and other dry grains, which are deteriorating food, are between 20 and 60%. Approximately 25 to 40% of the world's cereals are contaminated with mycotoxins produced by different fungi during storage (Kumar et al., 2007; Prakash et al., 2013). The development of products based on natural compounds, such as essential oils for crop protection and, consequently, the decrease in food contamination by mycotoxins stands out today due to their importance in production and human health (Kumar et al. , 2007; Ootani et al., 2013; Prakash et al., 2013).

In general, most of the chemical components of the essential oils are terpenoids, including monoterpenes, sesquiterpenes and their oxygenated derivatives. Terpenes are active antimicrobial compounds of essential oils. The mechanism of action of this class of compounds is not fully understood, but it is speculated involving the membrane disruption by these lipophilic compounds (Farooq et al., 2013; Javaid and Shoaib, 2013, Ootani et al., 2013).

Citronella essential oil had the lowest values of DE_{50} and DE_{100} (Table 3) for inhibition of the mycelial growth of the fungi *Aspergillus* sp. In contrast, cinnamon essential oil had the lowest values of DE_{50} and DE_{100} for sporulation.

Several studies have been developed using cinnamon and citronella essential oils in the control of the fungi *Aspergilus* sp. (Viegas et al., 2005; Pawar and Thaker, 2006; Khan and Ahmad, 2011; Tian et al., 2012; Prakash et al., 2013, Ootani et al., 2016) These studies present positive results regarding the use of these oils in the inhibition of fungui growth and sporulation. Khan and Ahmad (2011) studying the *in vitro* effect of cinnamon, citronella and clove oils and their major components found that due to the accumulation of cinnamaldehyde at

Table 3. Effective dose to inhibit 50% (DE_{50}) and 100% (DE_{100}) of mycelial growth (MG) and sporulation (S) of *Aspegillus* sp. due to the application of cinnamon and citronella essential oil.

Essential oil	Regression equation				DE_{50} (mL L^{-1})		DE_{100} (mL L^{-1})	
	PIMG	R²	PIS	R²	MC	S	MC	S
Cinnamon	$\hat{Y}$ = 47.23x +16.97	0.67*	$\hat{Y}$ = 64.14x - 5.58	0.71*	0.70	0.87	1.76	1.65
Citronella	$\hat{Y}$ = 44.79x - 26.60	0.62*	$\hat{Y}$ = 51.30x - 8.95	0.98*	0.52	1.15	1.64	2.12

*Significant at 5% by the "t" test.

Table 4. Effective dose to inhibit 50% (DE_{50}) and 100% (DE_{100}) of the mycelial growth of *S. sclerotiorum*, as a function of the application of cinnamon and citronella essential oil.

Essential oil	Regression equation		DE_{50} (mL L^{-1})	DE_{100} (mL L^{-1})
	PIMG	R²	Mycelial growth	Mycelial growth
Cinnamon	$\hat{Y}$ = 47.18x + 16.43	0.79*	0.71	1.77
Citronella	$\hat{Y}$ = 54.18x + 3.49	0.97*	0.86	1.78

*Significant at 5% by the "t" test.

multiple sites of action, mainly in cell membranes and endomembranous structures of the cell fungus, cinnamon oil provided greater inhibition of sporulation when compared to the others.

For the mycelial growth of *S. sclerotiorum* (Table 4), cinnamon essential oil presented the lowest values of DE_{50} and DE_{100}.

The inhibition of the mycelial growth of the fungi *S. Sclerotiorum* on the plates in which cinnamon and citronella essential oils were added proves the antifungal action of these oils (Pansera et al., 2012; Jiang et al., 2013; Wafa`a et al., 2014).

Cinnamon and citronella essential oils presented antifungal action for fungi *Aspergilus* sp. and *S. sclerotiorum*, inhibiting the mycelial growth of both and the sporulation of the fungi *Aspergilus* sp. Thus, studies regarding the seeds treatment with these essential oils for storage and planting, aiming at the management of these fungi, become a viable alternative.

Conclusion

Cinnamon and citronella essential oils controlled the fungi *Aspergilus* sp. and *S. sclerotiorum*, with is recommended the dose of 1.6 mL L^{-1}, for both oils.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Combined agronomic and climatic approaches for sorghum adaptation in Mali

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In Sub-Saharan Africa, Genotype-Environment interaction plays a key role in formulating strategies for crop improvement. Multi-location trials have created enabling structure to determine varieties yield performance and stability. Crop modeling led to prediction of long-term and spatial effects of climate variability. Three improved varieties were compared to three landraces. Optimum cultivation areas minimizing the risk of crop failure were delineated by comparing predicted flowering dates and end of rainy seasons. Agronomic values were determined in trials from three climatically different zones in 27 farms. Yield stability was determined using linear regression depending on each environmental mean and the AMMI model. Photoperiod sensitive varieties have wider optimal cultivation areas whereas early-maturing varieties (photoperiod insensitive) are subjected to strong constraints on sowing date. In low productivity conditions, landraces and improved varieties are not distinct. As the environmental cropping conditions increase, improved lines become significantly superior to landraces. Photoperiod insensitive landrace is subservient to climate conditions of its area of origin and its productivity drops sharply when moved to a wetter area. Varieties studied combined productivity and stability traits. These findings are important steps toward breeding climate resilient varieties for meeting the challenges of climate smart agriculture and sustainable intensification.

Key words: Mali, sorghum, GxE, photoperiodism, climate change, yield stability.

INTRODUCTION

Population growth in Mali will lead to a short term food demand increase for both rural and urban populations. Dryland cereals production needs to follow population demand. So far, cereal production increase in Sub-

Saharan zones has mainly been achieved through cultivated surfaces expansion. However, the gradual saturation of rural are due to cropping and pastoral pressures requires increasing the productivity of cropping systems, in a sustainable way.

Mali has a dry tropical climate influenced by the monsoon, from May to October, during the onset of rainy season; thus growing season duration is varies from year to year which strongly impacts the potential of agricultural production (Sivakumar, 1988; Traoré et al., 2001; Lodoun et al., 2013).

Effects of climate change on agricultural production are difficult to analyze because climate change is accompanied by significant socio-economic change. Thus, despite climate change and recurrent droughts, cereals production increases in Mali; showing the capacity of African countries to achieve food self-sufficiency through intensification of agricultural production (van Ittersum et al., 2016).

As a result of climate change, rain distribution modifications can potentially affect drought occurrence. Droughts of the 1970s and 1980s in the Sahel caused a significant decrease in rainfall, but the consequences for rainy seasons onset and ending were lower (Le Barbé and Lebel, 1997; Traoré et al., 2001). Even if climate models are unclear in predicting the future distribution of African rainfall, an increase in climate variability and a succession of drought and flooding periods are expected (Thornton et al., 2010).

Recently developed high yielding sorghum varieties for the Malian Sudano-Sahelian zone poorly adapt to both environmental and population food requirements. Conversely, landraces are specifically well adapted to local biotic and abiotic stresses and have acquired excellent grain qualities with low yield potential.

These landraces have been selected by farmers over generations and they contribute to environmental constraints mitigation through sensitivity to photoperiod which is a very widespread trait among African sorghum varieties (Kouressy et al., 2008a; Sissoko et al., 2008). Photoperiod sensitivity naturally synchronizes flowering date with the end of rainy season, regardless of the sowing date (Cochemé et al., 1967; Andrews, 1973; Vaksmann et al., 1996).

Farmers define adapted sorghum cultivars as "landraces with grouped maturity" regardless of their sowing dates: u be nyogon konô in Bambara language (Sissoko et al., 2008). A variety is seen as adapted if flowering occurs within 20 days before the end of the rainy season (Traoré et al., 2007; Kouressy et al., 2008b) for a given zone.

This condition ensures a balance between satisfaction of water needs and avoidance of many biotic constraints. Yield and grain quality are closely related to the flowering date. Grain of early maturing varieties is attacked by birds and altered by mold and insects, while late maturing varieties deplete soil moisture before the end of grain filling.

In the wake of the Green Revolution, photoperiod sensitivity has been eliminated by breeders in order to develop early maturing varieties with a broader geographic adaptation (Swaminathan, 2006; Morris et al., 2013). However, the rate of adoption of new early maturing varieties is very low (Sissoko et al., 2008). African farmers, especially Malians, still predominantly grow photoperiod sensitive landraces maturing later than modern varieties (Lambert, 1983; Kouressy et al., 2008a). Nowadays, development of high yielding photoperiod-sensitive varieties adapted to the Sudano-Sahelian climate has become a priority of dryland cereals breeding programs in West-Africa (Kouressy et al., 1998; Vaksmann et al., 2008; Haussmann et al., 2012). In addition, photoperiod sensitivity recently drew breeders attention to increase biomass yield for biofuels production (Olson et al., 2012).

A molecular marker assisted recurrent selection (MARS) program cumulated components of grain yield, grain and fodder quality and climate adaptation (Guindo et al., 2016; Guitton et al., 2018). An on-farm participatory selection program was implemented to develop varieties based on farmer practices and preferences (Leroy et al., 2014). MARS program was undertaken in Mali from 2008 to 2015. A bi-parental population was derived from the cross between two contrasting elite lines from IER (Institut d'Economie Rurale).

Both parents were medium height (<200 cm), well adapted to Sub-Saharan conditions and photoperiod sensitive. Furthermore, parents were interesting combiners based on grain yield and quality. Quantitative Traits Loci (QTLs) identified for target traits and positive alleles were aggregated in recurrent generations. Elite varieties from MARS program are being investigated on station and on farm as well as for seeds registered in Mali. This work intends to determine agronomic performances and genotype-environment interactions of new varieties compared to the most common landraces of the study areas. Multi-location trials were used to analyze genotypes' yield stability in conjunction with a simple crop model to interpret and understand agroclimatic long-term effects.

MATERIALS AND METHODS

Study area

Phenology data collections were carried out at Sotuba Research

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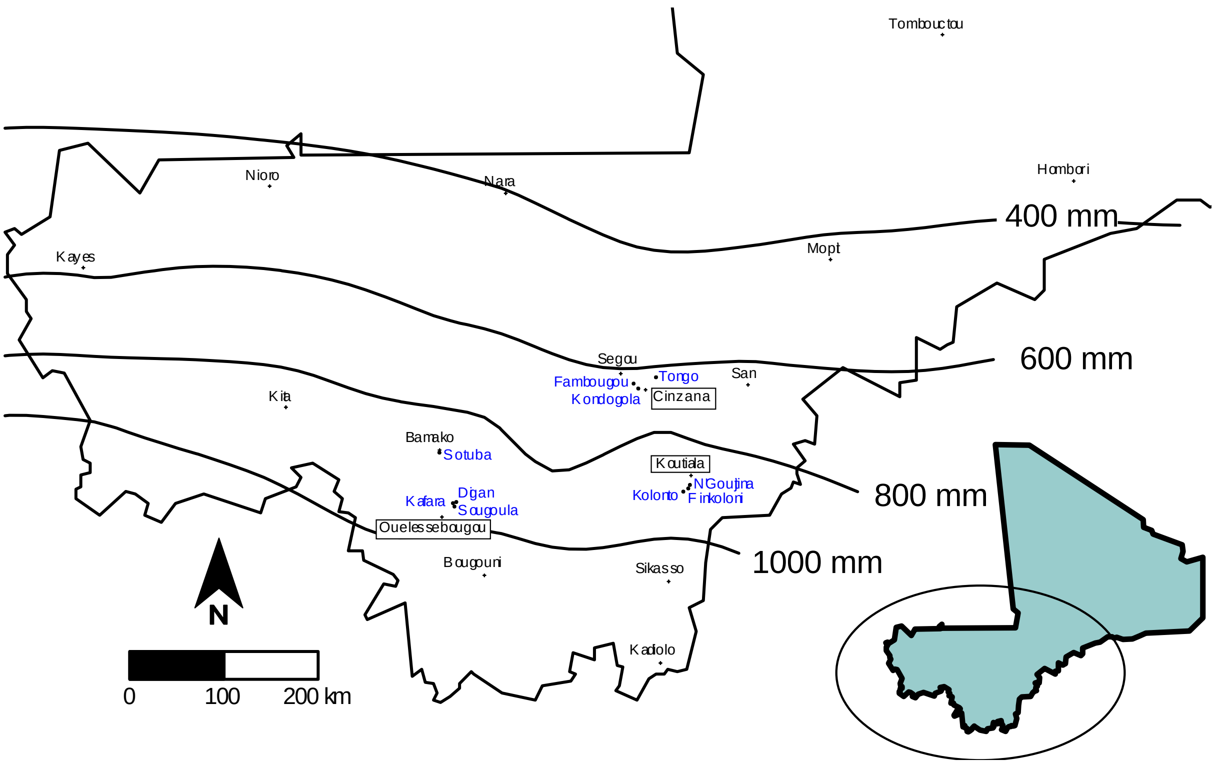

Figure 1. Location of Sotuba station and study areas in farmer fields. Average rainfall over the period of 1981-2010 for each location is indicated. Villages of Kondogola, Fambougou and Tongo are in Cinzana zone; villages of Kafara, Digan and Sougoula in the Ouélessébougou region; villages of Finkoloni, N'Gountjina and Kolonto are in the Koutiala region.

Station (12°39'N, 7°56'E, 381 m) in Mali. Agronomical studies were conducted in three contrasting climatic zones of the Malian Sudano-Sahelian band (Figure 1): Ouélessébougou, Segou and Koutiala. The multi-locational trial network consisted of 27 producers (three villages per zone with three farmers per village) (Figure 1). Villages from Kondogola, Fambougou and Tongo are in the Cinzana zone (40 km from Ségou); villages from Kafara, Digan and Sougoula arein the Ouélessébougou zone; while villages from Finkoloni, N'Gountjina and Kolonto are in the Koutiala zone.

All locations have mono-modal patterns of rainfall in summer (May to November) accounting on average 690 mm at Cinzana, 850 mm at Koutiala, 890 mm at Sotuba and 950 mm at Ouélessébougou. Koutiala and Ouélessébougou are located in upper southern Mali, the major Malian cotton and maize region. Cinzana is located further north (drier zone), where millet and sorghum dominate its cropping system. The soils are clay, silt clay, sandy loam and gravel types according to the toposequence position.

Plant material

Six varieties were tested in 2016 (Table 1), three improved lines and three landraces. Elite lines C2_075-16, C2_099-08 and C2_099-12 are photoperiod sensitive, medium height (<2 m height) with loose to semi-compact panicles. In partner villages, the most common landraces were selected as controls. Varieties Kalagnigue, Folomba and Jacumbe respectively come from Ouélessébougou, Koutiala and Cinzana. Jacumbe is an improved landrace (Teme et al., 2017) which is from a drier zone than Cinzana. This latter variety is fairly well adopted in central Mali due to its earliness. Landraces are tall (> 3 m height), guinea botanical type, with loose panicles.

GxE interaction and crop modeling

Environmental parameter calculation

Thermal time after emergence was computed using an algorithm developed by Jones et al. (1986), considering that growth speed increases as a linear function of temperature between a base and an optimal temperature, and then decreases linearly between optimal and maximal temperature. Cardinal temperatures were 11°C for base temperature (Lafarge et al., 2002), 34°C for optimum temperature and 44°C for maximum temperature (Abdulai et al., 2012). The resulting thermal time per day was used to calculate the progress of developmental processes. The Thermal Time from emergence to flag leaf ligulation (TTFL) was computed for each variety and each sowing date, expressed in degree days (°Cd). Thermal time to panicle initiation was derived from TTFL using the linear formula proposed by Folliard et al. (2004). Day length used is not astronomical day length but civil day length (sunrise to sunset plus civil twilight), which includes periods when the sun is 6° below the horizon, to account for photoperiod effect during dawn and twilight (Aitken, 1974).

CERES model adjustment

A trial with three sowing dates was used to study the phenology of varieties under different photoperiod conditions and to calculate CERES model coefficients (Ritchie et al., 1989; Guitton et al., 2018). This trial was replicated in 2015 and 2016. A split-plot design in two replicates was used. The main factor was three dates of sowing and the secondary factor was six varieties. In 2015, planting dates were June 21, July 20 and September 15. In 2016, planting

Table 1. List of varieties studied in 2015, 2016 in nine villages in Mali.

Name	Origin	Traits of interest
C2_075-16	Marker assisted Recurrent Selection	Productivity and stability, dual purpose value (grain and fodder).
C2_099-12	Marker assisted Recurrent Selection	
C2_099-08	Marker assisted Recurrent Selection	
Kalagnigue	Koutiala (Finkoloni)	Landraces adapted to their area of origin. Good grain quality.
Jacumbe	This variety is released in Cinzana but its area of origin is further north (Chegue) near Nara in the 400 mm rainfall zone.	
Folomba	Ouélessébougou (Kafara)	

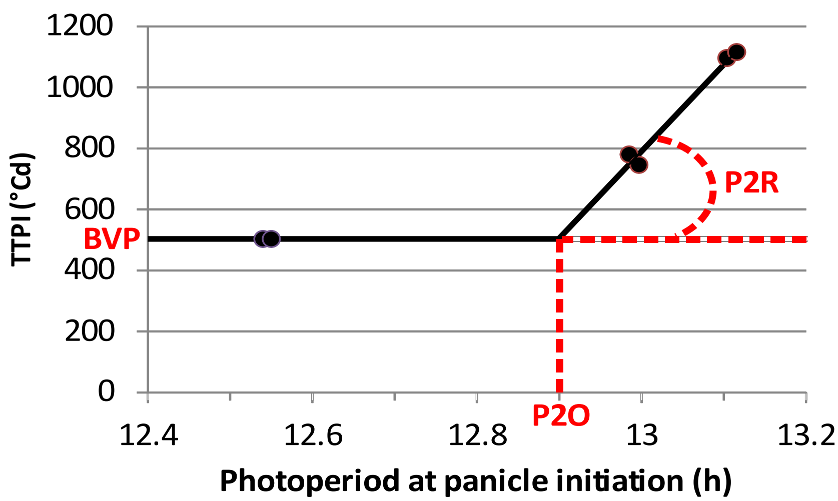

Figure 2. Thermal Time for Panicle Initiation (TTPI) depends on photoperiod according to CERES model. Three parameters, BVP, P2O and P2R, are derived from this modeling. Data from C2_099-08 were used to establish the figure.

dates were June 17, July 18 and September 14. Each year, the first two sowing dates were used to determine varieties behavior in farmer normal period of sowing conditions (long and intermediate photoperiod), while the third date (off-season planting) was to study short photoperiod effect. An irrigation system was used to ensure plant development without water shortage. The varietal response to photoperiod was modeled using the sorghum linear CERES model (Major et al., 1975; Major et al., 1990; Alagarswamy et al., 1991). This model (Figure 2) is based on a linear adjustment between photoperiod and the length of the vegetative phase (Chantereau et al., 2001; Sanon et al., 2014). After emergence, the shortest thermal time required to reach panicle initiation is known as the Basic Vegetative Phase (BVP). During this phase, floral induction cannot occur no matter what the photoperiod conditions are. The CERES model considers that below a critical photoperiod (P2O), the duration of the vegetative stage is constant and is equal to BVP. Above P2O, the duration of the vegetative stage increases as a linear function of photoperiod whose slope, P2R, defines photoperiod-sensitivity in degree days per hour of photoperiod increase (°Cd/h). A modified CERES model version was used (Folliard et al., 2004). Photothermal time accumulation was replaced by a critical photoperiod threshold (varying on plant age) below which sorghum panicle initiation occurs. The three model parameters (P2O, P2R and BVP) were calculated using a method presented by Guitton et al. (2018). For each family, the thermal time for panicle initiation was plotted for the three sowing dates against the photoperiod at panicle initiation date (Figure 2). In practice, BVP was calculated from the minimal duration of the vegetative phase observed at Sotuba in short day length conditions. The photoperiod sensitivity P2R was estimated as the slope of the line drawn between the points related to the sowing dates of June and July. The critical photoperiod P2O, corresponds to photoperiod at the intersection of this line and the BVP base line.

Delineating optimal cultivation areas

The method used comprises identifying the areas for which a variety can be sown during normal planting period to minimize biotic and abiotic risks. The optimum cultivation area of a variety is determined by combining information on photoperiod sensitivity, climatic variability and farmer practices (early and staggering sowing dates) (Soumaré et al., 2008). For each rainfall station in Mali, onset and end of rainy season was established using a simplified water balance model (Traoré et al., 2001). Flowering date is predicted using the CERES model. The difference (in days) between the predicted flowering date and the end of the rainy season gives an adaptation index. This adaptation index was calculated for each variety based on 1981-2010 Malian weather stations data. A geographical information system (Surfer® 14, Golden Software, LLC) was used to delineate areas for which the adaptation index is between -20 and 0 because an adapted variety flowers in the 20 days preceding the end of the rainy season was considered (Kouressy et al., 2008b). Spatial distribution of adaptation index uses a model of linear interpolation by kriging. This action was repeated for each variety considering two sowing dates. A first sowing date was simulated immediately after the installation of the rainy season and a second sowing date was delayed by one month. This duration corresponds to the general practice observed in farmer's fields.

Multi-location trials

Trials were conducted in 27 farms in randomized complete block designs (RCBD) with 2 replicates. Experimental plot consisted of 4 rows of 6 m long. The distance was 0.75 m between lines and 0.40 m between hills on the row. Thinning was done at two plants per hill, corresponding to a maximum density of 66 666 plants/ha. Chemical fertilizers (73 kg N, 30 kg P /ha) were applied.

ANOVA

An analysis of variance (ANOVA) was performed for each environment and trait separately as a RCBD (data and results not presented). A combined ANOVA was undertaken for all environments. Before pooling trials, Hartley test of homogeneity of residual variance for each trait was conducted. The model for the combined analysis across locations was:

$$Y_{ijk} = m + E_i + g_j + (gE)_{ij} + b_{ik} + e_{ijk}$$

Yijk is the observation in the ith environment of the jth genotype, in the kth block of the experimental design.
m is the grand mean
Ei is the effect of the ith environment
gj is the effect of the jth genotype
(gE)ij is the interaction of the jth genotype with the ith environment
bik is the effect of kth block in ith environment
eijk is the residual error.

Interaction GxE

In case of Variety x Environment significant interaction, several statistical methods are available for analysis of adaptation, ranging from univariate parametric models, such as linear regression of each genotype on the average yield of all genotypes in the studied environments (Finlay et al., 1963), to multivariate models such as the additive main effect and multiplicative interaction (AMMI) analysis (Gauch et al., 1988; Sabaghnia et al., 2008).

Regression slope approach

The Finlay-Wilkinson approach (Finlay et al., 1963) is designated to investigate GxE (Figure 4a). The method is to fit, for each genotype, a regression of the mean yields on the average environmental yield (the mean response of all varieties in each environment). The two important indices are the regression coefficient (slope) and the variety mean yield over all environments. Regression coefficients approximating to 1.0 indicate average stability. When this is associated with high mean yield, varieties have general adaptability; when associated with low mean yield, varieties poorly adapt to all the environments.

Regression coefficients increasing above 1.0 describe varieties with increasing sensitivity to environmental change (below average stability) specifically adapted to high-yielding environments. Regression coefficients decreasing below 1.0 provide a measure of greater resistance to environmental change (above average stability), and therefore increasing adaptation to low-yielding environments. The response of varieties to environments may be summarized by plotting the variety sensitivity coefficients (slope), against their means (Figure 4b).

The performance of the varieties may be predicted from the particular quadrant in which they appear on the plot (Kempton, 1984). Those in the bottom right-hand quadrant are relatively stable high-yielding varieties which should yield well consistently in all environments. Those in the top right-hand quadrant are high-yielding varieties.

Similarly, the two left-hand quadrants include lower-yielding varieties.

Additive main effect and multiplicative interaction (AMMI) model

The AMMI analysis fits a model which involves the Additive Main effects of ANOVA with the Multiplicative Interaction effects of principal components analysis (Sabaghnia et al., 2008). GxE scores can be used to construct biplots to help interpret GxE interaction. In the biplot, genotypes that are similar to each other are closer.

Likewise, environments that are similar were grouped together as well. When environment scores are connected to the origin of the plot, an acute angle between lines indicate a positive correlation between environments. A right angle between lines indicates low or no correlation between environments, and an obtuse angle indicates negative correlation. To estimate varieties stability, two indexes were used (Farshadfar et al., 2011).

The AMMI Stability Value (ASV) index was proposed to quantify and rank genotypes according to their yield stability (Purchase et al., 2000; Adugna et al., 2002; Farshadfar et al., 2011). Stability per se should not be the only parameter for selection, because the most stable genotypes would not necessarily give the best yield performance. Yield Stability Index (YSI) incorporates both mean yield and stability in a single index. YSI gives the most stable genotype with high grain yield (Farshadfar et al., 2011). Genotype x Environment interaction was studied using the AMMI function (package 'agricolae') in the R environment (R_Development_ Core_Team, 2008).

RESULTS

Phenological study - CERES model

Ceres model parameters calculation

Sowing delay caused a sharp reduction in the time from sowing to flag-leaf ligulation (SFD) for all varieties except Jacumbe whose SFD duration had little change between sowing dates (Table 2). For June sowing (in long days length), SFD of Jacumbe is short (56 days) compared to those of other landraces (Kalagnigue = 88 days and Folomba = 93 days). SFD of improved varieties are quite similar (98 days on average).

Photoperiod sensitivity is expressed by the reduction of SFD between June and July sowings. SFD of photoperiodic varieties is reduced by an average of 23 days for a staggered 30 day sowing (from June 17 to July 18). For the same period, the Jacumbe variety SFD is only reduced by 3 days. SFD was further reduced by 20 days between July and October sowings for other varieties, except for Jacumbe whose SFD was only reduced by 9 days. Parameters of CERES model was calculated (Table 2).

Table 2. Results of the 2015 and 2016 "sowing date" trials and adjustment of the CERES model parameters for the six studied varieties. SFD: duration from sowing to flag leaf appearance, BVP: Basic Vegetative Phase, P2O: critical photoperiod and P2R: photoperiod sensitivity.

Variety	SFD/Sowing dates						CERES model coefficients		
	2015 sowings			2016 sowings			BVP	P2O	P2R
	June 21	July 20	Sept. 15	June 17	July 18	Sept. 14	(°C.d)	(h)	(°C.d/h)
Jacumbe	56.6	49.0	44.2	56.2	53.6	44.6	432	12.94	319
Kalagnigue	90.0	69.5	57.9	87.9	67.2	52.6	573	12.91	1692
Folomba	95.7	71.8	57.1	92.7	70.8	50.5	539	12.86	2053
C2_099-08	93.9	69.8	49.0	97.3	72.3	48.0	503	12.90	2840
C2_099-12	92.8	71.3	54.1	97.8	73.7	48.4	503	12.86	2441
C2_075-16	93.3	72.4	55.2	98.4	80.2	54.2	590	12.77	1452

The photoperiod sensitivity of Jacumbe (P2R = 190°Cd/h) is much lower than that of the other varieties (2216°Cd/h on average). Differences on BVP and P2O values are weaker, the lowest and the highest BVP (469°Cd for Jacumbe and 591°Cd for C2_075-16) correspond approximately 7 days apart for the basic vegetative phase.

Delineating optimal cultivation areas

Adaptation areas of the 6 varieties studied are shown in Figure 3. The adaptation zone corresponds to an early sowing colored in blue; while adaptation zone corresponds to a late sowing is colored in red. The delay of sowing caused a shift in the adaptation zones towards the south. The adaptation zones of photoperiod-sensitive varieties are characterized by an overlap (colored in purple) which corresponds to the optimal cultivation area, the area in which cultivation of the variety is possible regardless of the sowing date. The two photoperiod-sensitive landraces, Folomba and Kalagnigue, delineate optimal area including or close to their region of origin. The optimal adaptation area of Kalagnigue (intermediate maturity) is located slightly further north of Bamako; whereas, Folomba optimal cultivation area is centered around Bamako. Improved varieties have optimal cultivation areas centered around Bamako and slightly similar to those of local varieties. The marker assisted breeding program has thus succeeded in preserving this character of landraces into the new varieties. Optimal cultivation areas of the most photoperiodic improved varieties (C2_099-08 and C2_099-12) are wider than that of C2_075-16. Conversely, Jacumbe optimal cultivation area is typical of photoperiod-insensitive varieties. Areas corresponding to early and late sowing do not overlap, so there is no place where this variety can be sown safely over a period of one month after the onset of rains. In case of early sowing, Jacumbe is adapted to the Sahelian band which is its zone of origin (>500 mm isohyet) and in case of late sowing, the optimal cultivation area moves towards the south in the Sudano-Sahelian band (isohyet 700 mm). In practice, the date of sowing of Jacumbe must be modulated according to the end of rainy season in the target zone.

Multi-location trials

In each climatic zone, the average yields of improved varieties are very similar from those of landraces (Figure 4). The landrace is still among the best varieties in its area of origin but its performance decreases if grown elsewhere. This is especially true for the variety Jacumbe which does not tolerate being grown further south (<700 mm). The flowering of Jacumbe in Koutiala and Ouélessébougou occurs before the end of the rains so that many constraints contribute to its lower yield (mold, birds ...). The performance of the other two landraces also decreases outside their area of origin but to a lesser extent. Conversely, the improved varieties have remarkable stability since they present good yield performances in the three zones. Four trials out of 27 were eliminated based on heterogeneity of variance. The ANOVA results for grain yield across locations are given in Table 3. Significant interaction GxE ($p<0.001$) in grain yield demonstrated that genotypes responded differently to variations in environmental conditions and necessitated the assessment of stability of performance for each of the six cultivars in order to identify those with superior and/or stable yields.

Regression analysis

Population mean yields and regression lines for the 6 varieties are shown in Figure 5, which illustrates different types of responses to the range of environments. With the exception of Jacumbe, a highly significant linear relationship is obtained between the site mean yield of the 23 farmers (environments) and the individual yields of varieties. Pairwise comparison of the regression lines

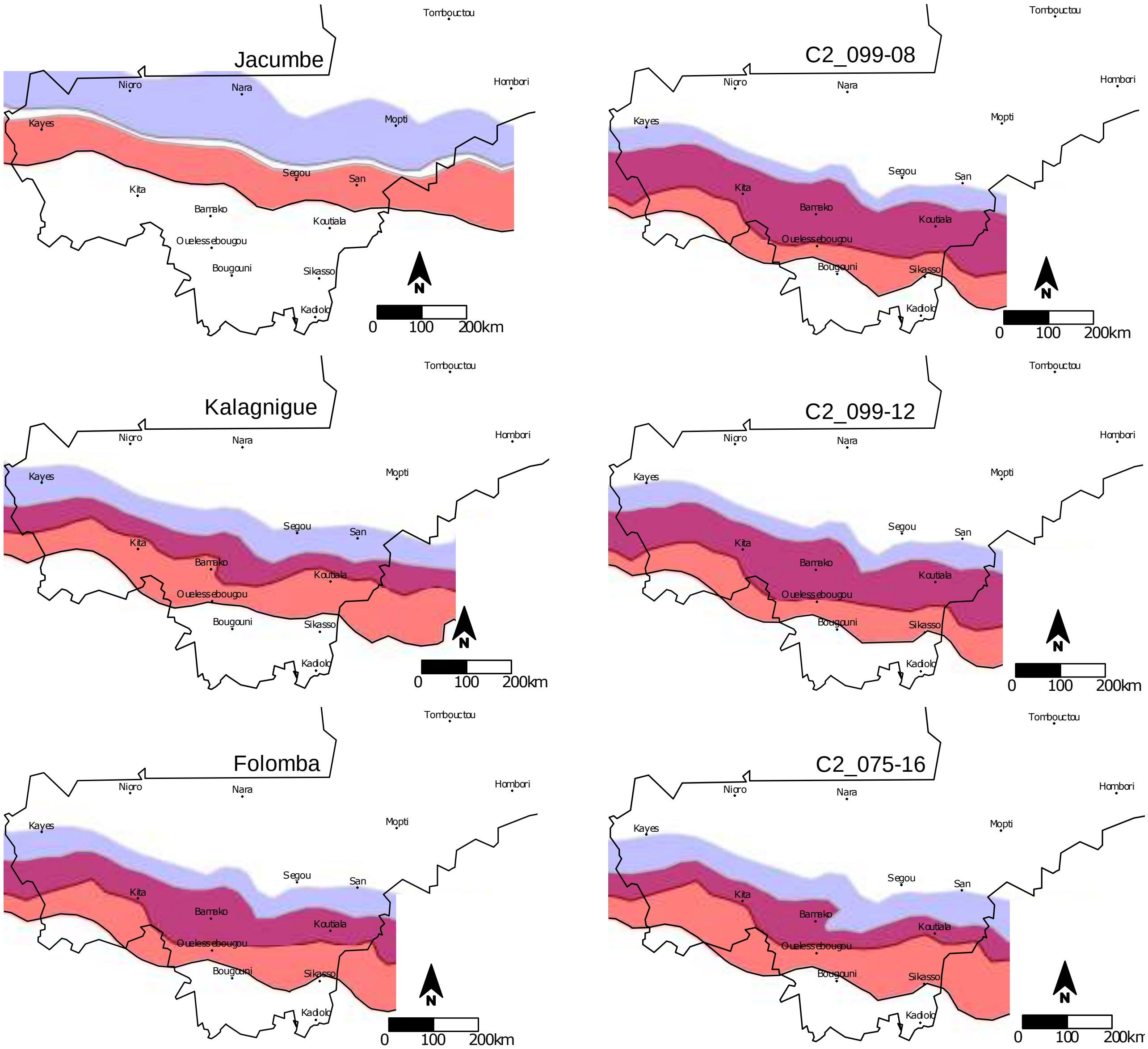

Figure 3. Delineation of optimal cultivation areas for the six studied varieties. The adaptation zone is in blue for an early sowing and in red for a late sowing. The optimal cultivation area (the overlap of the two zones) is in violet.

showed that the slopes of C2_075-16 and C2_099-08 are significantly different from those of the 3 landraces. Variety C2_099-12 has an intermediate behavior between improved lines and landraces (Figure 5a) Regression coefficients from 1.27 to 1.49, C2_075-16 and C2_099-08 are more sensitive to changes in the environment. These two varieties appear in top right-hand quadrant (Figure 4b) and could be described as being specifically adapted to high-yielding environments. It would be tempting to say that these varieties fail to adapt to poor environments. However, since all regression lines intersect for low-yielding environments (average yield around 500 kg / ha), it can be concluded that all varieties are the same in low-yielding environments. Folomba, Kalagnigue and C2_099-12 varieties, with regression coefficients closest to 1 (Table 4). are most stable over all environments. These three varieties appear in Figure 5b at the intersection of quadrants (slope of 1 and average yield). Jacumbe's yield regression slope is around 0.2 with a low coefficient of determination (R^2=0.21) showing that there is no linear relationship between the yield of this variety and the productivity of the environment. This resulted from numerous bird attacks that have been observed in the south (Ouélességbougou and Koutiala). Bird problem results from the early maturity of Jacumbe, which does not happen in its area of origin (dry area).

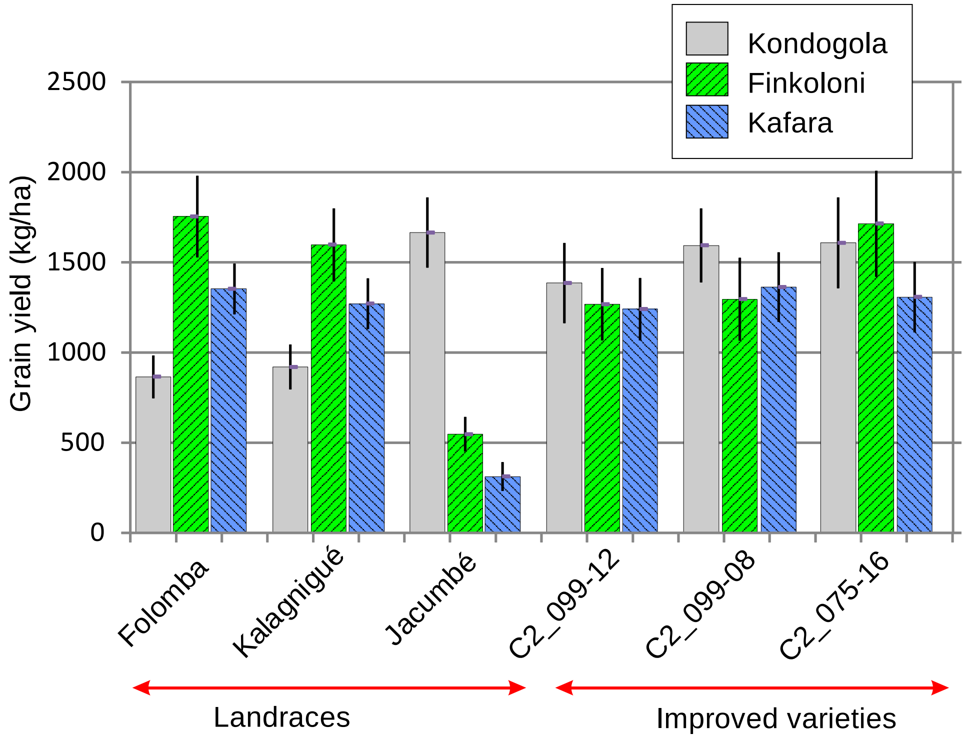

Figure 4. Average grain yields (kg/ha) of the six varieties in the three environments. The vertical bars represent the standard error.

Table 3. Analysis of variance for grain yield of 6 sorghum varieties tested in 23 environments.

Source	Df	Sum of squares	Mean squares	F value	
Genotype (g)	5	14628463	2925693	59.97	***
Environment (E)	22	112143433	5097429	127.02	***
Interaction (gE)	110	56002246	509111	10.44	***
Block (b)	23	923000	40130	0.82	
Residual (e)	115	5610363	48786		

*** Significant at p=0.001.

Table 4. Mean yield, regression slope and determination coefficient (R^2) of six varieties tested in 23 villages in Mali.

Variety	Mean yield (kg/ha)	Regression coefficient	R^2
C2_075-16	1480	1.487	0.91
C2_099-08	1336	1.265	0.92
C2_099-12	1216	1.044	0.86
Folomba	1300	1.061	0.74
Jacumbe	741	0.207	0.21
Kalagnigue	1250	0.935	0.75

AMMI results

On the biplot (Figure 6), landraces and improved varieties are positioned along the second axis with the exception of Jacumbe which contributes to the first axis. The presence of GxE interaction as seen in the north (Cinzana) and South (Ouélessébougou and Koutiala) are separated into (mega) environments on axe 1. The AMMI

Table 5. Mean grain yields in kg/ha (Y), AMMI Stability value (ASV) and yield stability index (YSI) for six sorghum genotypes tested in 23 environments and corresponding ranks (rASV and rYSI).

Variety	ASV	YSI	rASV	rYSI	Y
C2_075-16	40.3	5	4	1	1480
C2_099-08	24.7	4	2	2	1336
Folomba	41.0	8	5	3	1300
Kalagnigue	33.4	7	3	4	1251
C2_099-12	4.2	6	1	5	1216
Jacumbe	98.6	12	6	6	741

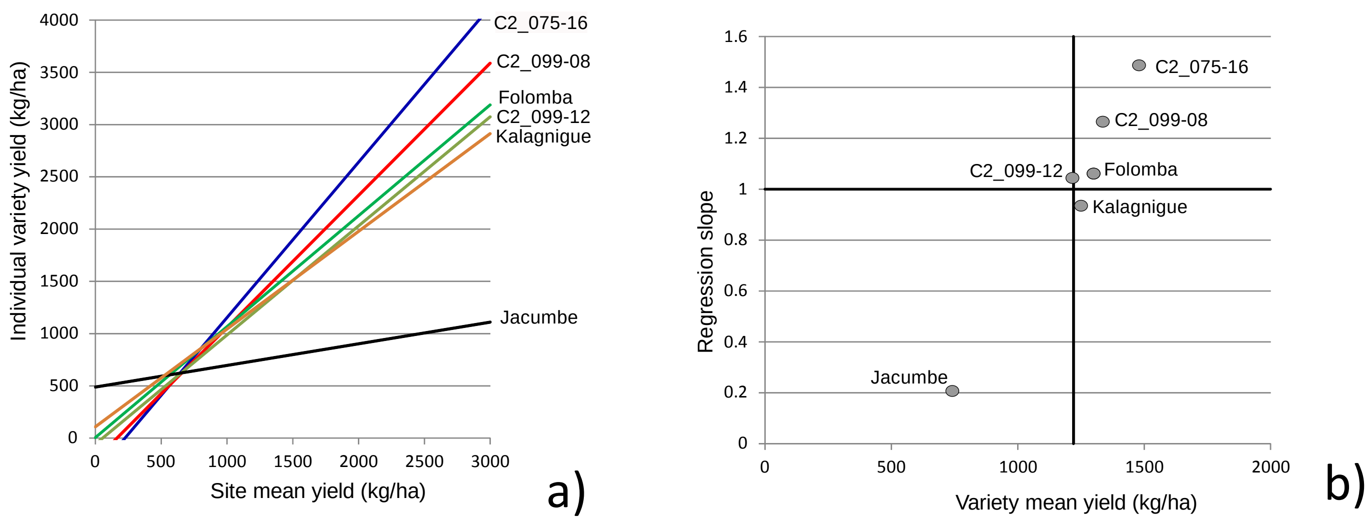

Figure 5. Stability analysis according to Finlay and Wilkinson (1963). (a). Plot of regression lines for grain yields of cultivars on average yields from 23 farmers in Mali. (b). Plots of the varietal regression slope on mean grain yield. The vertical line is the grand mean, whereas the horizontal line is the slope =1.

stability value (ASV) and the yield stability index (YSI) are given in Table 5. The most stable variety in the ASV index is C2_099-12, while Jacumbe variety is unstable and ranked last. The results for YSI are similar to those obtained by the regression method since the varieties C2_075-16 and C2_099-08 are the most stable with high grain yield.

DISCUSSION

The predictive value of multi-location trials is limited to the range of environments studied. It would be risky to generalize these results to other locations or other climatic situations. The two GxE study methods discussed here are complementary. Using agroclimatic maps facilitates rural planning, as well as ecological and economic decision-making (Cetin et al., 2018). Such maps, delineating optimal cultivation area, enable, in particular, avoidance of unsuitable varieties release. Conversely, multi-location trials provide an evaluation of cultivars response to soil fertility rather than an evaluation of their climatic adaptation.

The first sorghum breeding programs in Africa have shown that the choice of new varieties for any area is restricted to those which flower at the same time as the local varieties (Curtis, 1968). These climate adaptation rules may seem simple but early planting and matching flowering period to end of rainy season are limiting factors that account for much yield, yield stability and grain quality far above fertilizer inputs or tillage. For this reason, we decided to address climatic and agronomic approaches separately. It should be stressed that methods combining these approaches have been developed using a crop model to evaluate the expected genotype performance in a large sample of environments and to interpret the long-term and spatial effects of environment (Chapman et al., 2002; Dieng et al., 2006).

Furthermore, the use of crop models for generalization in space of photoperiod response should be done with caution since it has been shown that photoperiod sensitivity assessment becomes imprecise when one

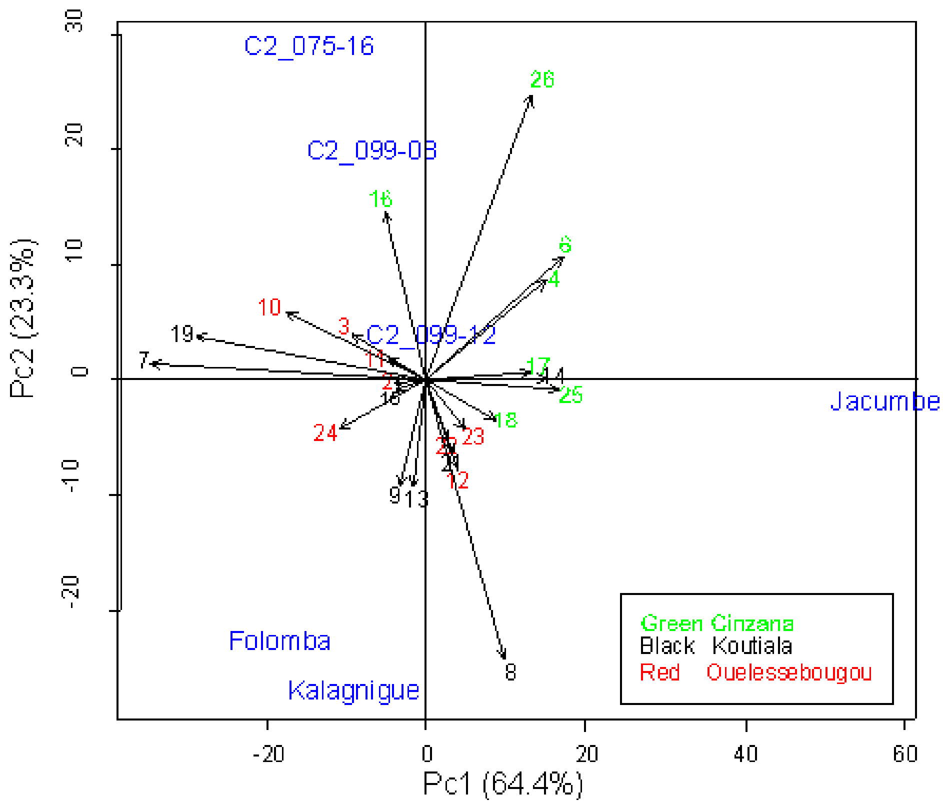

Figure 6. Genotype x Environment biplot of grain yield assessed in 23 environments (red) for six varieties (blue). Environment labels are colored to identify the region.

moves too far away, in latitude, from the area where the model was calibrated (Abdulai et al., 2012). Climatic and agronomic approaches show that Jacumbe, the early maturing variety, is specifically adapted to the dry (northern) part of the studied area. Its yield decreases rapidly if grown outside its area of origin. This finding contrasts with green revolution paradigms that opines that non-photoperiod sensitive varieties have a broad geographical adaptation (Bonneuil et al., 2009).

In reality, thanks to a large sowing window and good maturing conditions, photoperiod sensitive varieties have the widest cultivation area. Release of early maturing varieties is necessarily accompanied by a strong constraint on the sowing date that needs to be adapted to each target zone. However, delaying sowing after the onset of the rainy season is a risky advice. Sowing as of the first rains is always a race for Malian farmers (Viguier, 1947) because planting delayed after the installation of the rains lead to a considerable risk increase in crop failure (Andrews, 1973; de Rouw, 2004). Late planting produces lower yields for many reasons: damages and parasites, leaching of nitrogen and mineral elements, lower amount of radiation, low temperatures, flooding, weeds competition and aggressiveness of heavy rains.

In addition, all fields are rarely sown simultaneously, erratic precipitation at the beginning of the season leads to successive waves of sowing. It is not unusual for farmers to reseed two or three times, either because of low rate of emergence, loss of seedling due to early drought or because of pest attacks. The constraints of exploitation, lack of labor or farm equipment, often force farmers to stagger sowings.

Moreover, by grouping flowering, photoperiod sensitivity considerably limits the development of pests such as midge that benefits staggered flowerings to multiply (Etasse, 1977). There are concerns that the recent release of early maturing varieties in Mali will result in an outbreak of midge, which until recently was a minor problem in Mali (Kouressy et al., 2014). It has long been thought that combining photoperiod sensitivity of landraces with the productivity of modern varieties would not be possible (Sapin, 1983; Haussmann et al., 2012).

The findings of this research show that photoperiod-sensitivity is not an obstacle to the development of productive varieties that has been facilitated by the implementation of molecular marker-assisted recurrent breeding techniques, which lead to rapid accumulation of positive alleles.

In favorable environmental conditions, improved varieties yield exceeds 3700 kg/ha, significantly higher than landraces yield. Conversely, at low productivity (average yield 500 kg/ha), it is difficult to distinguish the varieties among them. In low yielding conditions, average yield of landraces is as good (if not better) than that of improved varieties. This result explains the weak release of improved varieties in farmers' fields. Farmers often prefer their landraces which, under traditional cultivation conditions present a more stable yield, almost systematically associated with a better grain quality (Luce, 1994).

On the other hand, new improved varieties would be useful to intensify farmer's production. So far, given the lack of high-yielding photoperiod sensitive sorghum varieties, farmers who wish to increase cereal production are turning to corn, which values higher fertilizer application. The challenge is therefore to improve sorghum productivity to make it a better option in more intensive production systems where it can even or beat corn.

Conclusion

In Sub-Saharan Africa, Genotype × Environment interactions in multi-location and/or multi-year trials are important. The only statistical consideration of interactions is that it does not always predict the responses of genotypes particularly with regard to climate change. The use of crop models effectively complements multi-location trials. Delineation of optimum cultivation areas can save considerable time for the release of new genotypes. Given the cost of a multi-location trial, modeling approach is much less expensive and would avoid experimentation outside target area. Rapid increase in African population (especially in towns) and the gradual saturation of rural areas will force African farmers to intensify agricultural production. Fertilizers and manure are being used more commonly by farmers, especially in the southern zone of Mali. Molecular marker-assisted recurrent selection allows combining the traits of interest in productivity and stability. It is therefore possible to sustainably raise the productivity of sorghum to make it a plausible alternative crop in an intensified cropping system. These findings are thus an important step toward breeding climate resilient varieties for meeting the challenges of climate smart agriculture and sustainable intensification. These two concepts are closely interlinked (Campbell et al., 2014). Climate smart agriculture lays emphasis on improving risk management which provides the foundations for enabling sustainable intensification.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Critical variables for estimating productivity in maize as a function of plant population and spacing

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The objective of this study was to find a group of independent variables that would influence and estimate maize (*Zea mays* L.) productivity, modeled by multiple linear regression. For that, an experimental delinquency in random order was used in a 2 × 2 factorial scheme, from two populations (45,000 and 65,000 ha^{-1} plants) and two spacings (0.45 and 0.90 m), with 20 replicates. Soil attributes and maize production components were evaluated. The soil attributes evaluated were bulk density, macroporosity, microporosity, total porosity, soil moisture and mechanical resistance to penetration, at depths of 0-0.15 and 0.15-0.30 m. The maize production components were plant height (PH), height of the first ear insertion (HEI), stalk diameter (SD), number of rows per ear (NRE) and number of grains per row (NGR). There was a positive correlation between the variables and production per hectare, except for grain moisture, soil moisture, macroporosity (0.15-0.30 m) and microporosity (0.00-0.15 m). The number of ears per hectare, the number of grains per row and the 100-grain weight served to estimate maize productivity. The methodology applied in this study was adequate for estimating production with an accuracy of 98% and can be applied to other experiments.

Key words: Production components, sowing, multivariat.

INTRODUCTION

Maize (*Zea mays* L.) is today the world's most widely grown cereal, with a production of 1,031.9 million tonnes expected for the 2017/2018 crop. World production is mainly concentrated in three major producers, the USA, China and Brazil; these countries alone account for 65.62% of global maize production (FAO, 2017).

Productivity in Brazil was 17.72 sacks per hectare (CONAB, 2017). However, maize productivity in the Northeast is considered low and is related to climate conditions, the spatial arrangement of plants, as well as soil fertility and inadequate management practices (Sangoi and Silva, 2010).

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The physical attributes of the soil have been considered by some authors as indicators of the differences between areas under different management systems (Carneiro et al., 2009). According to Nascimento et al. (2014), one of the peculiarities of agriculture is the treatment adopted for the management of agricultural areas, which considers the production area in a homogeneous way, thereby disregarding the natural variability that occurs in areas of production.

The arrangement of maize plants through changes in population density, spacing between rows, plant distribution along the row, and plant variability, is one of the most important management practices for maximising the interception of solar radiation, optimising its use and strengthening grain yield (Fantin et al., 2016).

The use of multivariate statistical techniques evaluates variables simultaneously, identifying those having a real power of discrimination and giving an understanding of the relationships between the variables and the groups of quality class that they form (Gerhard et al., 2001).

Research has been carried out on the maize crop in order to identify the direction and intensity of linear relationships between variables or characteristics (Toebe and Cargnelutti Filho, 2013). Freddi et al. (2008), using a technique of multivariate analysis in evaluating principle components, found that high rates of maize productivity proved to be correlated with good growth in the aerial part of plants under conditions of lower soil density, giving high values for dry matter production of the roots, albeit, of small diameter.

Many farmers seek an estimate of productivity before the harvest, as they can then use the production forecast to assess their future transportation and storage needs for the product, as well as likely profits in the marketplace. Productivity estimates are useful for comparisons in trials of hybrids/varieties, for checking production variability in any one area or between different areas, or for comparing different management practices (Rodrigues et al., 2005).

Reetz model, Emater-MG (2000) method used by Rodrigues et al. (2005) and Bernardon (2005) in their original sources do not require a statistical or mathematical explanation to demonstrate their appearance. These methods are very practical for producers, whereas other methods used by Holzman et al. (2014) are more sophisticated and hardly accessible to small and medium producer, despite making predictions well in advance. A method or mathematical model is therefore necessary that is practical and accessible, with a statistical or mathematical construction that attests to its appearance, so that data from future experiments can better represent reality and assist the producer in his planning.

The aim of this study was to find a group of independent variables that would influence and estimate productivity in maize (*Z. mays* L.), modelled by multiple linear regression.

MATERIALS AND METHODS

The study was carried out in an experimental area belonging to the Department of Agricultural Engineering of the Federal University of Ceará in Fortaleza in the State of Ceará, Brazil, in a Yellow Red Argisol (EMBRAPA, 2013), located at 03°43'S and 38°32'W at an altitude of 19 m.

According to Koppen classification, climate region is type Aw, tropical rainy with precipitation in summer-autumn and annual average temperatures of 28°C and precipitation of 900 mm.

Before setting up the experiment, soils samples were collected for chemical characterisation of 0.20 cm layer, which presented the following chemical composition: pH in H_2O: 5.3; Ca: 1.23 cmolc dm^{-3}; Mg: 0.58 cmolc dm^{-3}; Al: 1.00 cmolc dm^{-3}; Al + H: 1.55 cmolc dm^{-3}; K: 1.20 cmolc dm^{-3}; cation exchange capacity (CEC): 6.05 cmolc dm^{-3}; and V: 73.5%.

The experimental area is in the initial stages of setting up a no-tillage system. In November 2014, the forages crotalaria, sorghum and Mombasa grass were planted to form straw for sowing maize in March 2015.

During cultivation of maize, additional irrigation was given using a conventional sprinkler system. ET_0 was calculated by a class A tank, installed on grass with a border of 100 m; the tank coefficients were obtained with Doorenbos and Pruitt (1977) model. In ETc calculating, the K_c for different phenological stages of crop was used, which varied between 0.2 and 1.6, as per Guerra et al. (2004).

Maize seed used in the experiment was Al Avaré cultivar, considered low to high technological cultivar, with 98% purity and 85% survival, aiming for one population of 65,000 plants per hectare, with a spacing between rows of 0.90 m at a sowing density of six seeds per metre, and for another population of 45,000 plants per hectare, with a spacing of 0.45 m between rows at a sowing density of three seeds per metre.

During cultivation of maize crop, base and cover fertilisation were carried out based on chemical analysis of soil; for base fertiliser, 250 kg ha^{-1} of NPK 10-28-20 commercial formulation was used. Cover fertilisation was carried out during the V_2, V_4 and V_8 stages of maize, using 300 kg ha^{-1} urea and 120 kg ha^{-1} potassium chloride. To control the presence of fall armyworm (*Spodoptera frugiperda*), four applications of Lufenuron (a.i.) product at a dose of 18 g ha^{-1} of active ingredient, and Lannat BR phosphorous insecticide (active ingredient: methomyl) were given at the V_4, V_8, V_{12} and R_1 stages. Sowing was manual, following the order of treatments.

The experimental design was of completely randomised blocks in a 2 ×x 2 factorial scheme, comprising four treatments (T1 - P1S1, T2 - P1S2, T3 - P2S1 and T4 - P2S2): two populations (P1 - 45,000 plants ha^{-1}; P2 - 65,000 plants ha^{-1}) and two spacings (S1 - 0.45 m; S2 - 0.90 m), with 20 replications for each treatment, for a total of 80 experimental units. Each plot was 3 m in width and 10 m in length, with a working area of 0.90 × 5 m^2, the central part of rectangle, giving 4.05 m^2 of working area per plot.

The soil attributes and maize production components were evaluated. The soil attributes evaluated were bulk density, macroporosity, microporosity, total porosity, soil moisture and mechanical resistance to penetration, at depths of 0-0.15 and 0.15-0.30 m. The maize production components were plant height (PH), height of the first ear insertion (HEI), stalk diameter (SD), number of rows per ear (NRE) and number of grains per row (NGR), with the data collected from 10 plants in the working area to determine the mean value of each treatment for these variables. The value for the number of ears per hectare (NEH), production per hectare in kg (PPH) and maize dry matter (DM) were collected in the working area, with the values for grain moisture (GM), the emergence speed index (ESI), and100-grain weight (HGW) being estimated per hectare.

For PH, ten plants were selected from working area. The HEI was determined by measuring from the ground surface to the first ear insertion using a tape measure. The SD was obtained by means of a digital calliper, calculating the average for largest and smallest diameters measured at internode located above first node of adventitious roots. The NRE was obtained by counting number of rows in ten ears from each plot. To determine the NGR, the number of grains per row was again counted in ten ears from each plot, to obtain the average for each treatment. The ESI was calculated from daily counts according to methodology proposed by Maguire (1962), after applying emergence test. The HSW was obtained according to Seed Analysis Rules (BRASIL, 2009).

DM was determined by cutting the maize plants 2 cm above ground surface in working area, all the plants were then weighed, subtracting grains weight after thrashing, thereby obtaining mass weight of green straw in grams. To determine PPH, all ears in working area were collected followed by threshing.

Initially, using statistical planning, the minimum number of samples for a normal distribution of data was calculated. The statistical methodology adopted allows verification of the number of samples necessary for data normality in the experiment by the standard mean error. Immediately afterwards, with the standard mean error available, a 10% β error was considered, and by means of a graph of operating characteristic curves, the number of samples to be used in the evaluations was found (Montgomery, 2004). The minimum number found was 10 samples for each treatment; however, with the idea of increasing data normality, a standard number of 20 samples was determined for each replication.

The soil attribute data were submitted for analysis of variance, in which data that presented no significant difference between treatments were eliminated; differences between mean values were compared by Tukey's test at 5% significance. With the remaining variables, a correlation matrix was prepared, and any variables that had no significant correlation with production per hectare, were eliminated.

Multiple linear regression modelling was then performed, evaluating each assumption, making the necessary variable transformations and verifying the impact of each variable on production using the Stepwise method for modelling. The last step was model validation using data from experiments carried out in the same area by Santos et al. (2017) and Nicolau (2016), to check the estimating power. All the analyses were carried out using the SPSS Statistics v.22 software (IBM).

RESULTS

By means variance analysis, it was found that physical attributes of soil for treatments population and spacing that did not present a significant difference were eliminated, those being macroporosity (0-0.15 m), microporosity (0.15-0.30 m), total porosity (0-0.15 m), total porosity (0.15-0.30 m), bulk density (0-0.15 m), bulk density (0.15-0, 30 m), soil resistance (0-0.15 m) and soil resistance (0.15-0.30 m).

The first assumption was validated using Durbin-Watson statistic (d=1.887). The VIF was used to diagnose multicollinearity, where all the variables were at the acceptable level (1.011≤ VIF ≤1.412). Residual normality was validated by Kolmogorov-Smirnov and Shapiro-Wilk tests (Table 2), neither of which rejected the null hypothesis. Homoscedasticity was also checked (Figure 1) as per Mâroco and Pinheiro (2014). Linearity of the coefficients is guaranteed by the adopted model, in this case the least-squares method (Corrar et al., 2012). The sample size was within the desired range, with 20 replications (observations) for each treatment, for a total of 80 observations (Hair, 2009).

Multiple linear regression identified the variables Log (ears per hectare), Log (number of grain per row), Log (100-grain weight) and Log (number of rows) as significant predictors of Log (production per hectare), as shown in Table 3.

This model is highly significant and explains a high proportion of the variation in Log (production per hectare) (Table 4). In this experiment, plant height was not included in the model; the same results were found by Mourtzinis et al. (2013), where plant height was not included with any significant predictor. Kappes et al. (2017) found no correlation between plant height and grain productivity.

The next step was to verify by means of the model, the closeness of the productivity estimate to the actual productivity. Data from the experiment carried out by Santos et al. (2017) were used for this, as shown in Table 5.

Nicolau (2016) also carried out research with maize in the same experimental area as the present work, as described in Table 6. The Shapiro-Wilk test was used for normality, as there were less than 30 samples (Mâroco and Pinheiro, 2014).

DISCUSSION

In their research, Harrell et al. (1996) and Babyak (2004) found that the inclusion of variables that have no influence on dependent variable still presents problems of multicollinearity with other independent variables, which can lead to problems of overfitting, and should therefore be avoided. Including these variables in the analysis consequently makes no sense, as previously shown by Siqueira et al. (2008), Oliveira Júnior et al. (2010) and Nascimento et al. (2014).

Based on Pearson correlation analysis (Table 1), the variables that had no significant correlation with production per hectare were eliminated, including grain moisture, macroporosity (0.15-0.30 m), microporosity (0.0-0.15 m) and stem diameter, in relation to the last variable having no significant correlation.

Mourtzinis et al. (2013) found similar results in their linear regression model for grain yield; stem diameter was not included with a significant predictor. Kappes et al. (2017) found the same result and attributed this to the crop being well supplied by nutrients from soil and applied fertilisers, and little dependent on translocation of nutrients from stem to grains; stem diameter is considered an important characteristic of organ used to store

Table 1. Pearson correlation between variables.

Variable	Production per hectare	
	Pearson correlation (R)	*p*
Production per hectare	1	-
Plants per hectare	0.519**	<0.001
Grain moisture	-0.065 [ns]	0.568
Soil moisture (0.00-0.15 m)	-0.318**	0.004
Soil moisture (0.15-0.30 m)	-0.406**	<0.001
Macroporosity (0.15-0.30 m)	-0.104[ns]	0.357
Microporosity (0.00-0.15 m)	-0.140[ns]	0.214
100-grain weight	0.415**	<0.001
Total dry matter	0.450**	<0.001
Height of first ear	0.227*	0.043
Plant Height	0.373**	0.001
Number of grains per row	0.534**	<0.001
Number of rows	0.458**	<0.001
Emergence	0.362**	0.001
Stem diameter	0.085[ns]	0.452
Ears per hectare	0.590**	<0.001

n = 80 samples.

Table 2. Test of residual normality.

Test	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	dF	Sig.	Statistic	dF	Sig.
Standardised residual	0.102	80	0.038	0.959	80	0.012

[a]Lilliefors correlation of significance; dF: significant difference; Sig.: significance.

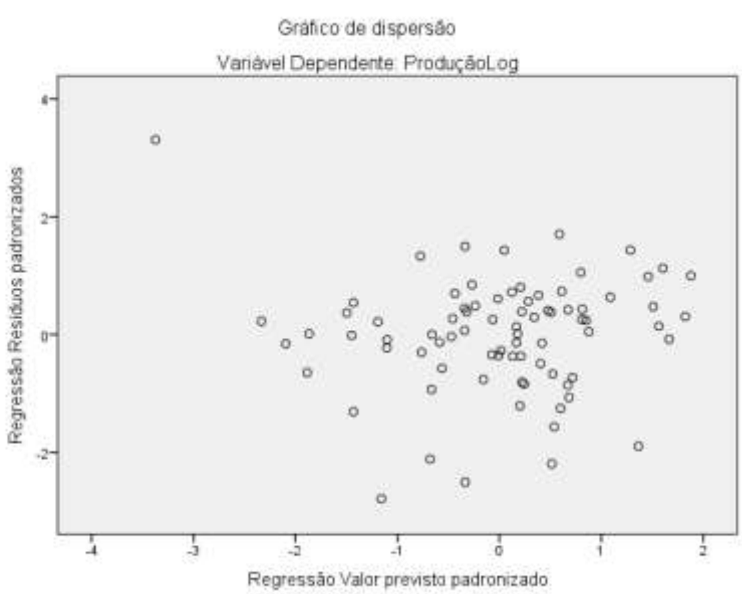

Figure 1. Scatter plot of homoscedasticity.

Table 3. Coefficients for the dependent variable, Log (production per hectare in kg)[(a)].

Model	Non-standardised coefficients		Standardised coefficients	t	Sig.
	Beta	Standard error	Beta		
Constant	-4.866	0.085		-57.485	0.000
Log (Ears per hectare)	1.009	0.015	0.672	69.474	0.000
Log (Number of grains per row)	0.979	0.022	0.499	43.649	0.000
Log (100-grain weight)	0.943	0.023	0.394	40.884	0.000
Log (Number of rows)	0.940	0.046	0.235	20.598	0.000

[a]Dependent variable: Log (Production per hectare); t-Wald test; Sig.: significance.

Table 4. Model summary for the dependent variable, yield per hectare[(e)].

Model	Change statistics									
	R	R^2	Adjusted R^2	Standard error of the estimate	Change in R^2	Change F	df1	Df2	Sig. Change F	Durbin-Watson
1	0.630[a]	0.397	0.389	0.161	0.39	51.306	1	78	0.000	1.887
2	0.892[b]	0.796	0.791	0.094	0.39	150.665	1	77	0.000	
3	0.977[c]	0.954	0.952	0.045	0.15	259.497	1	76	0.000	
4	0.997[d]	0.993	0.993	0.017	0.03	424.292	1	75	0.000	

[a]Predictors (constant) - Log (ears per hectare); [b]Predictors (constant) - Log (ears per hectare), Log (number of grains per row); [c]Predictors (constant) - Log (ears per hectare), Log (number of rows), Log (100-grain weight); [d]Predictors (constant) - Log (ears per hectare), Log (number of grains per row), Log (100-grain weight), Log (number of rows); [e]Dependent variable - Log (production per hectare).

Table 5. Test of normality of the productivity estimate*.

Treatment	Shapiro-Wilk		
	Statistic	df	Sig.
Actual-MS2	0.825	4	0.156
Estimated-MS2	0.802	4	0.105
Actual-BS1	0.896	4	0.409
Estimated-BS1	0.976	4	0.878
Actual-MS1	0.998	4	0.992
Estimated-MS1	0.889	4	0.379
Actual-CS1	0.886	4	0.365
Estimated-CS1	0.773	4	0.061
Actual-BS2	0.971	4	0.850
Estimated-BS2	0.922	4	0.549
Actual-CS2	0.985	4	0.929
Estimated-CS2	0.939	4	0.648
Actual-T	0.777	4	0.067
Estimated-T	0.961	4	0.783

BS1: *Brachiaria* intercropped with the maize, sown on the same day as the maize; BS2: *Brachiaria* intercropped with the maize, sown at stage V4 in the maize; MS1: Mombasa grass intercropped with the maize, sown on the same day as the maize; MS2: Mombasa grass intercropped with the maize, sown at stage V4 in the maize; CS1: *Crotalaria* intercropped with the maize, sown on the same day as the maize; CS2: *Crotalaria* intercropped with the maize, sown at stage V4 in the maize; T: Monocropped maize, control.
*Source: Santos et al. (2017).

Table 6. Test of normality of the productivity estimate**.

Treatment	Shapiro-Wilk*		
	Statistic	df	Sig.
Actual-M1-C1	0.960	4	0.780
Estimated-M1-C1	0.933	4	0.610
Actual – M1-C2	0.948	4	0.705
Estimated- M1-C2	0.907	4	0.469
Actual-M1-C3	0.910	4	0.483
Estimated-M1-C3	0.918	4	0.525
Actual-T1	0.960	4	0.777
Estimated-T1	0.802	4	0.106
Actual-M2-C1	0.883	4	0.352
Estimated-M2-C1	0.927	4	0.578
Actual-M2-C2	0.936	4	0.630
Estimated-M2-C2	0.940	4	0.653
Actual-M2-C3	0.954	4	0.744
Estimated-M2-C3	0.938	4	0.644
Actual–T2	0.957	4	0.762
Estimated-T2	0.994	4	0.977

M1: Disk mechanism; M2: shaft mechanism; C1: cover of *Crotalaria*; C2: cover of Mombasa grass; C3: cover of sorghum; T1: maize in bare earth (disc), T2: maize in bare earth (shaft).
**Source: Nicolau (2016).

photoassimilates that contribute to grain filling.

Grain moisture, soil moisture at both depths, macro-porosity (0.15-0.30 m) and microporosity (0.00-0.15 m) correlated negatively with production per hectare; other variables however had a positive correlation. It was found that plants per hectare, number of grains per row and number of ears per hectare, correlated with production per hectare. Despite these variables correlating with production, the correlation was weak; but this may be associated with the fact that these data come from agricultural experiments, with little experimental control over such factors as rainfall, and physical, chemical and biological conditions of soil, in addition to all of these factors being variable over time and under intemperate conditions, according to Pimentel-Gomes (2009).

To carry out the multiple linear regression, a preliminary regression was made, where the assumptions were observed, and some seen to be violated; each variable was therefore transformed by the base ten logarithmic function, as suggested by Hair (2009) for the problem of homoscedasticity. Multiple linear regression employing a stepwise selection of variables was used to obtain a parsimonious model that would predict the production per hectare as a function of independent variables (ears per hectare, number of grains per row, 100-grain weight and number of rows). The assumptions of model were analysed, namely the absence of serial autocorrelation between residuals, multicollinearity between independent variables, residual normality, homoscedasticity of residuals and coefficients linearity.

The final model found for Log (production per hectare) = -4.866 + 1.009 Log (ears per hectare) + 0.979 Log (number of grains per row) + 0.943 Log (100-grain weight) + 0.940 Log (number of rows). Observing the beta coefficients (Table 7) demonstrates the importance of production: Log (ears per hectare), Log (number of grains per row), Log (100-grain weight) and Log (number of rows). This implies that number of ears per hectare has a very strong impact on production. The increase in grain productivity due to increase in population can be explained by adjustment in plant development as a function of population density. Therefore, at low densities, individual plant production is generally high, but productivity per area is small, as verified Vian et al. (2016), who found that component that best correlated with productivity in a maize crop in an irrigated area with adequate spatial plant uniformity was the number of ears per area.

These variables explain around 0.98 of the variability in production, agreeing with Vian et al. (2016), who reported that in the 2011/2012 crop, the coefficient of determination of production components explained 0.90 of variation in grain productivity. The number of ears per area, 100-grain weight, number of grains per ear and number of grains per row had a direct effect on productivity, with correlations classified as high (0.65 and 0.54) for the first two variables and low (0.26 and 0.23) for the last two variables, respectively.

Table 7. Mean values for comparing productivity between pairs.

SV	Compared mean values	Actual mean	Estimated mean	t	df	Sig.
Pair 1	Actual-M1-C1 × Estimated-M1-C1	6260.20	7717.45	-1.23	3	0.31
Pair 2	Actual-M1-C2 × Estimated-M1-C2	3612.75	4178.22	-0.65	3	0.56
Pair 3	Actual-M1-C3 × Estimated-M1-C3	5722.78	6599.96	-0.92	3	0.43
Pair 4	Actual-T1 × Estimated-T1	6413.88	9202.60	-1.22	3	0.31
Pair 5	Actual-M2-C1 × Estimated-M1-C1	5903.25	7381.82	-1.28	3	0.29
Pair 6	Actual-M2-C2 × Estimated-M2-C2	3636.58	6826.23	-2.73	3	0.07
Pair 7	Actual-M2-C3 × Estimated-M2-C3	4998.28	5986.32	-1.26	3	0.30
Pair 8	Actual-T2 × Estimated-T2	4344.73	6669.28	-1.53	3	0.22
Pair 9	Actual-BS1 × Estimated-BS1	6475.56	6808.77	-0.47	3	0.67
Pair 10	Actual-MS1 × Estimated-MS1	6286.63	6534.95	-0.19	3	0.86
Pair 11	Actual-CS1 × Estimated-CS1	6925.75	8052.85	-1.65	3	0.20
Pair 12	Actual-BS2 × Estimated-BS2	6709.08	6177.50	0.389	3	0.72
Pair 13	Actual-MS2 × Estimated-MS2	6069.07	6242.46	-0.21	3	0.85
Pair 14	Actual-CS2 × Estimated-CS2	7862.39	5583.04	7.5	3	0.01
Pair 15	Actual-T × Estimated-T	6942.94	6888.41	0.051	3	0.96

SV: Source of variation; BS1: *Brachiaria* intercropped with the maize, sown on the same day as the maize; BS2: *Brachiaria* intercropped with the maize, sown at stage V4 in the maize; MS1: Mombasa grass intercropped with the maize, sown on the same day as the maize; MS2: Mombasa grass intercropped with the maize, sown at stage V4 in the maize; CS1: *Crotalaria* intercropped with the maize, sown on the same day as the maize; CS2: *Crotalaria* intercropped with the maize, sown at stage V4 in the maize; T: Monocropped maize, control; M1: disk mechanism; M2: shaft mechanism; C1: Cover of *Crotalaria*; C2: Cover of Mombasa grass; C3 : Covering with sorghum; T1: corn on bare soil with disc; T2: corn on bare ground with stem; t: Paired t-test at 5%

For the other variables that were not included, such as the physical attributes of the soil and the remaining agronomical components, it is possible that in this experiment the other variables had a greater impact on the final regression model, as shown by Mourtzinis et al. (2013). To apply the logarithmic properties to the multiple regression the following expression was found:

$$\text{Log(PH)} = -4.866 + 1.009\text{Log(NEH)} + 0.979\text{Log(NGR)} + 0.943\text{(HGW)} + 0.940\text{Log(NRE)} \quad (1)$$

Therefore,

$$\text{PH} = 13.6 \times 10^{(-6)} \times (\text{NEH})^{1.009} \times (\text{NGR})^{0.979} \times (\text{NRE})^{0.940} \times (\text{HGW})^{0.943}$$

where PH = Production per hectare in kg; NEH = Number of ears per hectare; NGR = Number of grains per row per ear; HGW= 100-grain weight and NRE = Number of rows per ear.

There are various methods for estimating productivity, among them Reetz (1987) and Emater-MG method (2000), which considered some of the variables found in t model. Bernardon (2005) employs a model that uses some of these same variables, but does not refer to the appearance of the model in his work; for these three cases, there is no mathematical argument showing the construction of these models.

The multiple regression should be tested for each region, to adapt the constants because of changes that can occur in the mean values of these variables due to genetic or environmental factors, as verified by Vázquez et al. (2012), Menezes et al. (2015) and DuoBu et al. (2013). For the producer, these methods for estimating productivity are more practical and economical compared to methods used by Holzman et al. (2014) and Li et al. (2014). Calibration was by solving a linear system for unknowns A, B, C, D and E using the equation:

$$\text{Log(PPH)} = \text{A} + \text{B.Log(NEH)} + \text{C.Log(NGR)} + \text{D.Log(HGW)} + \text{E.Log(NRE)} \quad (2)$$

using earlier data or previously constructing pilot projects from which the values for Log (PPH), Log (NEH), Log (NGR), Log (HGW) and Log (NRE) can be obtained, thus a linear system can be set up for the unknowns A, B, C, D, and E.

Both the estimated and actual data achieved normality (Tables 5 and 6); the paired t-test was then applied, as it was the most appropriate in this case (Mâroco and Pinheiro, 2014).

It was found that the expression was good at estimating productivity, irrespective of the type of data collection or management, although a significant difference in mean values was seen for pair 14, which can be avoided by calibrating the model (Table 7). Santos et al. (2017)

Table 8. Result of the productivity modelling*.

Variable	Mean value-Modelling	Mean value-CS2	t*	df	Sig.
HGW	28.55	38.67250	-3.748	82	0.000
NEH	30638.90	50625.00	-4.276	82	0.000

HGW: 100-grain weight; NEH: number of ears per hectare; t: test for equality of mean values (Wald test).
Source: Santos et al. (2017).

found that between intercropped and moncropped maize, regardless of the intercropping configuration or time of sowing, there were no changes in the phytotechnical characteristics nor a decrease in productivity of the maize.

When variables were compared using the model, both modelling data and CS2 data obtained by Santos et al. (2017) confirmed that NEH and HGW variables displayed a difference in mean values (Table 8), thereby justifying their higher productivity. However, both sets of data displayed equality of variance by Levene test.

Conclusions

The results showed that, in order of impact on productivity, the variables that best explain productivity in maize are NEH, NGR, HGW and NRE.

The variable, model, explains 90% of the variability in productivity. The model succeeded in estimating mean productivity with no significant difference from the actual mean value in 93% of the cases.

The model proved to be effective, requiring calibration in all cases due to the possible changes that the variables can undergo regardless of the management or environmental factors.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Welfare effect of eliminating commodity price volatility: Evidence from Tanzania coffee farmers

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This paper investigated the welfare consequences of reducing coffee price volatility in Tanzania. GARCH (1,1) model is fitted with monthly coffee prices from 1998 to 2017 to estimate the conditional and unconditional variance of the residual. The coefficient of relative risk aversion and unconditional variance of GARCH (1,1) model are applied in a typical Lucas-like representative argent model to examine the welfare consequences of eliminating price volatility using the case of coffee farmers in Tanzania. The empirical finding shows that the welfare gain from eliminating price volatility for coffee farmers in Tanzania is small. Taking into account the effects of reforms in coffee industry and economic crisis, the welfare gain remains at 1.139% of revenue from coffee sales per year. Given that coffee market is under oligopoly stage still there is some degree of monopoly in terms of regulations thereby rising a need of "check and balance" to ensure that bureaucratic challenges are addressed. Nonetheless inclusive hedging strategies, improving production and quality of coffee, provide the next step in improving the welfare of the coffee producers where reducing coffee price volatility at a cost might not be a desirable choice.

Key words: Tanzania, coffee price volatility, welfare consequences, and inclusive hedging mechanisms.

INTRODUCTION

Coffee is an important export cash crop in Tanzania. According to coffee board (2011) annual report, coffee accounted for almost 14% of total agricultural exports and 5% of total export value in Tanzania. The estimates of export earnings from coffee have been around USD100 million per annum over the last 30 years. The coffee sector provides direct income to more than 400,000 farmers/households thereby supporting the livelihoods of an estimated 2.5 million individuals. Coffee price volatility not only impinges the welfare of the household involved in coffee farming but also exert uncertainty on environmental degradation especially cutting trees as

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a supplements and can exacerbate family conflict in terms of resource availability[1].

Volatility in the commodity markets has an inherent risk to small farming households in developing countries. As pointed out by Deaton (1999) and Minot (2014), commodity exports make up a large share of agricultural livelihoods in many low-income countries. Agricultural commodity prices volatility has been higher in 2000s relative to the preceding decades, raising concern among policymakers and various international organizations (FAO et al., 2011). The volatility of coffee prices, like other commodities, is explained by the global market practices (Temu, 1999; Baffes, 2003; Arezki and Bruckner, 2011). The study by Morgan et al. (1999) and FAO (2004) found out that supply surge, macroeconomic condition, non-compliance with International Commodity Agreements (ICAs), agricultural subsidies and other supportive policies in developed countries, relatively inelastic demand and poor quality branding among farmers are the key factors explaining commodity price volatility.

Since the great depression in the 1930s, nations all over the universe have implemented a number of policy instruments aimed at stabilizing prices. Newbery and Stiglitz (1981), Reihart and Wickham (1994), Yang et al. (2001), Demeke et al. (2008) and UNCTAD (2011) have summarized the policy tools used by United Nations Agencies, and various government aiming at mitigating the impact of volatile commodity prices. Such interventions[2] include: the establishment of quotas and buffer stock arrangements, reformed pricing within commodity arrangements, outright cartels, stabilization funds, agricultural boards, International Commodity Arrangements, External Compensatory Finance by the IMF and the STABEX by the EU, production restriction measures and the liberalization policies. Other policy instruments are income support programmes, market-based mechanisms (financial instruments), and revenue management, diversification and value addition (Appendices I and II). However, as shown in (Appendix II) these interventions had limited success.

Over time, developing countries including Tanzania have attempted to intervene in the market by separating domestic commodity prices from international price via the Tanzania Coffee Board (TCB), Cooperative Unions, and different reforms in the coffee industry that guaranteed farmers a minimum price for their production (Bryla, 2004). In the case of coffee industry, three laws were enacted namely: the Coffee industry Act (CIA) of 1977, The Coffee Marketing Board Act (CMBA) of 1984 and The Coffee Industry Act (CIA) of 2001 (Appendix III). In addition, from 2001, the World Bank in collaboration with other partners started providing technical assistance and capacity building to allow farmers to access markets in Tanzania. These initiatives were directed at the cooperative unions. Initially, Kilimanjaro Native Cooperative Union (KNCU) attempted to use options in designing a hedging strategy that matched its risk profile. The core objective of these strategies were: to ensure the cooperative maintain and observe an agreed floor price to farmers during trade seasons, and to reduce the cooperative's financial exposure to price volatility and reducing values of stocks of coffee held for curing.

However, this strategy allowed a smoothing-out of price spikes within a marketing year. With the low knowledge on how to use derivative markets, producers have used traditional means such as self-insuring through asset accumulation, savings and access to credits, income diversification and informal insurance arrangements as strategies to mitigate risks emanating from commodity price volatility although each mechanisms have had a number of limitations (Bryla, 2004). As pointed out by Baffes (2003) the coffee board in Tanzania during the liberalization period in early1990s, was no longer guaranteeing farmer's prices, rather than acting as the regulatory authority.

Decision-making in the Tanzanian coffee sector should take into account the knowledge about price behaviour and device appropriate mechanisms to distribute resources in dealing with the impact of price volatility on the welfare of the coffee producers. For instance, how do poor household coffee producers cope with global and domestic risks emanating from price volatility that can jeopardize farm profits and exert uncertainty on income and generally on productivity?

Figure 1 shows the evolution of prices paid to coffee growers and returns of coffee prices. It is clear that coffee prices have not been stable at all. The price series on the right panel are evidently leptokurtic and they are relatively large numbers of observations that are far from average. Coffee prices grew at 55 percent in the year 2011 though in 2017 recorded a negative growth rate of 4.4%. This raises the debate on the welfare impact of volatility emanating from commodity prices. We address this question in the context of coffee farming households in Tanzania.

To take this question into perspective in the notion of expected utility theory we employ the coefficient of relative risk aversion and unconditional variance[3] of GARCH (1,1) model in a typical Lucas-like representative argent model to examine the welfare consequences of eliminating price volatility for the case of coffee farmers in Tanzania. The gist of this approach is that if the resulting coefficient is low, then the costs of interventions to diversify risks or to stabilize prices may outweigh the

[1] Monthly Economic Review Bank of Tanzania, 2011

[2] Government interventions refer to any measure related to coffee price risk, market stability, coffee quality and marketing implemented by key organs in the Tanzanian coffee marketing system. These organs include the government, TCB, cooperatives and producer associations. Basically domestic intervention are informs of liberalization policy, regulations, risk management measures, quality improvement, political influences, taxation structures and infrastructure.

[3] As price-takers in global commodity markets, smallholder farm households are often vulnerable to the unpredictable events (Blouin and Macchiavello, 2013)

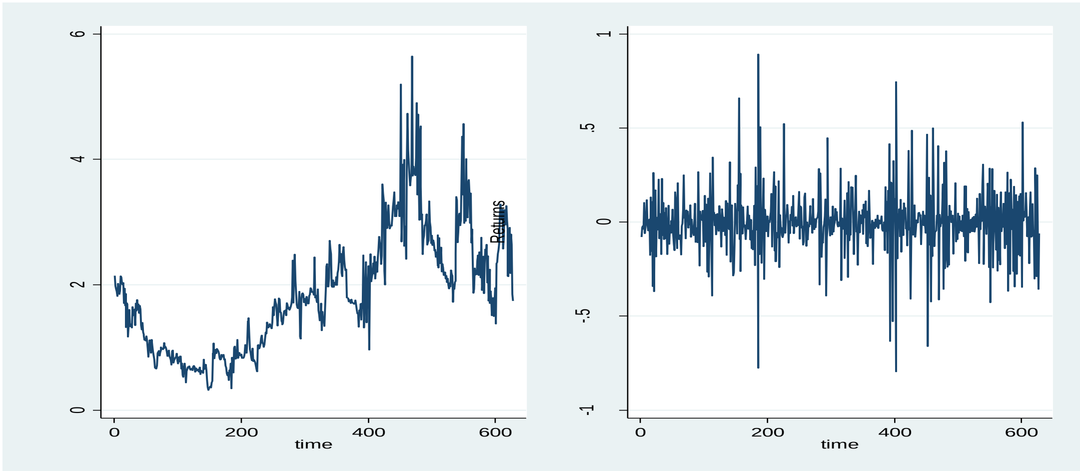

Figure 1. Coffee prices (USD/kg) and returns (%).

benefits of these efforts and vice versa is true if the coefficient is high. Evidently, our estimations show that the welfare gains of reducing coffee price volatility for the producers are small.

Price risk faced by coffee producers

Studies on the impact of commodity price volatility on growth, public finance and welfare in commodity-dependent economies are huge in literature (Reihart and Wickham, 1994; Swaray, 2000, 2005; WB, 2005). In absence of clear hedging mechanisms, producers remained uncertain about the dynamics of prices. The usual conclusion drawn from these studies is that uncertainty arising from commodity price volatility has a detrimental impact at the farm and macroeconomic level. At the farm level, it hampers farmers from the effective allocation of resources, accesses to credit, utilizing advanced production technology; leading to lowering their income.

At the macro level, commodity price volatilities tend to affect government's fiscal revenue, trade balance, exchange rates and creditworthiness. Larson et al. (1998), Chaudhuri (2001) and Rutasitara et al. (2010), argue that the price effect had been the most significant determinant of export earning volatility in most commodity-dependent economies. This implies that commodity price volatility has an impact on economic variables such as GDP growth, development, poverty reduction and debt servicing[4]. In addition, commodity-dependent economies are exposed to a 'specific risk to trade exposure' generated by the volatile world's commodity prices. This is the aggregate risk that affects all the agents in the domestic economy in a perfect correlated way although with different magnitude.

Monitoring African Food and Agricultural Policies (MAFAP) (2011) has cautioned coffee exporters against depressing the welfare of the coffee producers by paying low auction price at the beginning of the year and receive a high premium at the point of exports at the end of the year. For instance, in 2010 prices had escalated by nearly 60 percent by the end of the year benefiting the traders while farmers received a lower price based on low quotation made at the beginning of the year. This entails that prices were far lower than what farmers could have potentially received if they had sold their coffee at the end of the year.

Magnitude of export and import commodity price volatility in Tanzania

Tanzanian export basket involves both traditional and non-traditional crops. It imports a significant share of both intermediate, consumable goods and foodstuffs. The prices of these commodities are historically volatile. For instance, it can be observed that from 1990 to 2014, coffee (Arabica) is more volatile with the standard deviation of 0.47 compared to robusta, which recorded a standard deviation of 0.34 per annum, while the price of tea is more volatile (0.39) than the price of cotton (0.25) and robusta coffee per annum. The price of gold is the least volatile (0.05). The price of oil is the most volatile commodity among all with a standard diversion of 0.62 implying that it can divert from the mean by almost 62% per barrel in USD dollars per annum. Figure 1 in Appendix IV show the monthly volatility of traditional and non-traditional exports, and the volatility of oil imports. Specifically, the price of oil can deviate from the mean by almost 3% per month. Other exported commodities such as tea and cotton have an average volatility of 1% per

[4] Swaray (2005) find that, price volatility has imposed difficulties in commodity dependent economies to service their debt obligation.

month although in the year 1998 and 2008/2009 the volatility increased to 2.8 and 3.5 respectively. It appears they were adversely affected by the economic crises of 1998 and 2008/2009. It can be observed from Figure 2 (Appendix V) that Tanzanian export earnings volatility (EEV) is highly irregular. From the year 2000 to 2007 export earnings deviated from the mean by 3 percent per month with lowest records being 2.8 percent. EEV was more volatile in the year 2008/2009 as a result of the economic crisis with the highest point deviation from the mean of about 3.3%. The volatility of export earnings averaged between 3.1% from 2009 to 2010 before reaching 2.9% in the boom that followed thereafter. However, much of the volatility of export earnings was attributed to the volatility of traditional exports as compared to non-traditional exports. The right panel in figure 2 shows that non-traditional export earnings are less volatile that is, about 5 and 2 times compared with traditional export earnings on higher and lower point respectively. On the left panel, we observe that imports are more volatile than export earnings. It is almost 3 times more volatile compared to export earning indicating more burdens to the balance of payment.

LITERATURE REVIEW

Theoretical literature review

There is a set of literature that relates commodity price volatility and welfare. The common approach used is the compensation of variation especially for food products using household data. Turnovsky et al. (1980) argue that in the scenario of a single commodity price stabilization, the consumer preferences for price volatility depend upon the basic parameters: income elasticity of demand for the commodity, the price elasticity of demand, the share of the budget spent on the commodity and the coefficient of relative risk aversion. All of these parameters enter in an intuitive way and the analysis includes the conventional consumer's approach. However, the basic assumption of the utility maximization and revealed preference theories is that the consumer knows with certainty the prices of all goods and services as well as feasible consumption bundles. In the real world, these assumptions may not reflect the reality. Jehle and Reny (2001) argue that many economic decisions have an uncertainty component and conclude that in a real situation, the operation of economic agents cannot always operate under such lucrative conditions. This is in line Von Neumann (1953) and Morgestern (1944) who state that the ultimate result of a decision taken by the consumer may not be known until it occurs despite the consumer's knowledge of the possible probabilities of the different possible outcome.

Lack of appropriate/deep insurance markets entails an adverse welfare consequence not only to organisation for economic co-operation and development (OECD) countries but also in developing countries. The situation is perverse in developing countries where insurance markets are underdeveloped and frequently missing (Shiller, 2009). The study by Aizenman and Pinto (2005) and Loayza et al. (2007) corroborates with that of Shiller (2009) in the sense that good times tend not to offset the negative impact of bad times, which leads to permanent negative effects in developing countries. Incomplete markets, sovereign risk, conflict-ridden politics, inefficient taxation, procyclical fiscal policy, and weak financial market institutions signify the reason for such asymmetry.

Empirical literature

Other studies inform that commodity prices are inherently volatile creating instability not only in the global commodity markets but also in price stabilization schemes in local governments (Heifner and Kinoshita, 1994; World Bank, 2000). A strand of empirical literature in favor of this claim relies upon the conversional standard deviation of price or the coefficient of variation as a measure of volatility (Serven, 1996; Acemoglu et al., 2003; Mobarak, 2005; Malik and Temple, 2009; Di Giovanni and Levchenko, 2010).

There exists a rich body of literature that has investigated the determinants of price volatility. Classic macroeconomic reasons such as exchange and interest rate fluctuation, yield and stock levels, climate change, and fuel price variations have been generally cited as the main contributing factors of changes in commodity price volatility (Pindyck and Rotemberg, 1990; Roache, 2010; Apergis and Rezitis, 2011; Karali and Power, 2013). Other studies such as Hnatkovska and Loayza (2005) and Ranciere et al. (2008) identify other source of macroeconomic volatility to be external factors (exports, global prices, terms of trade or international interest rates) and internal factors (such as economic policy, agricultural production, and natural or climatic disasters). Similarly, these studies conclude that it is possible to distinguish between exogenous sources of macroeconomic volatility (related to international trade, agricultural production and natural disasters) and endogenous sources (linked to volatility in economic policy or domestic socio-political conditions).

The literature on the effects of commodity prices on growth is wide. Ramey and Ramey (1995) show that the unpredictability of economic policy caused by volatility[5]in growth rates has a negative effect on the average growth rate of the economy. According to estimates produced by Hnatkovska and Loayza (2005), based on a sample of 79 countries show that increasing the average value of volatility by the value of its standard deviation results in

[5] Volatility is associated with risk in that it provides a measure of the possible variation or movement in a particular economic variable (Aizenman and Pinto, 2005)). In quotation of Wolf, (2005), two key connotations of volatility are: Variability (all movements) and uncertainty (unknown movement). Conceptually, volatility at a given time can be decomposed into a predictable and an unpredictable component.

an average loss of 1.3 points for growth in GDP over the period 1960 to 2000, and 2.2 points for the decade 1990 to 2000. Volatility can, indeed, act as an obstacle to economic and social development

Other studies such as Dehn (2000) estimate the impact of shocks in the price of raw materials on investment in developing countries. Similarly, Combes and Guillaumont (2002) show that vulnerability to volatility in global prices has a negative effect on the quality of economic policy and growth. Under imperfect financial markets, the government and individual households are unable to protect themselves fully against risks, which affects their revenue hence adjusts their consumption to the volatile economic activity (Aizenman and Marion, 1999; Wolf, 2005). The study by Aguiar and Gopinath (2007) and Loayza et al. (2007) confirms that volatility is driven by external factors, especially in relation to terms of trade, generates internal volatility in relation to consumption, particularly in developing countries.

In recent years, literature has increasingly focused on the impact of commodity price volatility on public finance in developing countries. Such studies estimates the impact of commodity prices in public finance mainly based on time series and cross-sectional studies (Kumah and Matovu, 2007; Collier and Gunning, 1999; Medina, 2010; Kaminskky, 2010; Villafuerte et al., 2010; Spatafora and Samake, 2012). The overall conclusion from these studies is that commodity price volatility has detrimental effects on government finance hence making fiscal policy uncertainty.

Other empirical literature focuses on the welfare effect emanating from price changes and volatility. For instance in estimating the welfare impacts of rising food prices in India using compensation of variation approach, Weber (2015) finds a 10% price increase on average causes of welfare loss to 5 to 6% of monthly income in rural areas and 3 to 4% welfare loss in urban areas. The same study concludes that poverty is felt below the poverty line by 4.69 and 2.19%of households in rural and urban regions respectively. The finding by Loayza et al. (2007) show that volatility has a direct welfare cost for risk-averse individuals, as well as an indirect one through its adverse effect on income growth and development.

Analysing the relationship between volatility risk and economic welfare in an analytically tractable growth model in U.S.A. Xu (2017) concludes that in contrast to level risk, which is always welfare reducing for a risk-averse household, volatility risk can increase or decrease welfare depending on model parameters, such as the magnitude of risk aversion. Furthermore, the study shows that the welfare impact of volatility risk is largely negligible. The calibrated model estimates that the welfare cost of volatility risk is equivalent to a 0.0062% decrease in annual consumption. Using general equilibrium set up, Van Campenhout et al. (2013) finds that price movements have real welfare implications in the short run. Changing prices affected welfare predominantly in a negative way, with welfare losses up to 36 percent of initial welfare for people below the poverty line.

Rapsomanikis and Sarris (2006) estimate the impact of international and domestic commodity price volatility on agricultural income instability in Ghana, Peru, and Vietnam using microeconomic approach. They compute household's income variances and coefficients of variation, which allow to indicate the level of income variability and to capture whether it depends on the world or domestic price shocks. The study finds that the influence of international prices on income is small and the main source of income instability is domestic prices.

Using household data, Balié et al. (2016) estimate the effect of cereal price shocks and volatility on farmer's welfare in Sub-Saharan Africa. The study confirm that farmers are likely to benefit more from policy interventions inhibiting cereal price increase which is potential to farmer's welfare gain compared to extremely expensive price stabilization policies. However, targeting the poorest portion of the population is important in order to protect farmers' from substantial welfare loss imposed by price volatility.

Utilizing household survey data in Vietnam, Magrini and Montalbano (2012) investigate the welfare impact of people's exposure to risk induced by opening up trade. The study finds a negative welfare effect of "ex-ante" changing behavior induced by risk exposure. Furthermore this study confirms that households that are involved in main "export farm" are more vulnerable than "non-traded non-farms". The conclusion derived from this study is that "economic stabilization policies" should receive more attention even in absence of downside shocks.

Karanja et al. (2003) analyses the effects of market reforms on the evolution and volatility of producer prices in Kenya using monthly producer prices of four commodities including coffee and found that real producer prices for coffee, tea, and maize significantly declined during the reform period. Although producer prices seem to exhibit higher volatilities in general, these volatilities are higher during the reforms period. The argument is that there is limited private sector participation in agricultural markets while international trends in agricultural commodity prices seem to play a major role in influencing high volatilities.

A similar argument relating to market participation is also in line with Ponte (2002) when giving an account of the coffee market in East Africa. Inspired by the major changes in global agricultural markets, it is viewed that liberalization in African countries has led to the substantial involvement of Multinational Corporations (MNCs) in domestic trade and processing hence the consequence has been to hinder independent local traders from accessing the markets. This, eventually, leads to non-competitive behavior among few large-scale actors.

The impact of domestic reforms on agricultural prices is also evident in studies on developed countries. Yang et al. (2001) uses GARCH models to examine the impact of USA agricultural liberalization policy on agricultural commodity prices. The results show that liberalization reforms have an impact on price volatilities on many commodities. However, the impact differs across commodities: that is, whereas liberalization seems to increase price volatility of some commodities, volatility decrease is reported for other commodities. An earlier work by Crain and Lee (1996) on USA farm programmes also confirms that agricultural reforms have the impact on price volatility.

Mofya-Mukuka and Abdulai (2013) confirmed a reduction in the share of Tanzania prices in the world price. The implication is that the reforms in the coffee industry led to more government intervention, which resulted in a negative impact on producer prices. For instance, increasing the government's role in trade, pricing and exports of coffee, and thus resulting in reduced transmission of world-domestic prices. This could have negative implications on the farmer's welfare because where producer prices do not respond to changes in world prices, the producers are not able to benefit from world price increases.

While the pre-reform policies ensured some price stabilization in the sense that declines in world market prices were not fully and quickly passed on to producers, they also resulted in some delays in passing on price increases to producers. Many studies have documented the concerns about the rate and symmetry of price response that are normally raised if a sector in the marketing channel is highly concentrated and dominated by few firms or marketing agents (White and Leavy, 2001; Abdulai, 2002).

Utilizing Deaton's approach in the application of the coefficient of variation, Leyaro (2009) estimated the effect of commodity price change on consumer welfare in Tanzania using Household Budget Survey (HBS) Data. Accounting for both static and dynamic (second order) effect of commodity price changes, the study confirms that in real term price rises have detriment impact of consumer welfare, especially on poor consumers in the rural compared to non-pour in urban though the scope of the paper was limited to price changes for foodstuffs.

Gemech and Struthers (2014) uses Lucas model to estimate the welfare gain for Ethiopian coffee producers from eliminating coffee price volatility. The study finds that the welfare gains for coffee producers to be very small and cast drought on the efforts to stabilize prices. Mohan et al. (2016) using the same Lucas model came up with contrary results that welfare gains were a bit high and was about 4.8 percent per year for the coffee sales in India.

Reviewed literature has focused on the causes and impact of commodity price change and volatility on growth, public finance and welfare using both macro and micro data. There is a limited case for estimating the welfare gains of eliminating volatility arising from commodity prices. Given this fact has not been investigated in a specific country like Tanzania, this study attempts to bridge this knowledge gap.

METHODOLOGY

Measuring price volatility

GARCH (1,1) model

There are a good number of Autoregressive Conditional heteroskedasticity models (ARCH), first pioneered by Engle (1982) being used in the literature to estimate risk. The extension of ARCH model into the generalized autoregressive conditional heteroskedasticity (GARCH) model is referenced to Bollerslev (1986). These models, common in most financial instruments are increasingly used to capture fluctuations in variance over time compared to the traditional model of the coefficient of variation.

GARCH models have become superior, replacing the common measures of volatility like coefficient of variation and standard deviation, which have the constant range and tend to overstate variability in non-trending series (Engle, 2001). GARCH models are superior to other standard time-series models in the sense that, the conditional variance of a real stochastic process is non-stationary and it varies over time due to the heteroskedastic nature of time series (Bollersleve, 1986).

According to the study of Tomek and Peterson (2001), GARCH model whittles away part of kurtosis in commodity prices. However GARCH (1,1) model can distinguish between the conditional and unconditional innovations potentially for modeling risk (Gemech and Struthers, 2014). The word conditional implies explicit dependence on a past sequence of observations while the word unconditional applies more to long-term behavior of a time series and assumes no explicit knowledge of past information and is termed as a good proxy for risks (Mohan et al., 2016). The practical application of these models is notable with GARCH (1,1) being the most preferable (Engle, 1982; Engle and Victor, 1993; Goodwin and Schnepf, 2000; Rahman et al. 2002; Wang, 2003; Swaray, 2007; Mohan et al., 2016).

More specifically, GARCH (1,1) models have been suitably used in investigating the impact of reforms in agricultural prices. For instance, Yang et al. (2001) employ GARCH model to investigate the effect of liberalization on agricultural price volatility in the United States of America (USA) whereas Engle (2001) proposed the use of Maximum Likelihood (ML) to estimate GARCH models in an environment of a single price variable.

To find coffee price volatility in Tanzania, the GARCH model pioneered by Bollersleve (1986) as an extension of Engle (1982) ARCH model is adopted. The proxy for price risk then becomes the unconditional variance of GARCH (1,1) model. The classic specification of the GARCH methodology is described in the following of equations.

$$\Delta P_t = \eta + \sum_{t-1}^{n} \delta_i \Delta P_{t-1} + \varepsilon_t \quad (1)$$

$$\varepsilon_t \mid \Omega_{t-1} \approx N(0, h_t) \quad (2)$$

where

ΔP_t is the first difference of the natural logarithms of coffee price series at time t, and δ_i is the respective coefficient for price differences. The white noise term is denoted by ε_t, which under the conversional GARCH model, it is rationally assumed to be normally distributed with zero mean and constant variance h_t therefore Ω_{t-1} represents all available information at time $t-1$.

$$h_t = y_0 + \sum_{i=1}^{m} \alpha_i \varepsilon_{i-t}^2 + \sum_{i=1}^{g} \beta_i h_{t-1} \quad (3)$$

$$h = E\left(\varepsilon_t^2\right) \frac{y_i}{1 - \sum_{i=1}^{m} \alpha_i - \sum_{i=1}^{g} \beta_i} \quad (4)$$

The coefficients in equation (3) and (4) should fulfill the following conditions: $y_i > 0$, $\alpha_i \geq 0$, i =1,2… $m, \beta_i \geq 0, j = 1, 2, ...q$ and $m, \beta_i \geq 0, j = 1, 2, ..., q$. The process will be stationary if $\alpha + \beta < 1$ and $\alpha + \beta < 1$ is satisfied. Thus, the conditional variance will converge towards the unconditional variance of the innovations as expressed in equation (4). To capture all the relevant information contained in $p_t = f(\Omega_{t-1}, X)$ equation (3) can be rewritten as:

$$h_t = y + \sum_{i=1}^{m} \alpha_i h_{t-1} + \sum_{j=1}^{g} \beta_j \varepsilon_{t-j}^2 + q_i D \quad (5)$$

Price volatility is accounted for by the conditional variance (h_t), which is specified as a linear function of: past values of conditional variance, past squared errors and a market reforms dummy D. The coefficients α_i and β_i are the ARCH and GARCH parameters respectively.

However, α_i explains how fast the model reacts to news in the market while β_i states how persistent the conditional heteroskedasticity is over time. It is worth to note that if the coefficient β_i is large, effects from economic news in the market will have a tendency to remain. Lag lengths for the conditional variance and squared residuals are denoted by m and q respectively. Equation (5) is purposely designed to mimic the volatility-clustering phenomenon, i.e. large disturbances, positive or negative, become part of the information set used to construct the variance forecast of the next period's disturbances.

Variance of the residuals is decomposed into conditional (predictable) and unconditional (unpredictable) to measure price volatility more precisely (Ramey and Ramey, 1995; Moledina et al., 2003; Gemech and Struthers, 2014). Mohan et al. (2016) uses similar approach to investigate the effect of coffee price volatility on welfare in Ethiopia. The conditional variance has relatively less relevance for measuring risk, as it is predictable by economic agents using past information. On the other hand unconditional variance is unpredictable and therefore is a better measure of the price risk faced by farmers. We then utilizes the unconditional variance as measuring risk to quantify the welfare gains obtained from eliminating price volatility of coffee in Tanzania.

Empirical estimates of the risk aversion parameter

The empirical estimate of the risk aversion parameter (γ) is well documented in the literature. The guiding theories on these estimates are the expected utility theory and pricing theory. These theories are knowingly in explaining risky behaviours (Harrison and Rutstrom, 2009; Harrison et al., 2010). An empirical study by Cardenas and carpenter (2005) estimates the value of γ in developed and developing countries and do not support the view that degree of risk aversion is much higher in developing countries than in developed countries. This finding contradict somewhat intuitive perception that poor people in less developed countries are necessarily risk averse than people in developed countries across all income and stakes (that is, gambles and bets). Table 1 provides the summary findings of the value of γ.

Empirical model

The coefficient of the CRRA and the expected utility theory are used with the combination of the unconditional variance to estimate the welfare gain for coffee producers from eliminating price volatility. The coefficient of CRRA and the expected utility theory are important aspects because it gives parameters to be used in the Lucas welfare function. The CRRA has been used in developing countries to measure risk (Cardenas and Carpenter, 2005; Schechter, 2007; Harrison and Rutstrom, 2009; Harrison et al., 2010). This measure theorizes that the functional form of the utility functions underlying the attitudes to risk for such people satisfies the condition $dR_u / dq = 0$ resulting into a Luca's CRRA of 1987 as specified in equation 6:

$$U(q) = q^{1-\gamma} / 1 - \gamma \quad (6)$$

Where

$\gamma \in (0,1)$ and $\gamma = R_u(q)$

The question is that what are the welfare gains from stabilization would be for the coffee producers if all consumption variability were eliminated. To answer this question we follow the similar approach by Lucas (2003) which basically measures the welfare effect of eliminating overall consumption variability by considering a single consumer who is endowed with a stochastic consumption stream. Considering a single consumer with a stochastic consumption stream with risk aversion, Lucas derives the "*compensation parameter"* (The welfare gains from eliminating consumption risk). Aggregate demand (income) is composed of consumption and saving ($Y = C + S$) (Keynes, 1936). However, it is assumed that producers have negligible savings; therefore consumption is equal to income. The welfare gain ϕ refers to the amount by which the farmer would have to be compensated to be indifferent between the risky and deterministic/certain income streams from coffee's receipt and is given by.

$$\phi \approx 1/2 \gamma \sigma^2 \quad (7)$$

This study follows the Lucas model specified in equation (7) to estimate the welfare effect of elimination coffee price volatility for the case of coffee farmers in Tanzania. However, the use of

Table 1. Estimated value of the risk aversion parameter.

S/N	Authors	Approach	Country	Value of γ
1	Harrison et al. (2010)	Bets and Lotteries	Rural Households in Ethiopia, India and Uganda	0.536
2	Schechter (2007)	Bets and Lotteries	Rural Paraguayan	1.92
3	Cardenas and Carpenter,(2005)	Bets and gamble	DCs	Less than 1
4	Binswanger (1980), Nielsen (2001) and Barr (2003)	Bets and Lotteries	DC	Less than 1
5	Barr (2003)	Two stage experiment	Rural villages in Zimbabwe	0.65
6	Mohan et al. (2016) benchmark uses	Applied	Ethiopia	0.6 to 1
7	Moledina et al. (2003) benchmark uses	Applied	Thailand, Argentina USA	0.6 to 1

Source: Compiled from various authors.

Table 2. Descriptive statistics.

Statistics	Coffee	Log differences of coffee
Mean	1.843	-0.000
Variance	0.879	0.026
Standard deviation	0.938	0.163
Skewness	0.704	0.083
Kurtosis	3.279	8.060

Source: author's computation.

equation (7) requires knowledge of the value of risk aversion parameter (g) and the amount of risks (s^2). The value of (g) and (s^2) are summarized in Table 1 and 4 respectively. Moledina et al. (2003), Bellemare et al. (2013) and Mohan, et al. (2016) provide the basic insight in applying Luca (2003) approach in estimating the welfare effects of eliminating price volatility in rice, wheat, and coffee prices in India and Ethiopia respectively.

Data sources and type

The study uses auction coffee prices data from 1998 to 2017 to investigate the welfare effects of eliminating price volatility for coffee in Tanzania. Auction prices are recorded in terms of (Usd/kg). Daily price for coffee is used since is the immediate prices received by the farmers for a transaction carried out at the first point of sale. The first point of sale occurs at the nearest market to the producer's farmer (usually place of production) and therefore is assumed not to include transaction margins (transfer costs) such as transport costs. Tanzanian Coffee Board (TCB) reports coffee farmer's prices on a daily basis based on auction marketing strategies. The price data include three major Tanzanian coffee types by the origin of growing zones (Southern, Northern and western) each with district price paid to the farmers. The weighted average is converted from local currency to US cents at the contemporaneous exchange rate and supplied to the International Coffee Organization by the TCB. The dummy variable is set equal to one from January 1993 to December 2007 when market liberalization was implemented and zero otherwise. If Dummy turns out to be positive and statistically significant, then reform policy would have had an impact in increasing price volatility and vice versa.

Estimation results for coffee in Tanzania

Descriptive statistics of data

The standard deviation is viewed as a measure of volatility. Log difference in Coffee prices appears to be volatile with the standard deviation of 0.16. Skewness is a positive and statistical difference between zeros, and indicates that there are more values above the zero mean than below. It is also evidenced that coffee prices portray fat tails (excess kurtosis) for the log differences of coffee prices since they all above the normal distribution. When is abnormally high, might be probably due to regulated markets in the country during most of the period under consideration (Table 2).

Estimation results GARCH (1,1)

To be more precise, we tested the ARCH effects and took into consideration all the diagnostic tests (autocorrelation, normality test) for robust results. These tests confirmed that the squared residuals are truly heteroskedastic, autocorrelated and with ARCH-effect. All the tests rejected the null hypothesis at 5 percent level. The coefficient of the ARCH specification was positive and significant warranting the next procedures of fitting GARCH (1,1) model of coffee price volatility.

However, to ensure unbiased results, stationarity tests are carried out using Augmented Dickey-Fuller Test (ADF) and Zivot and Andrews (1992). Zivot and Andrews (1992) unit root test is important as it takes into account structural break in the intercept and trend of the series. Moreover, it searches all over the possible single breakpoints. Since the objective of this study is to get the appropriate measure of risk by taking into account all the policy reforms, a search for a single structural break was appropriate. ADF and Zivot Andrews test confirms that coffee price series have unit root in level but stationary at first difference. Table 3 shows the results for ARCH (1) and GARCH (1,1) model. Table 3 show that the sum of the estimated coefficients satisfies the boundary constraints that is, $a_i + b_i < 1$. These coefficients are positive and statistically significant at 5% level implying that, volatility is persistence and it is measured by the sum ($a_i + b_i$).

This suggests that the current volatility (measured by the variance of the error term) depends on both the past period's news about volatility and the last period's volatility. The coefficient for dummy variable is positive though not significant, while that take into account the effect of economic crisis has a negative sign and insignificant. The immediate impression is that the effect of reforms

Table 3. Summary results for GARCH (1, 1) model of Coffee prices.

Parameter	No reforms and crisis	With reforms	With crisis
y	0.004*** (-0.00)	0.004*** (-0.000)	0.004*** (-0.000)
a	0.353*** (-0.050)	0.353*** (-0.050)	0.353*** (-0.050)
b	0.564** (-0.034)	0.564** (-0.034)	0.564*** (-0.034)

Standard errors in parentheses * p<0.05, ** p<0.01, *** p<0.001.

Table 4. Annualized variance.

Variable	Annualized variance		
	No reforms and crisis	With reforms	With crisis
Unconditional	0.038	0.038	0.038
Conditional	0.001	0.001	0.001
Total	0.039	0.039	0.039

Source: Author's computation.

Table 5. Estimates of welfare gains from eliminating coffee price volatility in Tanzania.

Risk aversion parameter	No reforms and crisis (%)	With reforms (%)	With crisis (%)
0.6	1.139	1.133	1.139
0.8	1.519	1.511	1.519
1	1.899	1.889	1.899
2	3.798	3.778	3.798

Welfare Gain $l \approx \frac{1}{2} gs^{2}$ where g ranges from 0.6 to 2 and s^{2} is the variance.

Source: Author's computation.

and world economic crisis on producer auction price volatility is almost negligible.

To estimate the welfare gains of eliminating coffee price volatility using a Lucas (2003) model requires the calculation of the amount of risks herein referred as the "annualized unconditional variance"[6]. Then we regenerate unconditional Variance utilizing equation (4). Table 4 show the results for annualize variances. We then use the regenerated unconditional variance and the parameter of risk aversion to estimate the welfare gains of eliminating coffee price volatility in Tanzania. Table 5 provides the summary results.

DISCUSSION

The aim of this paper is to estimate the welfare gains of eliminating coffee price volatility. Owing to the notion of expected utility theory, we employ the coefficient of relative risk aversion and the unconditional variance of GARCH (1,1) model in a typical Lucas-like representative argent model of 2003 to examine the welfare consequences of eliminating price volatility for the case of coffee farmers in Tanzania. The gist of this approach is that, if the resulting coefficient is low, then the costs of interventions to diversify risks or to stabilize prices may outweigh the benefits of these efforts.

Evidently, the study estimations show that the welfare gains of reducing coffee price volatility for the producers are small. Table 5 shows the magnitude of the potential gain from reducing coffee price volatility (risks) using conditional and unconditional variance. We make an inference based on unconditional variance (the unpredictable component of the residual), which is the accepted standard measure of risks. We then proceed using a benchmark value of risk g=0.6 and annualized unconditional variance to estimate the welfare gains from eliminating coffee price volatility in the spirit of Gemech and Struthers (2014) and Mohan et al. (2016). As shown in Table 5, the welfare gains is 1.139% of the income derived from coffee sales per year which are small thereby raising a debate about the efficacy of price stabilization policies enacted by both international and

[6] Annualized variance = $\sqrt{12}$

state economies. A similar conclusion is made by Gemech and Struthers (2014) for the case of coffee producers in Ethiopia. Mohan et al. (2016) came up with contrary results that welfare gains were about 4.8% per year for the coffee producer in India.

These results raise debate about the efficiency, effectiveness and sustainability of the policy measures to stabilize prices. Wright and Williams (1988) support the claim that in reality commodity policies can achieve price stabilization by stabilizing quantities but not prices. Welfare assessment implies that governments should avoid price stabilization policies and focus resources on policies that promote increased productivity. As pointed out by Mohan et al. (2016) that intervention are normally associated with a high implementation, monitoring and other regulatory costs. Thus, any attempt to eliminate coffee price volatility at a cost might not be the desirable choice for coffee producers. The usual conclusion is that stabilization is not feasible and feasible stabilization policies are costly.

Conclusion

Decision-making in Tanzanian coffee sector cannot isolate the knowledge of price behaviour and appropriate mechanisms to distribute resources in dealing with the impact of price volatility on the welfare of the coffee producers. This aspect not only requires appropriate hedging mechanism such as futures and options but also calls for strict strategies to revamp agriculture sector given its potential in the economy.

In an environment of the failure of the international commodity agreements and the high cost and mixed record of domestic stabilization policies, countries should rely on the market -based risk management instruments and safety nets. As the second-best policies for stabilization, market-based risk management instruments are supposed to provide farmers, traders, food agencies and even individuals with access to instruments that allow the sharing of price and weather risks and the smoothing of income variations. Simply, these instruments should help to complete markets. Also increasing production and income stream across the entire value chain requires among others re-planting the uprooted coffee trees and plant new coffee varieties, expansion of farm land, organization reforms, increase fertilizer usage, and control of coffee diseases and pests, ensure sustainable irrigation system as well as frequent monitoring of the coffee quality are imperative.

In addition, the strategic choice to produce and export high-quality coffee for a well-explored niche markets requires proactive government action to cooperate with other coffee stakeholders and co-operatives societies for the aim of increasing quality of coffee production, particularly in relation to coffee processing, financing and market access. Deliberate efforts to support private sector associations and enterprises in accessing technology, innovation in breeding species and appropriate financial packages will eventually ensure standard and quality coffee products. Promote tools such as value chain analysis, will helps entrepreneurs to see what problem and challenges need to be addressed within and beyond the borders as well as increasing market networks. Nonetheless, there must be appropriate mechanisms such as "check and balance" of any stabilizing funds to ensure bureaucratic challenges are addressed. Clearly, given that price volatility has intimate effects of the welfare of the farmers, a study to investigate the extent to which farmers are willing to pay as one of the strategies to stabilize prices at a mean remains the area for further research.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Appendix I

Table 1. Trade based policies measures commonly adopted after the 2008/2009 economic crisis.

Countries surveyed	Africa	Asia	Latin America	Total
	33	**26**	**22**	**81**
Market interventions-trade policy				
Reduction of tariffs and customs fee in imports	18	13	12	43
Restrictive or banned export	8	13	4	25
Domestic market interventions				
Suspension/reduction of VAT or other taxes	14	5	4	23
Released stocks at subsidized prices	13	15	7	35
Administered prices	10	6	5	21
Production support				
Production support	12	11	12	35
Production safety nets	6	4	5	15
Fertilizer and seeds programs	4	2	5	9
Market interventions	4	9	2	15
Consumer safety nets				
Cash transfers	4	8	4	12

Source: Constructed from Demeke et al. (2008).

Appendix II

Table 2. Stabilization policies since 1970s.

A: Supply management schemes	Aim	Failures
A1: Integrated Programme for Commodities (IPC) (UCTAD)-(1976-1980)	Finance buffer stock-reduce price fluctuations	Some commodities such as tin, sugar, coffee and cotton were dropped (global recession (1980s) and depressed prices)
Reinhart and Wickham (1994)	Stabilize prices at levels remunerative to producers	Difficulties of influencing prices via output management
A2: Common Fund for Commodities (CFC)- Gilbert and Wickham (1994)	-	Un unanimous agreement on price changes that would equitable to producers
Cashin; McDermott and Scott (2002)	-	Lack of enforcement mechanisms and the problem of free-riding
Rangarajan (1983)	-	Insufficient resource
A3: Establishment of Market Boards	Stabilization of prices via stockpiles and buffer stock facilities	Dismantled in 1980s and 1990s under SAP
-	Providing ancillary extension services	Bureaucracy and rent-seeking
B: Oil Supply Management -OPEC	Stabilization of prices in international oil markets	Rent seeking and challenges in quotas enforcement
C: Income Support Programmes	-	-
C1: Compensatory Financing Facilities (CFF)	Designed to compensate shortfalls in income and short-term price shocks	Yet 2008/2009 crises occurred with secular price declines
C2: Contingency and Compensatory Finance Facility (IMF)-(1988)- UCTAD (2003)	To smooth the effects of a temporary, exogenously caused shortfalls in merchandise export receipts	-

Table 2. Stabilization Contd.

-	Deals with countries with willingness to cooperate with IMF to address the problem	-
-	Help country with BOP problems	-
C3: The European Union's Stabilization of Export earnings (STABEX) -STABEX (Lome 1 Conversion)-(1975-1979)	It was part of comprehensive international commodity policy	It was observed to be cumbersome, pro-cyclical or too expensive to use
C4: EU's System for Safeguarding and Developing Mineral Production (SYSMIN) and Swiss Compensatory Programmes	Address the shortfalls in export earnings due to fluctuations in world price	-
-	Address domestic supply of agricultural commodities for ACP countries.	-
C6: (htt: www.rma.usd.gov/.) Risk management Agency (USA)-(1996)	Administer federal crop insurance Corporation (FCIC)	Diseases, droughts and flood
-	Non-Insurance-related risk management that help support agriculture	-
-	Sales of crops via licensed private contractual brokers	-
-	Provide insurance facilities (subsidies)	-
D: Market -based Mechanism- financial instrument	Rely on hedging programmes to mitigate the exposure to price volatility	Hedging is limited to developing countries event though risk is very high
-	Forward contracts, futures options to complex combinations e.g. collars, over-the -counter and tools.	-
E: Revenue management	Sovereign Wealth Fund	-
F: Stabilization Fund	Reduce the fluctuations in budgetary revenue for CDDCs	-
G: Diversification	Horizontal diversification into agricultural products and processes that capture proportion of the value chain	Structural barriers in international trade (tariff and standard escalation)
-	Diversification into non-agricultural activities that exploit comparative advantages	Scarce resources to invest in the sector-cost related to infrastructure and storage
-	Horizontal diversification into alternative crops.	Lack of skills in producing and marketing alternative products

Sources: Compiled from Deegon (2011) United Nations on Trade and Development.

Appendix III.

Table 3. Major reforms in coffee industry in Tanzania

Year	Major events in coffee market
1994	The beginning of major reforms, but under inherited CMBA of 1984;Poorly performing cooperative unions with inability to pay producers for their coffee; new players entered the market; private traders allowed to trade domestically, all coffee was cured at cooperative or government owned processing plants; establishment of Tanzanian Coffee Association to solve disputes between cooperative and private traders
1995	Poor performance of the cooperative system led into the emergence of Vertically Integrated Exporters (VIEs). This affected the auction delivery by having two types of coffee delivery (captive and non-captive coffee). There was also indication of uncompetitive behaviours in the marketing systems.
1996	Establishment of National Input Voucher System (NIVS). The NIVS operates a special input fund whereby licensed parchment buyers issue a specified portion of farmers' coffee payments in the form of input vouchers. This aimed at improving the deteriorating quality of coffee
1997-2000	Remarkable deterioration of coffee quality. This seems to be related to the declining share of cooperatives in traded coffee
2001	Emergence of organized producer groups for coffee marketing purposes: The World bank and other partners initiate market-based approaches for price hedging strategies based on cooperative systems; Re-establishment of TCB, replacing TCMB
2000-2002	The coffee board revoked buying licenses of private traders in order to protect cooperatives that secured loans from the government. The aim was to ensure the loan repayment
2002	The CIA of 2001 was assented; Coffee 'repossession' at the auction was abolished (i.e. no captive coffee at the auction
2002	Cooperatives and producer groups start participating in Fair trade arrangements. This only account for a small portion of the coffee traded
2003	Export regulations amended to allow producers to export coffee directly without passing the auction market
2004-2005	-
2006-2010	The Government abolished deduction of levy from growers to run TCB. The Government will now run TCB 100%
2010-2015	Crop Laws Miscellaneous Amendment Act number 9 of 2009 established among others the following; Shared functions to be covered by the stakeholders (research, extension, production, promotion, etc), stakeholders meetings/forums and contract farming
2016 -date	2018 the Government banned the private buyers purchasing coffee directly from growers. All farmers be organized into AMCOS

Appendix IV

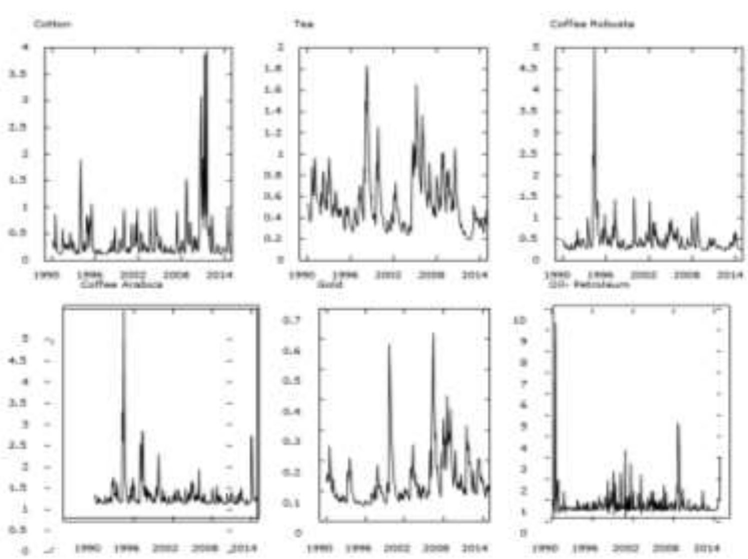

Figure 1. Monthly commodity price index volatility of cotton, coffee, gold, tee, and oil petroleum (%).
Source: Own computation from World Bank datasets (2014).

Appendix V

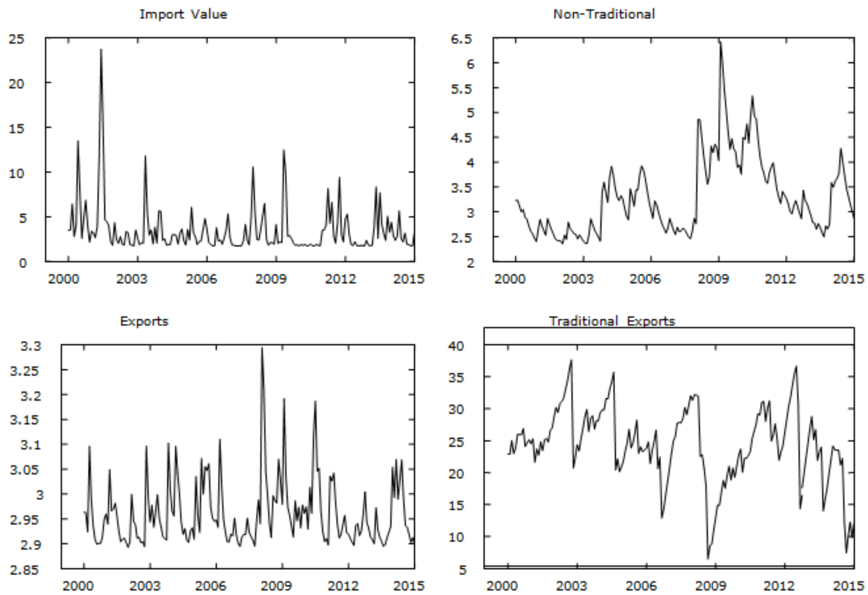

Figure 2. Monthly Export earnings volatility, traditional and no-traditional export volatility and import value volatility.
Source: Own computation from Bank of Tanzania datasets (2015).

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Production performance evaluation of Koekoek chickens at Adami Tulu research center

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A study was conducted to evaluate the production performance of koekoek chickens at Adami Tulu Research Center. Feed consumption, age at point of laying, annual egg production, mortality, and egg quality parameters were used as evaluation parameters. Mean feed consumption of starter, grower and layer of koekoek chickens at Adami Tulu Research Center was 56.4±4.6, 84.3±6.3 and 124±8.6 g/day, respectively. Koekoek chickens attain sexual maturity at 5 months and produce 213± 12.4 eggs per year. Their hatchability was 60% and mortality rate was 4% at Adami Tulu Research center. Their egg weight in gram (g) was 51.17±3.2. The egg yolk color, yolk weight in gram (g), albumin weight in gram (g) were 5.08±0.91, 14.96±1.6 and 31.2±2.7, respectively. The current study revealed that koekoek chickens adapt well to semi-arid agro-ecology of Ethiopia. Koekoek chickens are fast growers and good layers. So day-old chicken producers and distributors in semi-arid area can consider them as candidate breeds in their production. These dual purpose breeds need good managements like quality feed provision, good sanitation and vaccine administration. Therefore livestock extensions and farmers who have interest in introducing these breeds into their farm should have to provide necessary management practices to fully utilize their production potential.

Key words: Poultry breed, farming system, egg performance, mortality rate.

INTRODUCTION

Poultry production provides a major income-generation activity from sale of chickens and eggs. Poultry production also helps to meet the growing demand of animal source proteins. The fewer cultural or religious taboos associated with poultry products (Tadelle et al., 2003) and its contribution to balanced human diet have increased demand for poultry meat and eggs. Poultry production needs little investment compared to other livestock production, hence land less laborers and people organized in micro enterprises are able to raise chickens with low inputs. Farmyard/backyard type production, in which native chickens scavenge most of their food in rural community, is characterized by low egg production and poor growth rates. Lack of high egg layers and fast growth rate chickens breed are a major constraint to Ethiopian farmers (Zemelak et al., 2016). In Ethiopia poultry sector is characterized by low production and productivity; the growth rate is much lower than that of fast growing populations (ILRI, 2004). With this potential and production system native chickens cannot meet the

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high demand of Ethiopian populations. Because of the listed reasons exotic chicken breeds have been introduced by missionaries and government at different times to meet the high demand of poultry products. Transformation of both traditional backyard poultry production and expansion of exotic layer is very important to close the future projected gap in total meat and egg consumption (LMP, 2015). Introduced exotic pure breed chickens have been used to up-grade indigenous village chickens or used by commercial producers for egg and meat production.

Koekoek chickens are one of the dual purpose breeds introduced to Ethiopia. Since it is a tropical breed, it can be considered as suitable candidate breed for overcoming the problem of environmental stress. The breed is a composite of the White Leghorn, Black Australorp and Bared Plymouth Rock (Grobbelaar et al., 2010). Koekoek chickens were bred for the production of brown eggs and for the attractive deep yellow colored carcass (Grobbelaar et al., 2010). The breed matures at five months age, lays good numbers of brown eggs with excellent resistance to disease. The breed was introduced by Ethiopian Institute of Agricultural Research because of its good production traits (fast growth rate and good egg layers). However, in semi-arid agro-ecology of Ethiopia the breed was not evaluated. Previously introduced commercial and temperate breed failed to be sustained under farmers` management condition because of lack of evaluation in a representative environment to provide the unique management practices needed. Agro-ecology based evaluation of chickens enhanced the economic contribution of chickens for farmers (Zemelak et al., 2016). Evaluating the production performance of koekoek chickens in a new environment like semi-arid agro-ecology of Ethiopia was useful and contributed to the success of their uptake. Therefore, the study was done to evaluate the production performance of koekoek chickens in semi-arid agro-ecology of Ethiopia.

MATERIALS AND METHODS

Study area

Production performance evaluation of Koekoek chicken was done at Adami Tulu Research Center. Adami Tulu Research Center is located in mid rift valley of Ethiopia at an altitude of 1650 m above sea level and latitude of 7°9`N and 38°7`E. The average annual rain fall is 949 mm with an average minimum and maximum temperature of 14 and 29.6°C respectively; the relative humidity is 57.42 (ATARC, 2016).

Housing and management

The experimental pens were cleaned with water and detergents, and then disinfected before the experimental chickens were housed. The experimental pens were littered with properly dried tef *(Eragrostis tef*) straw. A total of two hundred day old koekoek chickens were brought from Debre Zeit Agricultural Research Center to be evaluated at Adami Tulu Research Center. Chickens were vaccinated against Newcastle, Bursa (Gumboro), and fowl pox diseases. Four brooding hay boxes each with a size of 4 m^2 were used for rearing of chickens for four weeks in starter house. Fifty chickens, with 10 male to 40 female rations were reared in each hay box for four weeks. Heat was supplied with 250 watt bulbs in brooding hay boxes until four weeks.

Three plastic tube feeders and three bell shaped (round) plastic waters were used to provide feed and water every day in hay boxes. After four weeks chickens were transferred to grower house that was partitioned with mesh wire into four sections. In each four sections (with 16 m^2), a total of fifty Koekoek chickens with a ratio of ten males to forty females were housed. Layers house were also partitioned into four sections; in each sections fifty Koekoek chickens with ten males to forty females chickens were housed similar to the growing period.

Four plastic tube feeders and four bell shaped (round) waters were used to provide feed and water during both growing and laying period. Tef straw used for bedding material was removed and replaced with new one every two weeks during the first four weeks. During growing and laying period, contaminated tef straw was removed and replaced with a fresh straw at two months intervals. An antibiotic (oxytetracycline 20% powder) was given to minimize the risk of disease outbreak. The chickens were also disinfected every two months during the replacement of the straw to protect the birds from external parasites.

Commercial poultry feed was used during the evaluation period. The feed was composed of corn, wheat middling, wheat bran, noug cake, soya full fat, rapeseed, salt, meat and bone meal, limestone and premix. Green feed was collected from poultry farm and freely provided at two days interval.

Chemical composition of the diet

Nutritional composition of the diet used during study is given in Table 1. From the commercial ration given in Table 1, 75, 90 and 130 g feed was offered during starter, grower and layer period respectively**.** The evaluation was done for two years on-station to collect all data.

Data collection

Feed intake was calculated by deducting feed refusal from feed offered each day. Mortality and egg production were recorded daily. Body weight of the chickens was taken at two months interval and age at point of egg lay was measured using suspended spring balance. Data on egg quality parameters were taken at a time (36 to 37 weeks) after onset of egg laying. Eggs were weighed using an electronic digital balance. Egg length, egg width and egg shell thickness were measured using electronic digital caliper and yolk color was determined by adjusting the score of yolk color on color fan from Roche. Albumin weight was calculated as the difference between egg weight and sum of shell weight and yolk weight.

Partial budget analysis was done using the formula developed by CIMMYT (1988); Ehui and Rey (1992) and Ibrahim and Olaloku (2000). The price of feed, medicine and chemicals were recorded. Feed intake per bird and price of feed per kilogram were used to calculate the cost of feed consumed by the chickens. Total gross return was obtained from sales of chickens and from total eggs laid per bird.

Statistical analysis

Data were analyzed using descriptive statistics. Standard deviation was used to compute the variation of the mean.

Table 1. Nutritional composition of the commercial diets used (% DM).

Nutritional composition	Starter	Pullet	Layer
Dray matter	88.56	87.93	90.00
Crude protein	19.01	15.47	16.00
Crude fiber	5.06	6.23	7.00
Crude fat	4.84	5.48	5.00
Ash	5.98	6.73	3.55
Ca(g/kg DM)	0.90	0.90	3.55
Energy(kcal/kg)	2950	2950	2800

DM = dry matter, % =percentage, kcal= kilo calorie
From the commercial ration shown in (Table 1) 75, 90 and 130 g feed offered during starter, grower and layer period respectively**.** The evaluation was done for two years on-station to collect all data.

Table 2. Feed intake, weight at different age, hatchability and mortality rate of Koekoek chickens under Adami Tulu Research center.

Parameter	Mean	Standard deviation
Feed intake during starter period (g/day)	56.46	4.60
Feed intake during grower period(g/day)	84.30	6.30
Feed intake during laying period	124.80	8.60
Weight of female chicken at two months(kg)	0.74	0.09
Weight of male chicken at two months(kg)	0.91	0.15
Weight of female chicken at point of egg lay (kg)	1.80	0.20
Weight of male chicken at five months (Kg)	2.70	0.30
Annual egg production	213	12.40
Age at point of egg lay (months)	5	
Hatchability (%)	60	
Mortality (%)	4	

RESULTS

Feed consumption and growth performance of Koekoek chickens

The mean values of feed intake and growth performance of Koekoek chickens are shown in Table 2. Some egg quality parameters of Koekoek chickens are given in Table 3. Production cost and return of Koekoek chickens are given in Table 4.

DISCUSSION

Feed intake of Koekoek chickens in the current study was higher than the feed intake reported by Banerjee et al. (2013) for the same breed most probably due to different quality feed used and temperature. Weight of Koekoek chicken was lower than that reported by Russel (2014) (3.5-4.5 and 2.5-3.5 kg) for male and female, respectively but higher than the 1.7 kg reported by Nthimo et al. (2004) for matured body weight of the female Koekoek chickens. The disparity is probably due to different management practices like feeding, health care and environmental differences. As shown in Table 2, Koekoek chickens were a fast growing breed and their feed intake was also high. they attain sexual maturity earlier (at five months) compared to indigenous village birds in Ethiopia that attain sexual maturity in seven months (FAO, 2004) and produce higher eggs compared to the 36-60 eggs production potential of indigenous birds per year (FAO, 2004). Age at point of laying of koekoek chicken in current study was similar to the report of Dessalew et al. *(*2013). The annual egg production of Koekoek chickens was higher than the 187.04± 13.4 eggs per year reported by Dessalew et al. (2013) and 195.9 eggs per year reported by Grobbelaar et al. (2010). This is probably due to different managements like feed type, feeding system and different climate that can influence the performance of chickens. The comparatively lower productivity associated with domestic chickens can mostly be attributed to low standards of management, health care and feeding (Russel, 2014). The current study used good quality layers diet which probably resulted in higher egg production compared to the on- farm study and lower egg production reported by Dessalew et al. (2013).

Table 3. Internal and external egg quality parameters of Koekoek chickens under Adami Tulu research center.

Parameter	Mean	Standard deviation
Egg Weight(g)	51.17	3.20
Egg length(mm)	34.43	1.90
Egg width(mm)	22.33	1.30
Shell weight(g)	4.99	0.50
Shell thickness(mm)	0.60	0.14
Yolk color	5.08	0.91
Yolk weight(g)	14.96	1.60
Albumin weight(g)	31.20	2.70

g= gram, mm= millimeter.

Table 4. Production cost and return of Koekoek chickens reared at Adami Tulu research center.

Item	Cost (ETB)
Total starter feed consumed (kg/bird)	3.40
Total grower feed consumed (kg/bird)	7.56
Total layers feed consumed (kg/bird)	44.00
Total feed cost (ETB/Kg)	473.25
Cost of medicament and disinfectant(ETB/Bird)	24 .75
Total variable cost(TVC),ETB	498.00
Gross return(GR), ETB	682.00
Net Return(GR-TVC),ETB	184.00

ETB = Ethiopian Birr, TVC = total variable cost, GR= Growth return.

The mortality rate of Koekoek chickens in the current study was very low (4%) indicating their adaptability to semi-arid environment. Even it adapted more than the previously introduced Fayoumi chickens whose mortality rate was 7.2% under similar environment (Tesfa et al., 2013) indicating preferability of semi-arid area. The average egg weight of Koekoek chickens was lower than the average weight of 55.7 g reported by Grobbelaar et al. (2010) but higher than 48.84 ± 6.77 g reported by Dessalew et al. (2013). This was most probably due to different ages of the layers, number of eggs considered for weight taking. The differences also were most probably due to difference in quality of feed used that enhanced the deposition of egg albumin and egg shell. The yolk colour value for koekoek chickens' egg was lower than the yolk color value of 10.79± 1.98 reported for the same breed by Desalew et al. (2013). In the current study, the chickens kept under intensive management condition and less exposed to green feed may have caused lower yolk color compared to the result reported by Desalew et al. *(*2013).

As partial budget analysis showed net return of 184 Ethiopian birr per bird was obtained. The major in-put cost that determined the return was feed cost compared to non-feed costs (Table 4). Similar to the current study, Gopalakrishnan and Lal (2004) reported feed cost representing 65-75% of the total of intensive poultry production. Formulating poultry ration from locally available agro-industrial by product and grain is a good alternative to minimize feed cost and a recommended input to maintain their production performance.

Conclusion

Koekoek chickens were well adapted to semi-arid agro-ecology of Ethiopia. They are fast grower and good layers. These dual purpose breeds need good manage-ments like quality feed provision, good sanitation and vaccine administration. Therefore livestock extensions and farmers who have interest in introducing the breeds into their farm should have to provide necessary management practices to fully utilize their production potential.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Rural public policies and the state of smallholders: Recent evidence from Brazil

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The aim of this article is to characterize the current situation of family farmers or smallholders in Brazil and establish a connection with the rural public policies that exist in the country. This study analyzed the most current available data regarding family farming in Brazil, which included almost 4.7 million smallholders and their characteristics. Two analytical tools for unsupervised learning were combined, Principal Component Analysis (PCA) and K-means clustering, which enabled the analysis of such a large database and the extraction of information concerning this sector. It was found that cooperative smallholders are considerably more likely to achieve higher incomes. A family farmer's income and productivity are related to their region and are higher in the South and Southeast and lower in the Northeast region. Crop diversification presented a negative impact on family farming activity, although this practice is considered highly important for agricultural sustainability. These results confirm, based on the data, empirical findings regarding the sector and also reveal new information such as the negative impact that rural assistance services are demonstrated to have on smallholders' income. Therefore, this study provides essential information to support policy makers in the process of formulating better and more efficient policies in order to strengthen smallholders in Brazil and guarantee food security in the future.

Key words: Family farm, rural programs, unsupervised learning, government support.

INTRODUCTION

According to the Food and Agriculture Organization of the United Nations - FAO (2014), by 2050, there will be approximately 9.6 billion people in the world, and food production will have to increase by 60% to meet this new demand, thereby placing more pressure on natural resources that are already scarce and showing signs of more food, but production must be undertaken with sustainability.

In this context, family farmers, also known as smallholders, are considered part of the solution for

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achieving food security and sustainable rural development (FAO, 2014). Smallholding is the prevalent agricultural arrangement, as almost 90% of farms, or approximately 500 million farms in the world, are owned and operated by families. These farmers occupy more than half of the total agricultural land and produce at least 53% of the world's food (Graeub et al., 2016; Lowder et al., 2014). The efficiency of smallholder farming relative to larger farms has been widely documented, and these farmers are capable of achieving high production levels per unit of land through the use of family labor in diversified production systems (Bosc et al., 2013).

Brazil plays a decisive role in the agricultural international market which is among the ten largest economies in the world. As it has the fifth-largest surface area and favorable location and climate, the country became the largest supplier of sugar, orange juice and coffee (OECD/FAO, 2015). In Brazil, family farmers represent more than 80% of the production units and play an essential role in the domestic market food supply. In 2006, smallholders were responsible for 38% of the gross value of Brazilian agricultural production according to the Brazilian Institute of Geography and Statistics – IBGE (IBGE, 2006). Additionally, according to the IBGE, in Brazil, approximately 4.3 million rural units are owned by families, and more than 12 million people depend on this activity for their subsistence.

The size of this sector and the enormous amount of information that it contains creates a massive quantity of high dimensional data that needs to be managed and carefully explored. According to Chakraborty and Joseph (2017), the development of new analytical tools, such as machine learning techniques, enables us to untangle important information and patterns that would pass unnoted if conventional approaches were used. Therefore, it is essential that new studies rely on updated databases and analytical tools that can generate new insights and relevant information to support policy makers and important decisions. The two-step cluster methodology employed in this research has been used in similar studies worldwide and generated excellent results, with a few examples of such coming from Herrero et al. (2014), Gaspar et al. (2011) and Sepúlveda et al. (2010).

The former traditional agricultural system based on the massive use of agrochemicals and fertilizers is no longer accepted as the best one. Globalization, climate change and a general societal perception of the importance of natural resources has led farmers to rediscover efficient sustainable practices and also consumers to demand more environmental friendly products (de Roest et al., 2018).

The Brazilian government has a range of public policies targeting family farmers that aim to increase their incomes, welfare and reduce social inequality. In order to have access to these policies, smallholders need to maintain a register in the Ministry of Agrarian Development (MDA) by completing a declaration form, known as the "DAP" (Declaration of Aptitude to Pronaf), and keep it updated. The present study is based on the information provided in these forms relative to millions of family farmers from every state of Brazil. Public policies can make a difference in the success or failure of an entire agricultural sector; therefore, studies to drive and point where investments should focus on are essential. Without public support and the correct investments, the only way to production growth would be through the expansion of agricultural land (Anang and Yanwen, 2014).

The reminder of this paper is structured as follows. First is a description of the database, techniques and methodology that was followed in this analysis. This is followed by a presentation of the results and discussion, and thereafter, the study's conclusions and outlined recommendations for further research and policy-making.

MATERIALS AND METHODS

Data source

The analyses conducted in this paper are based on the data from Brazilian family farmers. The database was obtained through the MDA in October 2014 and contains the most updated information about these farmers in Brazil. When filling the DAP form, smallholders provide detailed information regarding themselves and their farms, such as their age, gender, schooling, farm area, number of crops produced and total income. Therefore, the database creates a plentiful source of information about family farming in the country. Most studies about this sector in Brazil are based on the Agricultural Census data, which was last conducted in 2006 and can be easily accessed by everyone. Studies using data from the MDA are still scarce due to the restrictive bureaucracy involved in obtaining it. The database was refined by removing cases with missing values or highly distorted values (outliers) to minimize errors in the results. Approximately 3% (133,000 DAPs) were excluded, and the final database used for the analysis contained approximately 4.7 million declaration forms of family farmers from all states in Brazil. The most important variables were selected and are presented in Table 1. The variables include the age and schooling of the household head, the area in hectares and the state where the farm was located. Also included were the coefficient of production diversification, which was measured by Simpson's Diversity Index – SDI (Simpson, 1949), regardless of whether the farmer was part of a cooperative, whether the farmer received rural assistance and the farmer's income and productivity. The analyses were conducted using the software R Studio (R Core Team, 2017).

Principal component analysis (PCA)

Currently, with the ever-growing massive quantity of high dimensional data, researchers have found some obstacles to performing certain analyses. Principal component analysis (PCA) is a statistical technique for unsupervised dimension reduction, which is closely related to unsupervised learning and is used in very broad areas, such as meteorology, image processing, genomic analysis and information retrieval (Ding and He, 2004; Bishop, 2006). As defined by Hotelling (1933), PCA is the orthogonal projection of the data onto a lower dimensional linear space such that the variance of the projected data is maximized. According to Howley et al.

Table 1. Variable descriptions and summary statistics.

Variable	Description	Mean	Std. Dev.
Age	Household head age in years	44.8358	15.2110
Area	Total area of the farm in hectares	19.0604	33.3236
State	Brazilian state code	27.8471	8.8080
Production diversification	Simpson's diversity index coefficient	0.3529	0.2821
Cooperative	Dummy (0 = no; 1 = yes)	0.0497	0.2175
Rural assistance	Dummy (0 = no; 1 = yes)	0.0768	0.2663
Income	Total annual on-farm income in BRL	18,404.13	37,667.88
Productivity	Annual productivity in BRL/ha	8,345.119	334,852.2
Schooling	Schooling ranked from 1 to 10*	3.3010	1.4858

*1 – Illiterate, 2 – Literate, 3 – Elementary school incomplete, 4 – Elementary school complete, 5 – High school incomplete, 6 – High school complete, 7 – Certificate program incomplete, 8 – Certificate program complete, 9 – College incomplete, and 10 – College complete.

(2006), PCA enables us to transform the attributes of a dataset into a new set of uncorrelated attributes called principal components (PCs), thereby reducing the dimensionality of the original dataset while still retaining as much of the variability as possible. Each PC is a linear combination of the original inputs and each PC is orthogonal, which therefore eliminates the problem of collinearity. Thus, the PCA technique is commonly used to reduce high dimensional data, such as the one exploited in this paper, to enable a certain analysis. In addition, using this technique as a preprocessing step can improve the performance of machine learning techniques, especially in the classification of high dimensional data (He et al., 2011; Howley et al., 2006). As reported by Ding and He (2004), principal component analysis dimensional reduction is particularly beneficial for K-means clustering, thereby improving the cluster accuracy. This methodology proved to be very efficient in similar studies such as those conducted by Herrero et al. (2014), Gaspar et al. (2011) and Sepúlveda et al. (2010).

K-means clustering

Machine learning techniques can be divided into supervised and unsupervised learning, with this last one being characterized for having no category labels that tag objects with prior identifiers, and as such, the algorithm merely aims to find structure in the data, which has to be interpreted by the researcher (Chakraborty and Joseph, 2017; Jain, 2010). Most unsupervised algorithms aim to group observations according to common patterns. According to Ding and He (2004) and Jain (2010), the K-means algorithm is one of the most commonly used clustering techniques for large scale data due to its easy implementation, simplicity, efficiency and empirical success. Likewise, MacQueen (1967) states that the K-means procedure is easily programmed and is computationally economical, thereby making it is feasible to obtain qualitative and quantitative understandings of large amounts of N-dimensional data. As defined by MacQueen (1967), the K-means procedure consists of simply starting with K groups, each of which consists of a single random point and thereafter assign each new point to its closest centroid. After a point is added to a group, the mean of that group is adjusted in order to take account of the new point. Thus, at each stage, the K-means are, in fact, the means of the groups that they represent. According to Bishop (2006), the goal, therefore, is to find an assignment of data points to clusters, as well as a set of vectors $\{\mu_\kappa\}$, such that the sum of the squares of the distances of each data point to its closest vector μ_κ which is its minimum. Following Jain (2010), the corresponding function is defined as follows:

$$J(C) = \sum_{\kappa=1}^{\kappa} \sum_{\chi_i \in C_\kappa} \|\chi_i - \mu_\kappa\|^2$$

Clustering is used for knowledge discovery rather than prediction. It provides insight into the natural groupings found within data, resulting in meaningful and actionable data structures that reduce complexity (Lantz, 2013). As stated by Chakraborty and Joseph (2017), the K-means technique tries to minimize the differences within each cluster and maximize the differences between the clusters, thereby providing insights regarding the commonalities between observations.

RESULTS AND DISCUSSION

Initially, the variables "income" and "productivity" were transformed into logarithms following the current literature, as outlined by Wooldridge (2015) and Venables and Ripley (2013). In order to conduct PCA analysis, the data was standardized, transforming all features into comparable numerical ranges, and the conventions for such an analysis can be found in Bishop (2006), Chakraborty and Joseph (2017) and Jolliffe (2002). The PCA results can be found in Table 2. According to the results, more than fifty percent of the total variance can be explained by the first three PCs. The first PC is shown to be positively related to the farmer's income, productivity, state, cooperativism and schooling.

Subsequently, the k-means clustering technique was applied using the eigenvalues of each observation. A few tests were conducted with different combinations of numbers of PCs and numbers of clusters, seeking to identify the best sum of squares ratio. the first five principal components were decidedly kept, since these PCs together explain more than 75% of the data variance, and jointly with a set of ten clusters, attain a 67.4% sum of squares ratio. Figure 1 shows the scatter plot of smallholders divided into groups on the first two dimensions of PCA, making it possible to visualize the structures of some clusters.

Table 2. Importance of each principal component and the loadings of the variables.

Statistical variable	Importance of each principal component								
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
Standard Deviation	1.4510	1.1996	1.1204	1.0101	0.9721	0.9192	0.8342	0.7270	0.4072
Proportion of Variance	0.2339	0.1599	0.1395	0.1134	0.1050	0.0938	0.0773	0.0587	0.0184
Cumulative Proportion	0.2339	0.3938	0.5333	0.6466	0.7516	0.8455	0.9228	0.9815	1.0000

Demographic variable	Loadings of the variable								
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
State	0.451	-0.218	0.050	-0.102	0.028	-0.204	-0.730	-0.388	0.089
Age	0.013	-0.547	0.486	0.160	-0.109	0.125	-0.174	0.613	0.060
Schooling	0.295	0.225	-0.610	-0.063	0.114	0.009	-0.250	0.638	0.047
Area	-0.147	-0.548	-0.532	0.125	-0.189	0.237	0.109	-0.196	0.484
Diversification	-0.118	-0.262	0.020	-0.356	0.878	0.103	0.070	-0.004	0.057
Cooperative	0.331	-0.284	-0.050	-0.135	-0.046	-0.745	0.470	0.088	0.035
Rural Assistance	-0.015	-0.032	0.050	-0.888	-0.399	0.210	0.024	0.056	0.001
Income	0.537	-0.248	-0.115	0.094	0.004	0.442	0.255	-0.124	-0.592
Productivity	0.523	0.296	0.294	0.037	0.072	0.281	0.262	-0.022	0.629

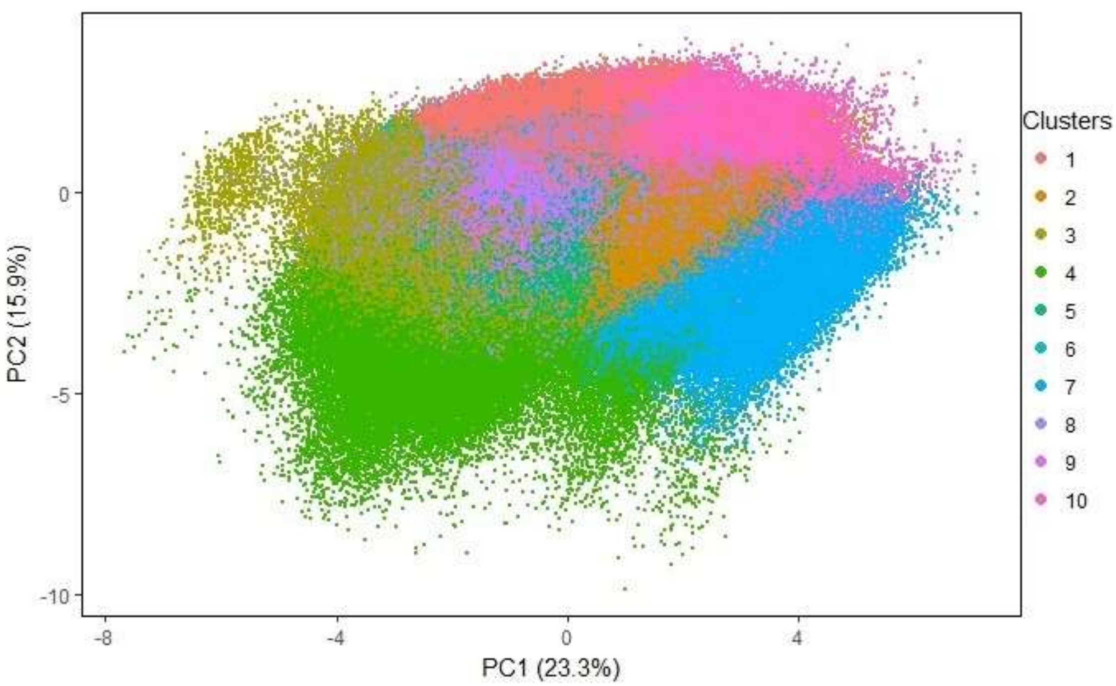

Figure 1. Scatter plot (Projection of smallholders divided by clusters on the first two dimensions of PCA).

After applying this two-step analysis jointly, it was possible to find the patterns and structures in these almost 5 million family farmers. For instance, the cluster number four, as shown in Table 3, is the smallest and has the highest mean area. However, smallholders in this group have low average income and the second lowest productivity, thereby demonstrating that though they own a larger area (in ha), these do not guarantee greater cash revenues. A fraction of farms can be in naturally unproductive areas or suffer from mismanagement, and more than 95000 (2%) family farmers in Brazil are in this situation.

One of the main points presented in the results can be seen in cluster number seven. This group has the largest

Table 3. Clusters' summary and means.

Cluster	Total	%	Age	Schooling	Area	Income	Diversity Index	Cooperative (%)	Rural Assistance (%)	Productivity
1	613,773	13.1	31.66	3.78	6.2	7,602.41	0.0178	0.055	0.00	11,192.83
2	617,266	13.1	54.03	3.31	15.83	42,889.77	0.3050	2.265	0.00	28,021.01
3	423,491	9.0	44.49	2.94	54.4	7,757.08	0.4172	0.144	0.01	115.99
4	95,632	2.0	47.88	3.28	184.96	23,068.28	0.3791	1.844	6.09	125.77
5	821,990	17.5	56.46	2.19	10.14	6,598.12	0.5896	0.107	0.00	1,555.76
6	810,682	17.3	32.48	3.81	7.8	6,481.60	0.5756	0.051	0.00	2,091.07
7	213,942	4.6	53.28	3.75	28.95	78,423.15	0.3622	88.804	8.91	6,671.22
8	335,090	7.1	43.88	3.1	14.79	12,554.32	0.3788	1.685	100.00	3,615.77
9	490,767	10.4	54.28	2.28	8.71	6,241.64	0.0266	0.071	0.00	3,602.55
10	276,789	5.9	32.49	6.24	18.64	54,666.04	0.2799	7.229	0.36	27,489.92

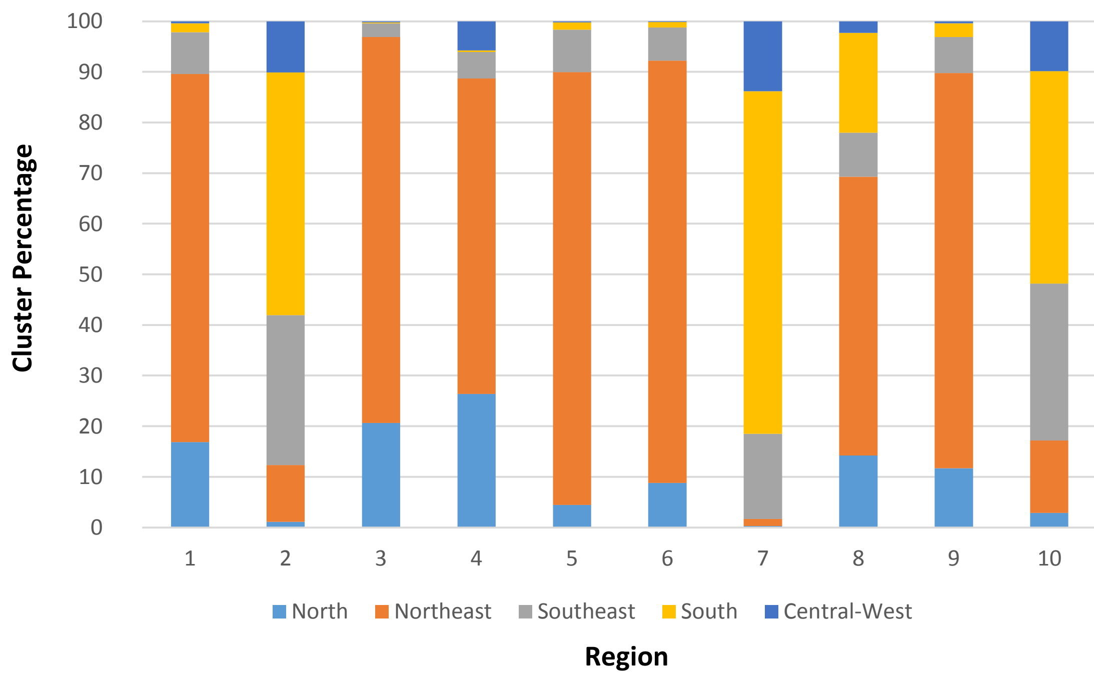

Figure 2. Smallholders by clusters and regions.

number of cooperated smallholders and the highest mean income, aside from its great productivity. Although other clusters achieved better productivity averages with much lower cooperativism, the mean income of this highly cooperated group is significantly greater than the mean income found in other clusters. Also, more than 80% of the farmers in this group are from the South and Southeast regions (Figure 2), thereby presenting evidence of the relation between the regions and income and productivity.

This study's results corroborate other studies, such as FAO (2014) and Ito et al. (2012), which state that cooperativism is a key factor to strengthen family farmers, since it plays an important role in their production and access to markets, and is an avenue for farmers to improve their incomes. However, this characteristic raises serious concerns, since only 5% of Brazilian family farmers are members of agricultural cooperatives (Herrera et al., 2017). The lack of cooperativism is also cited by Theodossiou et al. (2018) as one of the weaknesses of Greek agricultural sector. In order to guarantee the future of this sector, increasing cooperativism needs to be one of the targets of policy makers.

For decades, public policies have supported a production system based on specialization, intensification and scale enlargement developing a commercial food system driven by supermarkets where family farmers struggle to compete against industrial farmers. Additionally, the government has not encouraged smallholder's organization and empowerment, and thus they cannot act strongly as an oppositional force (de Roest et al., 2018; Córdoba et al., 2018; Blanc and Kledal, 2012).

One of the main public policies targeting the smallholder sector in Brazil is the PRONAF (National Program for the Strengthening of Family Farming), and despite the fact that the program has helped to improve small farmers' livelihoods, it is also criticized for making them highly dependent on the government. Furthermore, credit lines offered by PRONAF target the production of specific crops, such as commodities for exportation, leading family farmers to monoculture and specialization (Guanziroli et al., 2012; Córdoba et al., 2018).

Cluster numbers five and six are the largest ones. The first has the highest mean age and the second, conversely, has one of the lowest mean ages. Both groups have the highest average diversity indexes and have very low productivity and annual income. This presents some evidence that crop diversification may have a negative impact on smallholders' income and productivity, and also presents more evidence of the relation between the region and these two variables, since both clusters with more than 80% of the smallholders are located in the Northeast region of Brazil. One may also infer that the age of the household head does not interfere with income and productivity, considering that the mean ages found in between these two clusters are very distinct.

According to Li et al. (2009) and Meraner et al. (2015), intercropping promotes sustainable productivity growth that reduces agribusiness's negative environmental impacts. The vast majority of machinery and technologies that are developed are targeted to non-family farmers that practice monoculture, and thus diversified systems are very dependent on labor and manual harvesting, which increase production costs. As stated by Silva et al. (2018) and Coser et al. (2018), crop diversification and integrated agricultural systems are promising strategies to revert widespread land degradation and increase ecological production intensification. A study conducted by Steward (2013) in a village in the Amazon Estuary in Brazil showed that, with the emergence of new markets for agricultural crops, farmers are abandoning annual fields and replacing it with cash crops agroforests. Similarly, a research with approximately 3000 farmers in Kenya revealed that diversification with cash crops is a key intensification strategy in the country (Herrero et al., 2014).

One public policy with relative success in Brazil is the *Agricultura de Baixo Carbono* (ABC) – Low Carbon Agriculture program, which is strongly related with Brazil's Nationally Determined Contribution, offered at COP 21, for the reduction of greenhouse gas emissions. This program encourages farmers to adopt mitigation technologies such as pasture restoration that aim to reduce deforestation and increase the implementation of integrated agricultural systems (Silva et al., 2018). According to Coser et al. (2018), the strategy of the ABC program is to convert 15 million hectares of low-productivity pastures to agri-silviculture systems, which would account for a reduction of carbon emissions of 79.50 Tg ha^{-1} $year^{-1}$ during the first four years after its implementation.

Therefore, although this research results have shown that crop diversification might have negative impacts on farmer's income and productivity, this practice should be encouraged in order to increase agricultural activity sustainability. This can be achieved with more public policies that invest in the research and development of technologies for diversified systems that are accessible for smallholders. Theodossiou et al. (2018) reported similar findings, and the authors stated that agricultural policy and rural development should be designed concerning the protection of the environment.

By examining clusters two and ten, once more, we find evidence of the neutral effect of age on income and productivity, as observed in clusters five and six. These two groups with the two highest productivity averages also have great mean incomes. Nevertheless, one has a high mean age while the other has one of the lowest mean ages. In addition, the region seems to be very correlated to productivity and income when considering that more than 70% of family farmers from clusters two and ten are from the South and Southeast regions.

As stated by Guilhoto et al. (2011) and Fernandes and Woodhouse (2008), this great relation between regions and income and productivity may be due to the contrasting structures found in different regions of the country. Family farmers from the South and Southeast regions of Brazil are more likely to succeed, while farmers from the Northeast region are more similar to peasants. The South is a very developed region with great infrastructure; while the Northeast region, as stated by Simões et al. (2010) and Berdegue and Fuentealba (2011) concentrates the country's poorest population and suffers from the lack of investment. Such enormous differences are a consequence of the high inequality found in this country that affects both smallholders and other sectors as well. Sietz (2014) adds that smallholders in Northeast are more vulnerable due to dryland condition and therefore need special attention from policymakers.

In an attempt to reduce these huge contrasts and improve family farmers' livelihoods, in 2003, Brazil's Federal Government implemented the Family Farming Food Acquisition Program (PAA) to provide incentives to smallholders to increase food production both for self-consumption and for sale at guaranteed prices to public sector procurement agencies. Later, in 2009, the National School Meal Program (PNAE) required public schools to allocate at least 30% (that is, BRL 1.1 billion) of food expenditures to direct purchases from smallholders.

Under the PNAE, an estimated 47 million free-of-charge meals are served in schools every day; and between 2003 and 2014, about BRL 3.3 billion was spent under the PAA program (OECD/FAO, 2015). However, according to Graeub et al. (2016), although both policies have shown good results, these are still short-term solutions. Other measures such as the research and development of technologies for family farmers, incentives to cooperatives and the availability of quality rural assistance service are seen to be of greater importance to ensure the future of the smallholder sector (Salazar et al., 2016; Anang and Yanwen, 2014).

Another relevant fact concerns the schooling level of smallholders, which does not show a significant impact on improving family farming. According to the results, cluster number ten has the highest schooling average and the second highest mean income and productivity. However, other groups achieved great income and productivity with much lower schooling levels. As stated by Yue et al. (2010) and Greiner and Sakdapolrak (2013), this can be explained by the fact that farmers who seek higher levels of education tend to gradually move to urban areas and secure a non-farm job, thus reducing their time and attention spent with the agricultural activity. Conversely, farmers that have lower levels of education but dedicate their full time and attention to their agricultural activity are capable of achieving greater incomes and productivity.

It was also found that in cluster number eight, in which all family farmers had received rural assistance, the income and productivity averages were very low. This result is the opposite of what we expected. Several studies highlight that the rural assistance provided to smallholders are essential for their development and production improvement (Muatha et al., 2017; Fernandes and Woodhouse, 2008; Marenya and Barrett, 2007). Regardless of their income and productivity, all family farmers in the country have the right to receive rural assistance, not only the poorest. For example, in cluster number seven, which has the higher mean income, almost ten percent of smallholders use this service. A study by Vasconcelos et al. (2013) shows how rural assistance service in Santa Catarina State, Brazil, is using landraces to help smallholders adapt to climate change. Therefore, the findings here raise an important question about the quality of the rural assistance service provided to Brazilian family farmers.

Conclusions

This study examined a database with the most current information regarding smallholders in Brazil. The innovative approach of using machine learning techniques revealed important characteristics of this farmers and the diversity of groups inside this sector. It is believed that this study provides interesting elements of discussion on the process of formulating public policies that are capable of delivering real solutions to smallholders in Brazil.

As a major contribution of this research, the importance of cooperativism to increase family farmers' incomes and productivity was highlighted. Only a small percentage of smallholders are part of agricultural cooperatives, a characteristic that needs to change in order for these farmers to gain access to markets, obtain better selling prices and improve their returns to scale. Also, a fraction of family farmers benefit from living in one region while others are impaired by living in a different location, a sign of the great inequality found in the country that is the reason for major differences in this sector.

In addition, crop diversification was demonstrated to negatively affect family farming. Intercropping is an important practice to increase agricultural sustainability and reduce environmental impacts. Further research should focus on how to improve diversification while simultaneously increasing farmers' incomes and productivity and seeking sustainable development.

It is necessary to take a closer look at the quality of the rural assistance service provided to smallholders in Brazil in order to understand why this variable presented a negative effect on family farming, which is contrary to what is found in other countries. Finally, this study has examined several public policies targeting this sector and, despite that some have shown relative success, especially those that are focused only on short-term solutions such as low interest credit lines and price supports. In order to guarantee the future of smallholders, public policies should focus on the research and development of technologies for family farmers, incentives to cooperatives and providing of quality rural assistance services. Alongside several other studies, it is believed that family farmers can ensure food security in the future. Nevertheless, they are still not considered a priority and are ignored in policy makers' agendas.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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