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Full Length Research Paper

Foliar application of molybdenum improves nitrogen uptake and yield of sunflower

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Molybdenum (Mo) foliar spray may improve the nitrogen acquisition by the plants and increase the crop yield. The effects of Mo foliar spray on nitrogen nutrition, achene yield and yield components of sunflower were investigate in this study. The experiment was carried out on a Rhodic Hapludox in Chavantes, São Paulo, Brazil under conventional tillage system. Treatments consisted of five Mo concentrations [0 (control), 26, 52, 78 and 104 g ha^{-1} of Mo] applied as foliar spray at the growing stage of eight developed leaves – V8 (18 days after plants emergence). Foliar application of Mo rates reduced the nitrate (NO_3^-) concentration, and increased the concentrations of ammonium (NH_4^+), total nitrogen (N) and Mo in the leaf tissue of sunflower. Molybdenum foliar spray did not affect the plant height, stem diameter, capitulum diameter and number of achenes per capitulum of sunflower. Application of 58 and 68 g ha^{-1} of Mo resulted in increased of the thousand achenes mass (40%) and achene yield (27%) of sunflower, respectively, compared to the control. Molybdenum foliar spray improves the nitrogen nutrition and the achenes mass resulting in the increased achene yield of sunflower. Results suggest that Mo deficiency can compromise the nitrogen metabolism of plants, and result in lower achene yield of sunflower.

Key words: *Helianthus annuus* L., molybdoenzymes, nitrate assimilation, plant nutrition.

INTRODUCTION

Molybdenum (Mo) is an important micronutrient for plant growth and occurs in several enzymes catalyzing diverse oxidation–reduction reactions in plants (Mengel and Kirkby, 2001). Molybdenum is component of the nitrate reductase, nitrogenase, xanthine dehydrogenase, aldehyde oxidase, and sulfite oxidase enzymes. Because of its involvement in the nitrate assimilation, nitrogen fixation processes, and transport of nitrogen compounds in plants, molybdenum plays a crucial role in nitrogen metabolism of plants (Li et al., 2013).

Molybdenum normally occurs in soil solution as molybdate ion (MoO_4^{2-}) (Mengel and Kirkby, 2001). Molybdenum deficiency can occur in very weathered soils due to continuous cropping, soil erosion, reduction of soil organic matter, and adsorption by Fe hydrous oxides and hydroxides particularly in acid soils at low pH (Kaiser et al., 2005). Significant increases on grain yield with foliar application of Mo have been reported in several soils of Brazil, with pH values below 5.2 (Škarpa et al., 2013; Zoz et al., 2012; Dourado Neto, et al., 2012; Valenciano et al.,

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2011; Biscaro et al., 2011; Calonego et al., 2010; Ascoli et al., 2008). The Mo availability increases with increasing soil pH and acid soils with pH less than 5.2, the amount of available Mo to plants is extremely low, i.e., 0.10 to 0.25 mg kg^{-1} (Mengel and Kirkby, 2001). Since Mo is highly mobile in the xylem and phloem, and crops require low amounts, this micronutrient can be provided by seed treatments and/or foliar spray. Molybdenum foliar sprays are often more effective than soil applications, particularly for acid soils, and are most effective if applied at early stages of plant development (Valenciano et al., 2011). Effectiveness of foliar spray depends on the nutrient uptake rate by the leaves and its translocation into the plant (Boaretto et al., 2003). The leaves rapidly absorb Mo applied by leaf spray. Campo and Hungria (2002) found that translocation of Mo to the nodules of soybean plants was very rapid, and reported the highest concentration of this nutrient in the nodules five days after application.

The effect of Mo fertilization on increasing plant yield is often related to an increased ability of the plant to utilize nitrogen (N). Biscaro et al. (2011) verified that nitrogen fertilization increased common bean grain yield only when combined with Mo leaf supply. The activities of nitrogenase and nitrate reductase are affected by the Mo status of plants, and their activities are often suppressed in plants suffering from Mo deficiency (Toledo et al., 2010). Molybdenum foliar spray (40 g ha^{-1} of Mo) at 25 days after plant emergence greatly enhanced the nitrogenase and nitrate reductase activities, resulting in increase of total N accumulated in the plant shoots of common bean (*Phaseolus vulgaris* L.) (Vieira et al., 1998). Calonego et al. (2010) found that the absence of Mo foliar supply promoted the accumulation of nitrate in the common bean leaves as result of the increased N availability in the soil, indicating the low efficiency of N assimilation of plants in the absence of this micronutrient. However, the effect of Mo foliar spray on nitrogen acquisition and achene yield of sunflower (*Helianthus annuus* L.) are still unknown.

Sunflower is an annual multi-purpose crop and it has great potential to become an economically important crop in the Brazil considering its use for food, both for animals and humans, fodder plant, and for oil, medicinal and industrial uses. This study investigated the effect of molybdenum foliar spray on nitrogen nutrition, achene yield and yield components of sunflower.

MATERIALS AND METHODS

The experiment was carried out in Chavantes, São Paulo, Brazil (23°04' S, 49°48' W, altitude of 510 m). The soil was a clayey Rhodic Hapludox (Red Latosol in the Brazilian classification), with 360 g kg^{-1} of clay, 130 g kg^{-1} of silt, and 510 g kg^{-1} of sand. Before starting the experiment, soil samples were taken from the surface layer (0 to 0.20 m), air-dried, sieved through a 2.0 mm mesh, and analyzed as in Raij et al. (2001). Soil chemical analysis showed pH in $CaCl_2$ 0.01 mol L^{-1} of 4.8, 18 g dm^{-3} of organic matter, 17 mg dm^{-3} of P (Resin), 7 mg dm^{-3} of S-SO_4, 1.9 $mmol_c$ dm^{-3} of K, 18 $mmol_c$ dm^{-3} of Ca, 7 $mmol_c$ dm^{-3} of Mg, 1.8 mg dm^{-3} of Cu (DTPA), 1.2 mg dm^{-3} of Zn (DTPA), 22 mg dm^{-3} of Fe (DTPA), 14 mg dm^{-3} of Mn (DTPA), 0.45 mg dm^{-3} of B (Hot water) and 0.21 mg dm^{-3} of Mo (1.0 mol L^{-1} ammonium acetate). The area has been cultivated in conventional tillage with soybean in the summer and corn in the fall/winter period.

The regional climate, according to Köppen classification, is Cwa (humid subtropical climate with dry winter and warm summer). The 30-year mean annual temperature is 20.8°C with July minimum of 10.7°C and January maximum of 30.2°C, and mean annual rainfall of 1,420 mm. The experimental design was randomized blocks with five treatments and four replications. Different concentrations of molybdenum [0 (control), 26, 52, 78 and 104 g ha^{-1} of Mo] were applied as a foliar spray at the growing stage of eight developed leaves – V8 (18 days after plants emergence). The Mo source used was Nutry® Molibdênio foliar fertilizer [210 g L^{-1} of Mo and 790 g L^{-1} of inert material, with 1,400 g L^{-1} density]. Molybdenum concentrations were defined according to the recommended product application to the sunflower crop (52 g ha^{-1} of Mo; that is, 250 mL ha^{-1} of commercial product). Applications were performed with a CO_2 pressurized sprayer with 150 kPa working pressure capacity, equipped with flat fan nozzle, adjusted to apply 180 L ha^{-1} broth. The plants were sprayed at dusk due to a lower likelihood of drift by wind speed reduction and higher relative humidity. After spray, a minimum period of 72 h without rain was observed, enabling the best use of the product. Each experimental plot consisted of eight 5.0 m long rows, considering the four central lines as floor area, ignoring 1.0 m from the ends of each row.

Sunflower [*Helianthus annuus* L., Syn 042 hybrid] was sown on October 28, 2013, in rows 0.70 m apart at a density of 4 seeds m^{-1}. Fertilization was carried out by applying 300 kg ha^{-1} 08-24-12 formulation at sowing and 200 kg ha^{-1} 20-00-20 formulation topdressing at the in the growing stage of eighteen developed leaves – V18 (30 days after plants emergence). Pests and diseases control was carried out with two applications of thiamethoxam + lambda-cyhalothrin (ENGEO™ PLENO) and azoxystrobin + cyproconazole (PRIORI XTRA®) at 56.4 g a.i. ha^{-1} + 42.4 g a.i. ha^{-1} and 50 g a.i. ha^{-1} + 20 g a.i. ha^{-1}, respectively.

The concentrations of nitrate (NO_3^-), ammonium (NH_4^+), total nitrogen (N) and molybdenum (Mo) in the leaf tissue of sunflower were determined in developmental stage R4 (at beginning of flowering). Fifteen mature leaves were collected from each experimental unit. The samples were dried in a forced-air oven at 55°C for three days, ground in a Willey type mill and submitted to chemical analysis procedures, as previously described by Malavolta et al. (1997).

Sunflower was harvested when it reached physiological ripeness (stage R9). Agronomic characteristics of the crop were assessed against the following variables: plant height, stem diameter, capitulum (flowerhead) diameter, number of achene per capitulum, thousand-achene mass, and achene yield corrected to 130 g kg^{-1} water content. Data were submitted to analysis of variance and regression, both at the 0.05 level of confidence. The significant equations with the higher coefficient of determination were adjusted. All analyses were performed using SigmaPlot 11.0 software for Windows (Systat Software, Inc., San Jose, CA, USA).

RESULTS AND DISCUSSION

Molybdenum foliar spray affect the nitrate (NO_3^-), ammonium (NH_4^+), total nitrogen and molybdenum concentrations in the leaf tissue of sunflower (Figure 1). Nitrate concentrations in the sunflower leaves decreased progressively with increasing Mo rates in the foliar spray

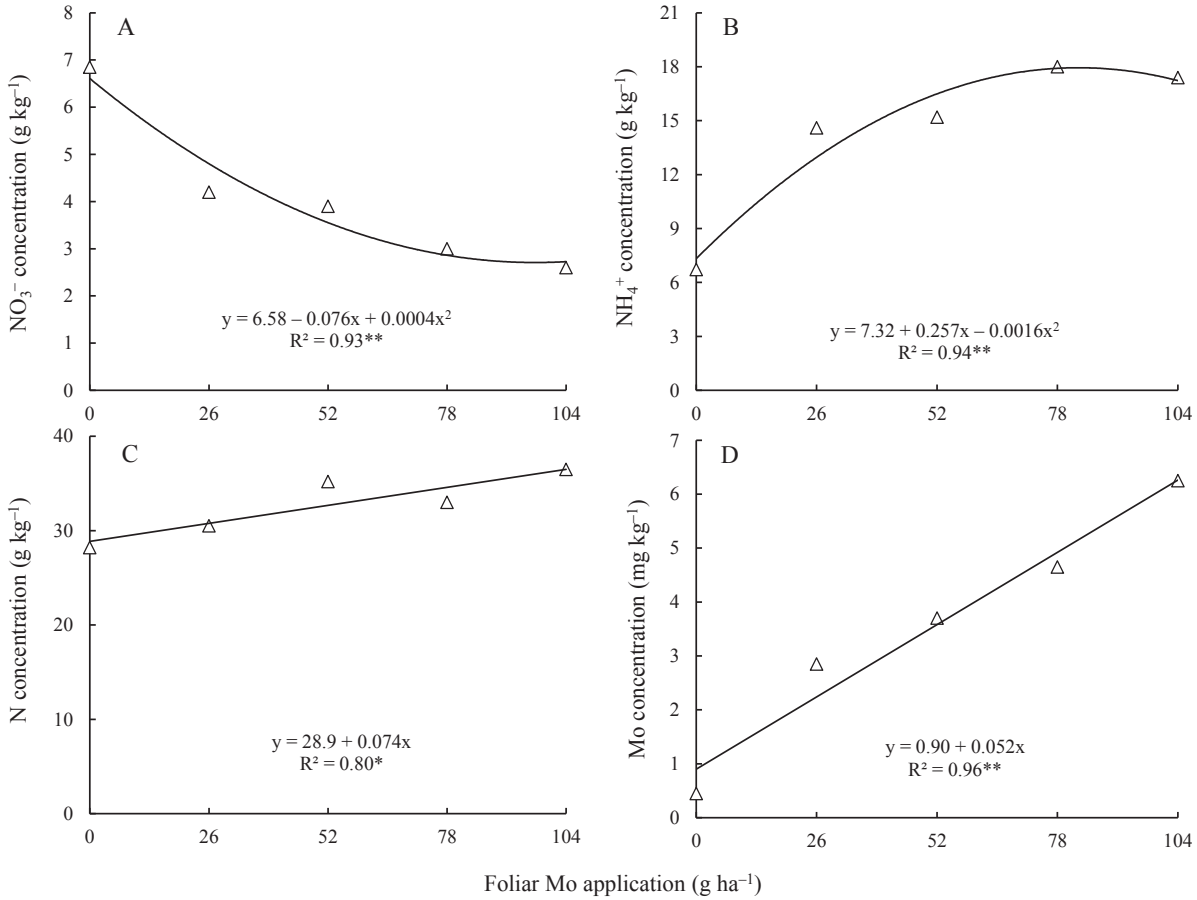

Figure 1. Effect of molybdenum foliar spray on concentrations of nitrate (A), ammonium (B), total nitrogen (C) and molybdenum (D) in the leaf tissue of sunflower (*Helianthus annuus* L.). * and **: statistical significance at 5 and 1%, respectively.

(Figure 1A). Nitrate reduced from 6.58 g kg^{-1} in the control treatment to minimum of 2.97 g kg^{-1} with the application of 95 g ha^{-1} of Mo, indicating mean reduction of 55%. This reduction of nitrate concentration in leaf tissue of sunflower with Mo rates occurred because this micronutrient plays an indispensable role in the nitrate assimilation taken up by plants. Molybdenum is component (cofactor) the nitrate reductase – enzyme that catalyzes the conversion of inorganic N in form of nitrate to nitrite.

The taken up NO_3^- by roots is readily mobile in plants and can be accumulated in vacuoles; however, for nitrate to be used in the synthesis of proteins and other organic compounds in plants, it must be reduced to ammonium (NH_4^+). The reduction is catalyzed by enzymes in two steps: the first step takes place in the cytoplasm by nitrate reductase (NR) transforming NO_3^- into nitrito (NO_2^-), and the second occurs in chloroplasts (shoots) or proplastids (roots) by nitrite reductase (NiR) converting NO_2^- to NH_4^+ (Rosales et al., 2011). The NO_3^- reduction to NO_2^- is the rate-limiting step for primary nitrate assimilation, and reductive ratios in roots and shoots depend on plant species, carbohydrates in plants, and nitrate reductase activity (NRA) as well as environmental conditions such as NO_3^- concentration, medium soil pH, complementary ions, light, and ambient CO_2 concentration (Li et al., 2013). Vieira et al. (1998) showed that the Mo foliar spray enhanced the nitrogenase and nitrate reductase activities resulting in increase of nitrogen accumulated in the common bean leaves. Calonego et al. (2010) reported that the absence of Mo supply promoted the nitrate accumulation in the common bean leaves, indicating the low efficiency of N assimilation by the plants in the absence of this micronutrient.

Molybdenum foliar spray resulted in the significant increase of NH_4^+ and total N concentrations in the sunflower leaves (Figure 1B and C, respectively). Ammonium concentration increased from 28.9 g kg^{-1} in the control to maximum of 36.6 g kg^{-1} with the application of 104 g ha^{-1} of Mo, indicating mean increase of 27%. Total N concentration increased from 7.32 g kg^{-1} in the

Table 1. Effect of molybdenum foliar spray on plant height, stem diameter, capitulum diameter and number of achenes per capitulum of sunflower (*Helianthus annuus* L.).

Foliar application of Mo (g ha^{-1})	Plant height (m)	Stem diameter (mm)	Capitulum diameter (cm)	Number of achene per capitulum
0	1.42	21.0	16.4	589
26	1.50	22.6	17.1	624
52	1.52	24.2	17.4	631
78	1.51	23.4	18.0	602
104	1.54	23.0	17.3	616
Mean	1.50	22.8	17.2	612
F test	2.04ns	0.10ns	1.74ns	1.22ns
Regression	ns	ns	ns	ns
CV (%)	13.1	8.8	7.1	6.8

ns: not significant. CV: coefficient of variation.

control treatment to maximum of 17.7 g kg^{-1} with the application of 80 g ha^{-1} of Mo, indicating mean increase of 142%. The increase of NH_4^+ and N concentration in leaf tissue of sunflower with Mo rates suggests that this micronutrient improved the plant nitrogen assimilation, that is, the NO_3^- reduction to NH_4^+ and subsequently converted in amino acids, proteins and other organic compounds in plants. All inorganic N taken up by plants is first reduced to NH_4^+, because it is the only reduced N form available to plants for assimilation into N-carrying amino acids (Ruiz et al., 2007).

Ammonium is then assimilated into glutamine and glutamate, which serve to translocate organic N from sources to sinks in legumes and non-legumes (Mokhele et al., 2011). The main enzymes involved are glutamate synthase (GS), or glutamine-2-oxoglutarate amino transferase (GOGAT), and glutamate dehydrogenase (GDH) (Wickert et al. 2007; Mokhele et al., 2011). Cao et al. (2008) found that GS has a vital role in NH_4^+ assimilation and the activity of the enzyme is considered critical and possibly rate-limiting step in NH_4^+ assimilation. Ammonium may be toxic to plants, because it can cause proton extrusion, which is associated with NH_4^+ uptake, changes in cytosolic pH and uncoupling of photophosphorylation in plants (Wang et al. 2007). Glutamine and asparagine are the preferential form in which N is assimilated and translocated (Mokhele et al., 2011). This is because these molecules show low C:N ratio, which represents an advantage for NH_4^+ incorporation to non-toxic forms (Frechilla et al., 2002).

Molybdenum concentration on the sunflower leaves increased with increasing Mo rates in the foliar spray (Figure 1D). Molybdenum concentration increased from 0.9 mg kg^{-1} in the control treatment to maximum of 6.3 mg kg^{-1} with the application of 104 g ha^{-1} of Mo, indicating mean increase of 600%. These results were expected due to the low availability of Mo in the soil and its application on the leaves. Molybdenum concentration between 0.6 and 10 mg kg^{-1} is considered adequate for normal growth of plants. Deficient plants shows leaf concentrations between 0.01 and 0.6 mg kg^{-1} (Malavolta et al., 1997). Regardless of the rate applied the Mo concentration in the sunflower leaves remained in the range considered adequate for optimum growth and development of plants. Molybdenum foliar spray did not affect the plant height, stem diameter, capitulum diameter and number of achenes per capitulum of sunflower (Table 1). These agronomic characteristics are predominantly determined by genetic factors, intrinsic to species or cultivar, being little affected by environmental or management factors.

The thousand achenes mass and achene yield of sunflower increased significantly with Mo foliar spray (Figure 2). The thousand achenes mass increased from 59.6 g in the control treatment to a maximum of 83.6 g with the application of 58 g ha^{-1} of Mo, indicating mean increase of 40% (Figure 2A). Based on the magnitude of direct and indirect effects determined by the path analyzes, Rigon et al. (2014) concluded that capitulum diameter and thousand achenes mass are the yield components that determine the achene yield of sunflower. Such inference reports the importance of the achenes mass for increasing the yield of sunflower. The increase in mass of achenes with Mo rates may be due to the increase in N assimilation and nutrition of plants (Figure 1C). The improvement in the N assimilation resulted in a greater amount of assimilates such as glutamine, glutamate and amino acids that were subsequently translocated to the achenes.

The achene yield of sunflower increased from 1,580 kg ha^{-1} in the control treatment to a maximum of 2,002 kg ha^{-1} with the application of 68 g ha^{-1} Mo, indicating mean increase of 27% (Figure 2B). Similar results were obtained by Lima et al. (1999), who found that the application of 75 g ha^{-1} Mo increased the common beans yield. Valentini et al. (2005) reported increase of 43% in the grain yield of maize with the application of 90 g ha^{-1} Mo. Foliar application of Mo up to a dose of 35 g ha^{-1}

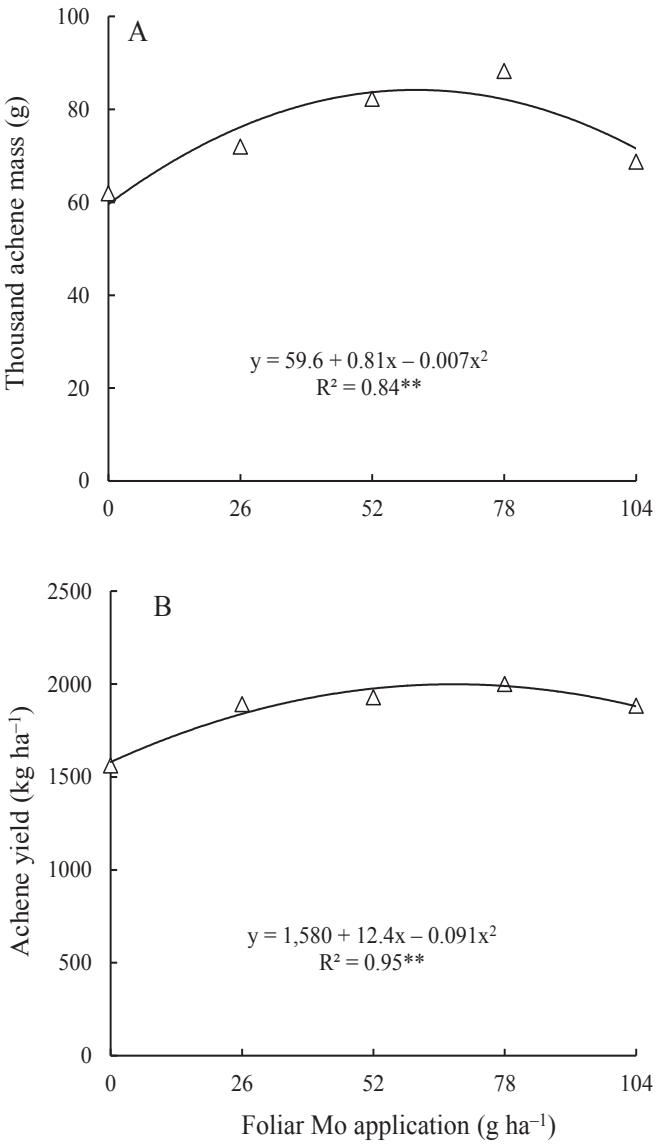

Figure 2. Effect of molybdenum foliar spray on thousand achenes mass (A) and achene yield (B) of sunflower (*Helianthus annuus* L.) **: statistical significance at 1%. CV: coefficient of variation.

increased the yield of wheat (Zoz et al., 2012). Škarpa et al. (2013) found that foliar application of Mo up to a dose of 125 g ha^{-1} at the beginning of vegetation (stage V-4) and developmental stage R-1 increased of achene yields of sunflower.

The effect of Mo fertilization on increasing grain yield is associated with increased ability of the plant to utilize N. Biscaro et al. (2011) verified that nitrogen fertilization increased common bean grain yield only when combined with Mo foliar supply. In general, the results presented here suggest that molybdenum deficiency can compromise the nitrogen metabolism of plants, and result in lower achene yield of sunflower.

Conclusions

Molybdenum foliar spray up to rates of 60 to 70 g ha^{-1} Mo improves the nitrogen nutrition of the plants and the achenes mass of sunflower resulting in the increased achene yield.

Conflict of Interest

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

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Full Length Research Paper

Technical-economical evaluation of a solar water heater with vacuum tubes collector, used in a rural area in Paraná, Brazil

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Solar radiation is a source of energy that can be used directly by residences and industries. In this work, the efficiency of a solar collector type all-glass installed in a rural area in Paraná, Brazil, in the winter period, was evaluated. Two daily showers were simulated in three different scenarios, to measure additional electrical consumption used to boost the heating of water. In the first scenario, the consumption was evaluated leaving the auxiliary heating system connected the entire day and, in the second, only in the afternoon period. This auxiliary heating system, controlled by a thermostat, was only connected when the temperature of the water in the boiler stayed below 40°C. In the third scenario, the auxiliary heating system was disconnected and the heating of the water occurred solely due to the solar heating system. These scenarios were compared with the use of the solar heating system together with an electric shower and with an electric shower alone. It was verified that the mean efficiency of the solar collector in the evaluated period was 51%. The electric shower, when used in conjunction with the solar heater, consumes 6.5 times less electrical energy than when used alone (192.55 kWh and 1240.34 kWh, respectively).

Key words: Renewable energy, vacuum solar collector, solar water heater.

INTRODUCTION

In 2013, the Brazilian electrical consumption per residency was of 124.858 GWh, which represented 27% of the country's consumption (Brasil, 2014). Of these, 24% were directed to the electric shower of the residency, in other words, 30.000 GWh were intended for the heating of water (Penereiro et al., 2010).

According to Mogawer and Souza (2004), almost all this energy is used during peak hours (between 18 h and 20 h), overloading the electrical system. This demand represents about 12.8% of the total need in this period, which corresponds to approximately 6.800 MW of installed power, almost half of the current 14.000 MW Itaipu Hydroelectric Plant's capacity, Paraná.

Use of conventional sources of energy to meet this

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Figure 1. Solar collector with vacuum tubes type all-glass.

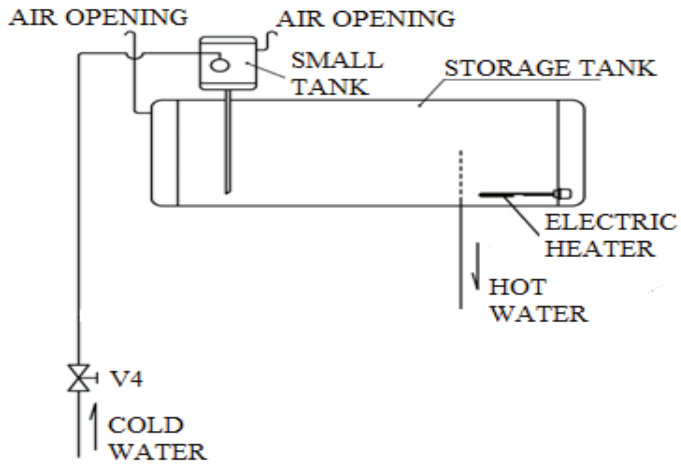


Figure 2. Diagram of thermal reservoir of solar heater. Source: EXXA Solar (2009).

demand causes ecological problems and reduction in supply. A possible solution though is the use of alternative sources of energy (Kousksou et al., 2014). The use of solar energy has intensified in Brazil, taking advantage of its high solar radiation index (Aldabó, 2002).

The South of Brazil has a high usage of electric showers, which means, despite being the region with the smallest solar radiation of Brazil, can contribute with the use of solar heaters, following the example of European countries, that intensely use this technology, despite its solar radiation being a little lower (Pereira et al., 2006).

One of the biggest implementation of this technology is established in India, in an industrial egg processing plant, where 1280 panels heat 110.000 L of water to 85°C, equivalent to a 1 MW power station, generating 78% saving of fuel oil (Nagaraju et al., 1999). Thus, the substitution of conventional heating by solar may be a great economic alternative, in order to reduce peak hour's electrical consumption in the country (Prado, 2007; Naspolini and Rüther, 2011).

Nevertheless, the high initial cost of this technology can be a negative factor. Moreover, the auxiliary heating for days with low solar radiation can use up a lot of energy, turning the system unviable. The project directly influences the efficiency (Wang et al., 2015), thus, diverse forms of this technology have arrived in the country in the last years, including, the solar water heater with vacuum tube collectors. These tubes have higher efficiency as they make more use of solar radiation, independent of the angle of occurrence of the same (Goerck, 2008). This fact is very important, because the dependence of the angle may be very significant in other systems (Elhab et al., 2012).

The aim of this work was to calculate the efficiency of a solar heating system with vacuum tubes collector, and verify its economic viability using three distinct scenarios.

MATERIALS AND METHODS

This experiment took place during the period of 1st June to 31st August 2013, at State University of Western Paraná, situated in the city of Cascavel, Latitude 24°59' South, Longitude 58°23' west and means altitude of 785 m. In this location, a vacuum tube solar water heater was connected to a boiler EXXA brand, with 1.6 x 2.6 m dimensions. It was installed facing north, with a 28° inclination. The collector shown in Figure 1, of the type all glass is made up of 20 glass tubes, directly connected to thermal reservoir.

This reservoir has 170 L of capacity and an electrical heating system of 1500 W. Above the thermal reservoir there is a small feeder tank, with a floating ball-cock. The water from this tank flows through an internal tube to a boiler, while the water heated by the collector rises by convection to the top of the reservoir. The design of the hydraulic system is highlighted in Figure 2.

Equipment used for measuring and recording data

Datalogger

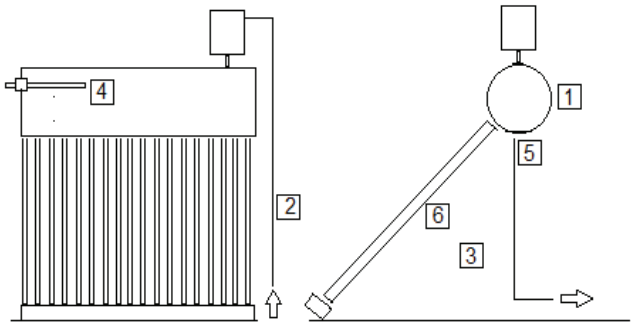
Data regarding temperature, electric current and solar radiation was collected every 10 s using a datalogger CR1 1000 model, of Campbell Scientific manufacture, which has 8 analogue inputs. A 12 V output was also used to power a contact that activates the electrical heating system of boiler when necessary, based on temperature of the water.

Thermocouple

Six thermocouples type J were used to measure temperature, interconnected to the data measuring system. Such thermocouples have mineral insulation with metal protection, allowing for them to be installed and used in direct contact with water. The diagram in Figure 3 shows the location of the temperature sensors in heater.

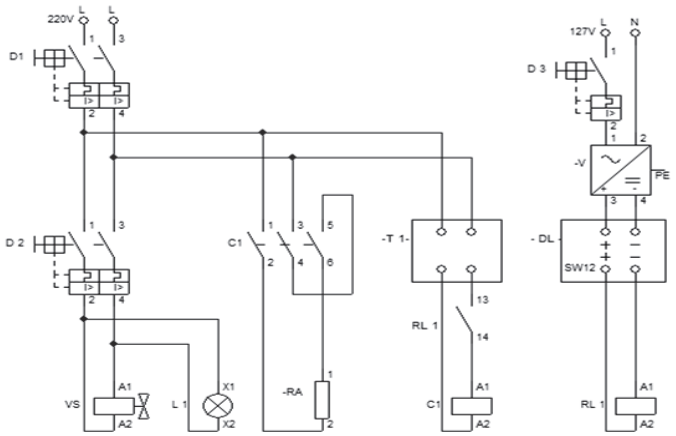
Pyranometer

The measuring of solar radiation was completed using a pyrometer of Kipp & Zonen manufacture; model CMP3, with sensitivity of 15.0 $\mu V\ W^{-1}\ m^{-2}$. It was installed close to the heater, and the values of



1 - Boiler's external sensor
2 - Cold water entry sensor
3 - Ambient temperature sensor
4 - Boiler's internal sensor
5 - Hot water exit sensor
6 - Collector's external sensor

Figure 3. Diagram of location of temperature sensors.



D1, D2 – Double pole fuse
D3 – Single pole fuse
VS - Solenoid valve
L1 – Indicator light
C1 – Triple pole contactor
SW 12 - 12 VCC exit controlled by internal temperature of boiler
RA - Heating element
T1 – Timer
RL 1 - Relay 12 VCC
V – Datalogger power supply
DL – Datalogger

Figure 4. Electric diagram of power supply of auxiliary heating system and solenoid valve.

radiation measured were stored by the datalogger every 10 s.

Devices used for control and signaling

Solenoid valve

The hot water exit was controlled by a double solenoid valve; model EVA-03 of EMICOL manufacture, controlled by a remote switch. It has 3/4"connection and 220 V power.

Timer, relay and contact

A timer was installed to control the running of the auxiliary heating system of the boiler, of Logica 600 model and Kienzle manufacture, like a relay and a contact controlled by 12V from a datalogger.

Installation diagram

The electrical installation to power the auxiliary heating system and the solenoid valve followed NBR 5410/2004 standards - Electrical installation of low voltage (ABNT, 2004). Its electrical connections are indicated in Figure 4.

Methodology

Daily consumption of hot waters

The daily consumption of hot water during the entire period of the experiment was set to two showers occurring at the end of the afternoon, with temperature of water being around 40°C, and 60 L of volume per shower. As temperatures of hot and cold water vary daily, a mixer of water was simulated for this occurrence. The output of hot water eliminated through the solenoid valve was measured, obtaining the constant amount of 6 L min^{-1}. Thus, through the time variation operating time of this valve, it was possible to obtain the volume of hot water that would be necessarily added to the cold water, to obtain a mixture of water of 40°C temperature. This timing was calculated using Equation 1, developed by the author. The values of hot and cold water used in the equation were obtained directly from recorded measurements in datalogger, moments before each simulation.

$$t = \frac{2400 - 60\,T_f}{Q\,(T_q - T_f)} \quad (1)$$

where:
t - time solenoid valve open (min);
T_f - temperature of cold water (°C);
T_q - temperature of hot water (°C);
Q - volume of hot water output (6 L min^{-1}).

Scenarios for the use of solar heater system

The datalogger was programmed to turn on the auxiliary heating system of the boiler when its temperature fell below 40°C. There were three scenarios for the installed system:
Scenario I - With the timer on "ON position", the auxiliary heating system stays connected and can be turned on any hour of the day, as needed to heat water.
Scenario II – The timer set in "automatic position" allows connection to auxiliary resistance between 12:00 and 18:00 hours only.
Scenario III – The timer on "OFF position" does not connect to the auxiliary heater at any time and the heating occurs only as a function of solar radiation.
The setting of the timer was changed at the end of each day, to sequence through the scenarios. Other than the scenarios studied, two simulations using an electric shower were used:
Simulation I – The shower is connected to the solar heating system in scenario III, and is used, when necessary, to boost temperature of "preheated" water.
Simulation II – The electric shower works alone, without any solar heating system to preheat the water.

Processing of data

Efficiency of solar heater calculation

The mean efficiency of the solar heating system was calculated

from data gathered between 6:00 and 18:00 h each day, and is given in Equation 2 (Duffie and Beckman, 2006).

$$\eta = \frac{Q}{A_c \sum S + Q_a)} 100\ \% \quad (2)$$

where:
η - efficiency of system (%);
A_c - area of solar collector (1,61 m²);
S - incidence solar radiation (Wh m^{-2});
Q_a - auxiliary electrical energy (Wh);
Q - energy needed to heat water (Wh).
The energy needed to heat the water (Q), was calculated using Equation 3 (Duffie and Beckman, 2006).

$$Q = m\ C_p\ (T_1 - T_2) \quad (3)$$

where:
m - mass of water in thermal reservoir (kg);
C_p - thermal coefficient of water (1.1628 Wh kg^{-1} $°C^{-1}$);
T_1 - maximum temperature of reservoir at the end of the period (°C);
T_2 - minimum temperature of reservoir at the beginning of the period (°C).

The area of the collector was calculated using Equation 4:

$$A_c = N\ D\ L \quad (4)$$

where:
A_c - area of collector (m^2);
N - number of tubes in collector (20);
D - diameter of internal tube (47x 10^{-3} m);
L - superficial length of absorbing surface of inner tube (1.713 m).

Calculation of energy balance of the system

The energy balance of the system was calculated using Equation 5, so that energy gained were due to incidence of solar radiation and the functioning of the auxiliary electric heating; and the losses of energy were due to losses through the walls of the boiler and replacement of cold water (Duffie and Beckman, 2006).

$$m\ C_p\ (T_s^+ - T_s^-) = Q_s\ \Delta t + Q_a\ \Delta t - (UA)_s\ \Delta t\ (T_s^- - T_a) - m_c\ C_p\ (T_c - T_f) \quad (5)$$

where:
m_c - mass of water consumed (kg);
T_s^+ - water temperature afterwards (ºC);
T_s^- - water temperature beforehand (ºC);
T_a - ambient temperature (ºC);
T_c - temperature of water used (ºC);
T_f - temperature of cold water (ºC);
Δt - time interval considered in simulation (1 h);
Q_s - solar energy transferred to fluid (Wh);
Q_a - electric energy transmitted to fluid (Wh);
U - global coefficient of heat transfer between reservoir and the air (W m^{-2} $ºC^{-1}$);
A - external area of thermal reservoir (m²).

The term Q_s expresses the useful thermal energy produced in the solar collector, and can be expressed in accordance with Equation 6.

$$Q_s = A_c\ F_R\ [S - U_L(T_{pm} - T_a)] \quad (6)$$

where:
F_R - extraction factor of heat of solar collector (adimensional)
S - incidence of solar radiation (W m^{-2})
U_L - global heat transfer coefficient between collector and the air (W m^{-2} $ºC^{-1}$)
T_{pm} - surface temperature of heat absorber of collector (°C).
Equations 5 and 6 were used to obtain the coefficients U and F_R, from the simulations made with real data collected in field research.

RESULTS AND DISCUSSION

Analysis of efficiency of solar heater

The efficiency of the collector was calculated using Equation 2, resulting in a mean value of 51%. Goerck (2008) evaluated a solar water heater with vacuum tubes collector with heat pipe in the region of Taquari (Rio Grande do Sul), estimating its efficiency to 43%.

Extraction factor of the collector (F_R) and thermal coefficient of boiler (U)

The factors UA and F_R were determined from Equation 5, using simulations performed with the Matlab 2012 software. The optimum value obtained for the F_R (extraction factor of collector) was of 0.62 with values ranging between 0.50 and 1.0 in increments of 0.01. For UA (product of thermal coefficient of the boiler by its external area), the optimum value was of 3.5, with values varying from 2 to 10, in increments of 0.5. Sabs (2009) has found the coefficient of 3.878 for various reservoirs exposed to open air. The optimum values obtained were the ones that presented the best fit of temperature measured data and of solar radiation to equation of energy balance.

Functioning of heater evaluation

Table 1 compares the performance and consumption of energy from the heater in the three scenarios. The third column of the table details the days in which the temperature remained above 40°C. In scenario 1, the consumption of electrical energy measured in 46 days,

Table 1. Comparison of consumption of electrical energy between the three scenarios reviewed.

Operation of auxiliary heating scenario	Total (days)	Temperature of boiler above 40 °C (days)	Measured consumption (kWh)	Daily mean (kWh)
Scenario 1	46	46	436	9.48
Scenario 2	15	15	38.9	2.59
Scenario 3	28	14	0	0

Table 2. Daily consumption of electrical energy for the heating of water for showering.

Days in Scenario 3 below desirable temperatures	Temperature of water (°C)		Addition of energy (kWh)	
	Preheated	Cold (Natural)	With preheated water	With cold water
11/06/2012	37.78	21.96	0.31	2.51
20/06/2012	33.55	20.55	0.90	2.71
05/07/2012	37.27	22.17	0.38	2.48
08/07/2012	37.50	16.65	0.35	3.25
10/07/2012	30.29	18.59	1.35	2.98
13/07/2012	36.14	16.13	0.54	3.33
17/07/2012	18.89	16.62	2.94	3.26
20/07/2012	37.60	15.27	0.33	3.45
23/07/2012	29.70	20.88	1.43	2.66
26/07/2012	23.96	22.00	2.24	2.51
29/07/2012	27.70	23.01	1.71	2.37
01/08/2012	35.83	20.77	0.58	2.68
16/08/2012	36.52	23.42	0.49	2.31
28/08/2012	25.96	19.31	1.96	2.88
Total (kWh)	-	-	15.51	39.38
Daily mean (kWh)	-	-	1.11	2.81

due to the operation of the auxiliary heating system, was of 436 kWh (average of 9.48 kWh day^{-1}). In the days in which the heater operated in Scenario 2, the temperature of the boiler also remained above 40°C at the end of the afternoon. The measured consumption of electrical energy was of 38.9 kW (mean of 2.59 kWh day^{-1}). It is noted that the insertion of the timer in the circuit in scenario 2, to limit the operation of the auxiliary heater only to the afternoon period, reduced in 72.68% the mean daily consumption in relation to scenario 1. In scenario 3, in 14 days (of a total of 28), the temperature of the boiler at 17 h was lower than the set temperature.

Evaluation of the use of solar collector as a preheater for an electric shower

The results obtained in Scenario 3 were used to make Table 2, which simulates the energy that would be consumed by an electric shower to heat water up to the required temperature for showers, from the preheated water by the solar heater, and from the natural water (cold). The results of the fourth and fifth column were calculated considering a water mass equal to 120 kg at 40°C (2 showers).

In the fourth column are the values calculated to complement the thermal energy needed to reach the set temperature of consumption from the temperature of water preheated by solar energy. This energy would be supplied by an electric shower with variable power that would consume a daily average of 1.11 kWh (Simulation I).

The last column shows calculated values of energy that would be consumed in the same days by a shower, also electrical, to raise the temperature of the cold water to 40°C (Simulation II). The daily mean consumption of 2.81 kWh of the shower would be, in this case, about, 1.5 times the consumption obtained when the preheated water with solar energy is used by the shower supply.

Of the five ways of operating the solar heater analyzed (Scenario I, II and III; Simulation I and II), the best result would be the one that meets the requirements of showers every day, with the least consumption of electrical energy.

Table 3. Determination of saving obtained using water preheated by solar energy to feed an electric shower.

Month	Daily mean global radiation (Wh $m^{-2}day^{-1}$) (Tiba and Fraidenraich, 2000)	Mean temperature of preheated water (°C)	Energy consumed by shower for preheated water to reach desired temperature (kWh)	Mean temp. of cold water (°C) (Lima, 2012)	Energy consumed by shower for cold water to reach desired temperature (kWh)
Jan	5556	52	0	19	90.84
Feb	5000	48	0	19	82.05
Mar	5000	47	0	18	95.16
Apr	3333	37	14.62	17	96.28
May	3333	33	31.90	13	116.79
Jun	2778	28	50.34	12	117.21
Jul	2778	28	50.34	12	121.12
Aug	3333	33	31.90	13	116.79
Sept	3889	37	13.46	14	108.84
Oct	4444	42	0	16	103.81
Nov	5556	50	0	17	96.28
Dez	6111	54	0	18	95.16
Annual consumption (kWh)	-	-	192.55	-	1240.34
Annual cost of consumed energy (US$)	-	-	36.90	-	237.73
Annual saving (US$)	-	-	200.83	-	-

Annual saving of combined use of electric shower with solar heater

Table 3 shows a simulation of annual saving obtained when using an electric shower of variable power to heat water from an initial temperature (cold or preheated by solar heater) up to the desired temperature for a shower (about 40°C). Figure 5 shows a comparison between the energy consumed by shower using preheated water, with the energy consumed by shower using cold water, to reach the desired temperature. These data were obtained from columns 4 and 6 of Table 3.

The simulation shown in Table 3 indicates an annual saving of US$ 200.83, obtained by reduction of consumption of electric energy of a shower fed with water preheated by solar energy (annual cost of US$ 36.90), when compared with a shower fed with cold water from supply network (annual cost of US$ 237.73). The cost of US$ 0.1916 per kWh of electrical energy is applied to consumers in residential category (COPEL, 2013).

The temperature of the preheated water, in the third column of the table, was estimated based on potential heating of solar collector when exposed to the mean monthly radiation in the West of Paraná (Pereira, 2002).

The values of additional energy, in the fourth column, are of thermal energy necessary for the water, already preheated by the solar collector, to reach 40°C. There is a greater need of extra electrical energy between May and August, because these months coincide with smaller values of ambient temperature and solar radiation. However, in the month of April, a lower radiation is compensated by higher ambient temperature, while in September the opposite occurs.

The table was created taking into account that the water stored is at ambient temperature. Therefore, the constant temperature of the cold water in the fifth column was considered equal to the lowest average ambient temperature registered in the city of Cascavel between 1972 and 2009 (Lima, 2012).

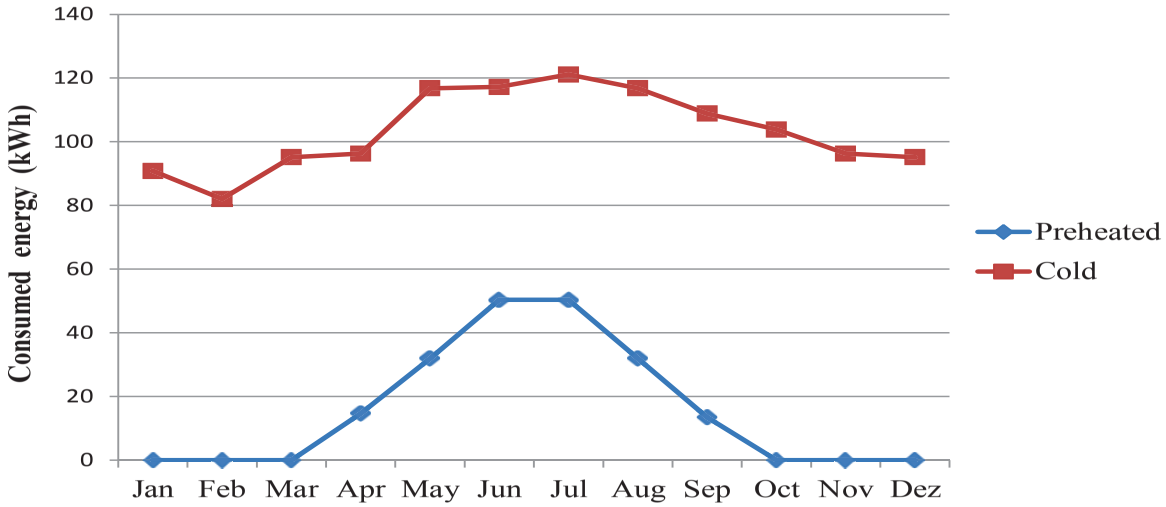


Figure 5. Comparison of the energy consumption between the preheated and cold water.

Table 5. Comparative economic analysis for the 5 options presented.

Options	Annual consumption of electrical energy (kWh)	Annual cost of electrical energy (US$)	Initial cost of equipment (US$)	Annual cost (US$)	Total annual cost (US$)	Pay back compared with simulation 2 (years)	Meets the requirements of hot water?
Scenario 1	2412.50	462.15	1141.25	117.51	579.65	(NA)	Yes
Scenario 2	238.28	45.65	1141.25	117.51	163.15	7.23	Yes
Scenario 3	0.00	0.00	1141.25	117.51	117.51	5.59	No
Simulation 1	192.55	36.89	1182.92	121.80	158.68	7.16	Yes
Simulation 2	1240.34	237.60	41.67	4.29	241.89	Reference	Yes

(NA)= Not applicable since payback is negative.

The values in the last column show the necessary energy for a shower to reach the set temperature for showering, when fed with cold water from supply network.

Economic analysis of investments

Table 4 shows data used to make financial analysis of investments. Table 5 presents a comparative economic analysis for the five options of heating water for showering. Analyzing Table 5, it can be noted that option "Scenario 1" has the highest annual cost (US$ 579.65), followed

Table 4. Outlay of financial analysis of investment.

Purchase cost of solar heater analyzed (US$)	974.58
Material and labour cost for installation of heater (US$)	166.67
Cost of electric shower (US$)	41.67
Cost of kWh (US$)	0.1916
Useful lifetime of heater considered (years)	15 years
Annual interest rate (%)	6.00

by option 'Simulation 2" (US$ 241.89). Option "Scenario 3" has the smallest annual cost; it however, does not meet the water temperature requirements in the coldest months. The options "Scenario 2" and "Simulation 1" are practically the same, since the latter has an annual cost a little less than the former. Column 4 shows return time of investment (*payback* completion), in accordance with Newnan et al., (2011).

CONCLUSIONS

The mean efficiency found for the model of solar heater in study was of 51%. Three scenarios with solar heater were evaluated and 2 simulations with an electric shower were made. In scenario 1, the daily average energy consumption was of 9.48 kWh (auxiliary heating system connected without time restriction). In scenario 2 (working hours of auxiliary heating system restricted to the afternoon period), the daily average consumption was of 2.59 kWh, in other words, 72.68% lower than the previous.

In scenario 3 (auxiliary heating system turned off), 14 of the 28 days that the heater functioned, the water temperature at the end of the afternoon was lower than set, which makes this form of operation unviable. Simulating the energy that would be necessary for an electric shower to boost the temperature of water in these 14 days in Scenario 3, a daily mean consumption of 1.11kWh can be observed (Simulation I) against 2.81kWh (Simulation II), which would have been used by the same shower, if it were directly fed with cold water from network supply.

The annual costs of these ways of operating were calculated and compared, revealing that simulation I presents smaller cost and is more interesting due to flexibility of operating times of hot water. Finally, it was established that the return of investment in the installation of a solar heater connected to an electric shower, for an interest rate of 6% per year, occurs in about 7 years, when compared with using an electric shower alone.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Farmers' risk perceptions and adaptation to climate change in Lichinga and Sussundenga, Mozambique

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In Africa, climate change exerts significant pressure on the agricultural sector. Current changes in climate for most parts of Mozambique have resulted in increased frequency of droughts, dry spells and uncertain rainfall. This has resulted in loss of food production and smallholder farmers are most vulnerable to these climatic disasters as they affect the food security status of the household. Despite an increased number of country level case studies, knowledge gaps continue to exist at the level of impact analysis. In addition, while adaptation and coping strategies with climate change and variability have become key themes in current global climate discussions and policy initiatives, literature on adaptation in Mozambique appears to be limited. The objective of this study was to assess the perception of smallholder farmers to climate change and adaptation strategies in Lichinga and Sussundenga districts of Mozambique. Using data obtained from a survey carried out in Lichinga and Sussundenga districts in Mozambique descriptive statistics analysis was undertaken using SPSS software to characterize the households, in terms of perceptions and coping strategies of the household to climate change. The farmers from both districts sited rainfall variability and higher temperatures to have severely affected maize production. Due to the late onset of rains, in Lichinga the planting period has changed from November (47.5%) to December (70%) while in Sussundenga the planting period has changed from September/October (40%) to November (62.5%). The rain seasons have become shorter and dry seasons are longer. Some farmers have switched from growing maize to growing drought tolerant crops, such as cassava, sweet potato and cultivation of horticultural crops in wetlands as strategies to cope with the climate change.

Key words: Climate variability, farmer's perceptions, adaptation strategies.

INTRODUCTION

Climate variability and droughts are already important stress factors in Africa, where rural households have adapted to such factors for decades (Mortimore and Adams, 2001). Historical data shows that the continent is already undergoing climate change. The continent is becoming warmer and drier. Rainfall is becoming less predictable. In Mali, Lacy et al. (2006) revealed a tendency for a shortening of the rainy season to induce farmers to shift some of their sorghum production to a variety with a shorter cycle than the traditional one. In a

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study from Burkina Faso, Nielsen and Reenberg (2010) found rainfed cereal production to be declining due to a change in climate and a shift towards a higher level of dependence on migration, livestock, small scale commerce and gardens. In the Sub-Saharan El Niño rains cause floods and destruction, while in the recent years droughts have also had catastrophic impacts (Nielsen and Reenberg, 2010). Recent events, such as the poor rains in Southern Africa 2001 and 2003, demonstrate that communities may already be suffering the consequences of less predictable weather patterns (Wiggins, 2005).

As the poorest country in Southern Africa, a region that is projected to become substantially hotter and drier, Mozambique is likely to feel the impacts of climate change more than most (Ehrhart and Twena, 2006). The most striking impacts of climate change over south-eastern Africa are expected to be an increase in the frequency and severity of extreme events such as droughts, floods, and cyclones Ribeiro and Chaúque (2010).

Climate variability directly affects agricultural production since agriculture is inherently sensitive to climatic conditions and is one of the most vulnerable sectors to the risks and impacts of global climate change. Climate change will affect food security by reducing livelihood productivity and opportunities. The impacts will be mostly negative in Mozambique (Ehrhart and Twena, 2006). Research by the Government of Mozambique suggests that mean air temperatures will raise by at least 1.8 to 3.2°C nationwide by 2075 (MICOA, 2007). Precipitation is predicted to fall by 2 to 9%, which will take greatest effect between November and May. As this coincides with the growing season, it will have an especially pronounced impact on crop yields (Ehrhart and Twena, 2006). Harvest failure and incidents of food insecurity in Africa have become regular events occurring at least once or twice every decade (Eriksen, 2005).

Most countries in Sub-Saharan Africa (SSA) rely heavily on agriculture for employment and food security for their economies. The sector also has large numbers of smallholder farmers, most of who produce under unfavourable conditions characterized by low and erratic rainfall and poor soils (Mutsvangwa, 2011).

Most households succeed in protecting their short term consumption from the full effects of income shocks, but in the long term these shocks have consequences for low income households, which are forced to reduce their investment in children's health and schooling, or sell productive assets in order to maintain consumption (Trærup, 2010). Over time, rural households develop a range of coping strategies as a buffer against uncertainties in their rural production induced by annual variations in rainfall combined with socio-economic drivers of change (Cooper et al., 2008). Coping strategies may be preventive strategies such as altering planting dates, introducing other crops and making investments of water equipment, or may be in-season adjustments in the form of management responses (Trærup, 2010). Farmers can adapt to climate change by modifying the set of crops planted and their agronomic practices (Blanc, 2011). The latter most often include consumption smoothing, the sale of assets such as livestock, remittances from family members outside the household and income from casual employment (Niimi et al., 2009; Kinsey et al., 1998).

While extensive research on the impacts of climate change has tended to focus on impacts on country level, less effort has been directed at household level in developing countries, and little has been done on the farmer risk perception and adaptation. There is thus need to investigate the farmer risk perception and adaptation to climate change on agriculture in Mozambique, at the household level, considering that agriculture remains the backbone of the country's economy. This study seeks to contribute to the body of research on climate change by investigating the vulnerability of smallholder farmers in Mozambique.

METHODOLOGY

Study sites

The study was conducted at Lichinga and Sussundenga Research Stations in Mozambique. Mozambique´s economy is essentially agricultural; its agriculture is predominantly subsistence, characterized by low levels of production and productivity. In 2009, it contributed 24% of GDP (INE). In addition, the sector employs 90% of the country's female labour force and 70% of the male labour force. This means that 80% of the active population is employed in the agriculture sector.

Lichinga Research Station is located in Lichinga district to the west of the Niassa province and lies 12° 30′ to 13° 27′ S; 34°50' to 35°30' E. The site receives unimodal rainfall between November and April ranging from 900 to 2000 mm per annum. The temperature ranges from 16.1°C to 32.9°C with an annual average of 22.9°C (MAE, 2005a). The agricultural production is predominantly rain fed (MAE, 2005a). The soils are ferralsols according to FAO (2006) soil classification system. The soils are red in colour with compacted structure (Geurts and Tembe, 1997). The soil fertility is poor with CEC of 27.80 cmol kg^{-1}, low base saturation ranging from 1.75 to 9.63 cmol kg^{-1} and soil organic matter of 6.78%. These soils are deficient in nitrogen (0.69%) but have high level of phosphorus (1750 ppm).

Sussundenga Agrarian Research Station is located in Manica province, Central Mozambique and lies 19° 20′ S; 33° 14′ E, with an altitude of 620 m. The area has a unimodal rainfall occurring between November and April with average annual rainfall of 1,155 mm (MAE, 2005b). The average minimum temperature is 9.5°C in the month of July and average maximum is 29.1ºC in the month of January (Famba, 2011), giving an annual average of 23.0°C (MAE, 2005b). The agricultural production is predominantly rain fed (MAE, 2005b). The soils consist of ferralsols, lixisols and acrisols (FAO, 2006). The soil fertility is poor with CEC of 25.80 cmol kg^{-1}, low base saturation ranging from 0.18 to 0.88 cmol kg^{-1} and soil organic matter content of 7.70%. These soils are deficient in nitrogen (0.78%) but have high phosphorus (1875 ppm) content.

Data collection procedures

A survey was conducted in Lichinga and Sussundenga districts of Mozambique and two villages were randomly sampled from each of

Table 1. Farmers' awareness of climate change over the last 10 years.

District	Rainfall		Temperature	Unusual weather conditions experienced		Noted changes	
	Changed (%)	Unchanged (%)	Changed (Hot) (%)	Drought (%)	Heavy rains (%)	Longer rain periods (%)	Shorter rain periods (%)
Lichinga	87.5	12.5	100	0	40	42.5	57.5
Sussundenga	90	10	100	45	0	0	100

N = 40 each district.

the selected Districts. The study sites are located within 20 km radius of Lichinga and Sussundenga research stations. The objective of the survey was to evaluate the farmers' risk perception and adaptation to climate change. The survey was carried out at Lichinga District from 16 to 17 February and at Sussundenga from 20 to 21 February, 2012 using questionnaire with open-ended and closed questions. The survey included face-to-face interviews of 80 farmers. Forty (40) farmers were selected in each district of which 20 came from one village. Selection of respondents was based on farmer's willingness to participate in the research. During the data collection process, the participants were told the objective of the study as well as its confidentiality. Interviews were done at farmers' homesteads. Respondents were household heads and in their absence, any member of the household was interviewed. In each district, a lead farmer was identified, contacted and met to make arrangements to meet other farmers and an interpreter was used where necessary.

The first phase of the survey was to collect data to assess the factors influencing farmers' decisions making on fertilizer use. Besides general household information, the questionnaire contained modules on agricultural productivity, types of organic and inorganic fertilizer use. Data on cropping systems, land use and maize production was also collected.

The second phase of the survey was to collect data to evaluate the farmers' risk perception and adaptation to climate change. In order to understand how farmers perceive climate risk events data on weather/climate change, weather event severity, weather event effects, indicators of change in crops operation and coping strategies was collected.

The data were analysed using the Statistical Package for Social Sciences (SPSS) version 16 (SPSS 16.0 for Windows, Release 16.0.0.2007. Chicago: SPSS Inc). Descriptive statistics, means, frequencies, percentages and cross tabulations were used to present the outcome of the research.

RESULTS AND DISCUSSION

Perception about climate change

Results in Table 1 show that 87.5% of respondents in Lichinga and 90% in Sussundenga were aware of climate variability and change. Farmers reported to have noticed significant changes in rainfall and temperature over the past ten years. The higher likelihood of insights on climate change with increasing age of the head of the household is associated with experience which lets farmers observe changes over time and compare such changes with current climatic conditions. Maddison (2006) reported farmer perception of climate change through noticing an increase in temperature and a decrease in precipitation. Similar results have been reported by Nhemachena and Hassan (2007) and Mubaya et al. (2008) who reported that majority of farmers across Southern Africa perceive warming and drying of climate and low unpredictable rainfall as indicators of climate change. Studies by McSweeney et al. (2012), Queface and Tadross (2009) and INGC (2009) indicated that in Mozambique the mean annual temperature have increased by 0.6°C and the mean annual rainfall decreased at an average rate of 2.5 mm per month between 1960 and 2006.

The results also showed that 40% of respondents in Lichinga have noticed heavy rains while 45% of respondents in Sussundenga have noticed drought in the last 10 years. 57.5 and 100% of respondents in Lichinga and Sussundenga respectively, believe that there is shift in the beginning of the rain season in both short and long rain seasons. Rains that would normally start in October and stretch up to April are now starting late in November and in most cases ending in February as indicated in Table 2. These results are supported by Usman and Reason (2004), who reported that in different parts of Southern Africa countries a significant increase in the number of heavy rainfall events have been observed and that MICOA (2007) and INGCC (2009), noted that farmers in the Central zone of Mozambique (Sussundenga) are the most likely to experience increased risk of droughts. A study by Ribeiro and Chaúque (2010) in Mozambique, revealed that farmers faced prolonged drought over the last few years causing a decrease in agricultural productivity.

The findings of this study showed that 40% of small holder farmers in the past ten years used to plant in November and but presently over 63% of farmers plant in November. This increase may be explained by the shift in the start of the rain season from October to November. These results are in agreement with those of Mary and Majule (2009) and Mortimore and Adams (2001) who found that the onset of rainfall has shifted from October to November.

Adaptation to climate change

Results in Table 3 show that coping strategies to climate

Table 2. Changes in planting dates in the last 10 years in percentage.

District	Farm operations dates changed (%)		Planting date for maize 10 years ago (%)				Planting date for maize now (%)			
	Yes	No	September	October	November	December	September	October	November	December
Lichinga	90	10	0	22.5	47.5	30	0	7.5	22.5	70
Sussundenga	75	25	5	30	40	25	2.5	12.5	62.5	22.5

N = 40 each district.

Table 3. Mitigation strategies to climate change effects.

District	Mitigation strategies (%)			Mitigations crops (%)		
	Change crop variety	Kitchen garden	Off farm job	Cassava and sweet potato	Cabbage, Onion and Tomatoes	Adopting improved maize variety
Lichinga	15	75	10	47.5	2.5	10
Sussundenga	35	32.5	32.5	65	5	17.5

N = 40 each district.

change employed by most households include change of crop variety, kitchen gardening and seeking for off farm job. With increased frequency of droughts the results showed that changing crops varieties was a strategy in which 15 and 35% of respondents in Lichinga and Sussundenga were using by growing drought tolerant crops. These results are similar to those of Mutsvangwa (2009), who indicated planting drought tolerant crops as the most common adaptive strategy among Gweru and Lupane districts in Zimbabwe. In Lichinga 47.5 and 65% in Sussundenga of the respondents were planting cassava and sweet potato. However in Lichinga 90% of respondents and 82.5% in Sussundenga reported not to be using drought tolerant maize variety. This result are similar to those of Cavane (2011), who reported that improved maize varieties, whose traits have been selected for drought tolerant, were not yet widely adopted. International Fertilizer Development Center (2012) reported that in Mozambique only five percent of smallholders use improved seed varieties. The results confirms with those reported in Zambia by Mubaya et al. (2008) that farmers do crop diversification to cope with low rainfall.

The results also indicated that 75% farmers in Lichinga and 32.5% of respondents in Sussundenga are engaged in kitchen gardening. Kitchen gardening is also intensified in both districts and this could be due to the fact that farmers take advantage of the fact that wetlands remain charged for a long time after the rains and they therefore grow crops throughout the year. This finding are consistent with studies by (Mubaya et al., 2008), which indicate kitchen gardening is a strategy adopted in Zambia and Mozambique to cope with climate change. The study indicated that farmers in Lichinga (10%) and Sussundenga (32.5%) in times of low rainfall concentrated more on off farm activities. Ziervogel and Taylor (2008) and Maddison (2007) indicated that due to low rainfall, farmers have moved towards non farming activities. The workers mentioned that off farm activities were considered to contribute significantly to the income of rural households.

The results also indicated that 47.5% farmers in Lichinga and 65% of respondents in Sussundenga are cultivating cassava and sweet potato as mitigation crop to cope with climate change effects. The study also showed the use of horticultural crops such as cabbage, onions and tomatoes as mitigations crops. Studies by Aggarwal et al. (2004); Easterling et al. (2007) and Maddison (2007), suggested that changes in temperature and precipitation call for changes in crop varieties more adapted to mitigate the effects of climate. Study done in Ghana by Acquah (2011), showed that farmers were using different crop varieties as major methods to cope with climate change. The respondents in Lichinga (10%) and Sussundenga (17.5%) reported not using improved variety such as resistant to drought due to high cost of seeds purchase. Enete and Achike (2008) and Cavane (2011) indicated that undercapitalized farmers fail to adopt the required level of agricultural technologies that will ensure profitable return.

CONCLUSION AND RECOMMENDATION

This study established that rainfall and temperature in study area has been decreasing and increasing, respectively, thus negatively affecting the production and management of crops. Different forms of changes on rainfall have been identified including shrinking of rain seasons due to late onset of rainfall period shifting from October to November or even December. A combination of strategies to adapt; such as proper timing of

agricultural operations, crop diversification, use of different crop and diversifying from farm to non–farm activities were applied.

Consequently the following recommendations have been proposed on the basis of the study:

i) Farmers should be encouraged and enabled to use crop diversification as adaptation coping strategy to guard against crop failure in times of adverse climatic conditions.
ii) All effective adaptation options that farmers have applied in the study area should be widely disseminated to others farmers.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Enhancing the shelf life of fresh-cut bitter gourd using modified atmospheric packaging

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The study of modified atmospheric packaging (MAP) of fresh-cut bitter gourd was taken to extend the shelf life. Low density polyethylene (LDPE) and polypropylene (PP) films with a thickness of 100 micron (µ) were selected due to their less permeability to O_2. The fresh-cut bitter gourd packaged under two different atmosphere (active – 3% O_2 and 5% CO_2 and passive – atmospheric air) and stored at 8±2°C. The results showed that active MAP in LDPE had a minimum reduction in the physiological loss in weight (4.2%), chlorophyll content (19.26%), ascorbic acid (15%) and minimum increase of color value 'a' (44%), titratable acidity (66%), bacteria (50%), fungi (42.4%) after 15 days of storage. The sensory evaluation of maximum overall acceptability 8.2 was recorded in active MAP in LDPE.

Key words: Modified atmospheric packaging, bitter gourd, active modified atmospheric packaging (MAP), passive modified atmospheric packaging (MAP), fresh-cut.

INTRODUCTION

Vegetables are rich sources of essential nutrients like minerals, vitamins A, C, and E, phytochemicals such as folates, glucosinolates, carotenoids, flavonoids and phenolic acids, lycopene, and dietary fibres (Fasuyi, 2006). India is the second largest producer of vegetables in the world (ranks next to China) and accounts for about15% of the world's production (Sandhya, 2010). It is estimated that around 20 to 25% of total vegetables are lost due to poor post-harvesting practices and less than 2% of the total vegetables produced in the country are commercially processed (Sandhya, 2010). The consumption of bitter gourd has increased due to awareness about medicinal properties rather than nutritious benefits.

Bitter gourd (*Momordica charantia)* is a member of Cucubitaceae family and it is one of the most popular vegetables cultivated in China, Taiwan, Pakistan, India, and Philippines for their immature fruits and sometimes for the tender leafy shoots (Yamaguchi, 1983). The immature fruits, called bitter melon, bitter gourd or balsam pear are harvested at developmental stages up to seed hardening. Bitter gourd has an important role as a source of carbohydrate, proteins, vitamins, minerals and other nutrients in human diet (Ali et al., 2008) which are necessary to maintain proper health. The beneficial health effects of bitter gourd have been attributed to the

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presence of antioxidants that act as receptors of free radicals. Ascorbic acid and β carotene are the antioxidants present in bitter gourd at high concentrations. Apart from its antioxidant property, it also has many medicinal applications and is used as an hypoglycemic agent for diabetic patients (Cefalu et al., 2008) and it is also beneficial against piles, blood and respiratory disorders and cholera.

Changes in lifestyle patterns has leads to increased demand for cut vegetables as the people do not have time to prepare vegetables at home as well as in hotels. Because of these factors, consumption of minimally processed products has significantly increased (Allende et al., 2006). As a result, the market demands for 'fresh-cut' vegetables have increased rapidly (Day, 2001). Wang et al. (2007) found that fresh-cut bitter gourd stored at 2°C had only limited storage of 4 days.

The shelf life of fresh-cut produce under ambient condition is very limited which can be extended by many preservation techniques like low temperature storage, controlled atmosphere, hypobaric and modified atmosphere packaging methods. Modified atmosphere packaging technology is one among them, which is largely used for minimally processed fruits and vegetables including fresh, ''ready-to-use'' vegetables (Sandya, 2010). Modified atmosphere packaging (MAP) of fresh produce relies on the modification of atmosphere inside the package achieved by the natural interplay between two processes: the respiration rate of the commodity and the permeability of the packaging films. Active and passive modified atmospheric packagings are the two systems generally recognized for packaging of fresh-cut produce (Kitinoja and Gorny, 1998). Passive atmosphere is the modification of the gas composition inside the package due to interplay between the product respiration rate and the gas exchange rate through the package. Active atmosphere is the modification of the gas composition inside the package by replacing, at the moment of packaging, the air with a specific gas mixture either by drawing a vacuum or filling a gas mix.

Though many vegetables are part of our dietary habit, the technology of ready to eat or ready to cook form of minimal processing is available only for few vegetables in India. Thus it is necessary to develop techniques to preserve bitter gourd. Keeping in view the above prospective, the present investigation on preservation of fresh-cut bitter gourd using modified atmosphere packaging with different packaging material has been taken to conduct studies under passive and active modified atmosphere packaging for enhancing the shelf life of fresh-cut bitter gourd.

MATERIALS AND METHODS

Raw material

Bitter gourd variety of CO 1 was purchased from the university orchard of Tamil Nadu Agricultural University, Coimbatore. Bitter gourd were harvested to developmental stage to seed hardening. After harvesting (within ½ h) the vegetables were stored at 8±2°C for 2 h before processing. Packaging materials such as Low Density Polyethylene (LDPE) and Poly propylene (PP) of 50, 75 and 100 µ thickness were procured from the local market, Coimbatore. The oxygen and carbon dioxide transmission rates were determined with the help of Manometric permeability tester (M/s. PBI Dansensor, USA).

Permeability of the packaging films

The permeability rates for oxygen and carbon dioxide were determined at a rate at which gases permeate through a film at specified conditions of temperature and relative humidity. The films used for the study should have low permeability to oxygen and carbon dioxide gases. The oxygen and carbon dioxide transmission rates were found with the help of Manometric permeability tester (M/s. PBI Dansensor, USA).

The permeability tester works on the principle of diffusion-Ficks law (Manometric pressure change via gas transmission through film). It consists of two chambers and a provision to keep the sample (film) in between the chambers. In the upper chamber, provision is made to regulate the gas pressure (for which permeability is to be determined) at the required level whereas in the bottom chamber vacuum is maintained. The instrument measures the time required for the pressure in the bottom chamber to increase to a predefined upper limit. The test sample of 10 cm (packaging film) was prepared and placed between the chambers. The gas analyser measures the gas concentration in the chamber and determines the permeability of the film and displayed digitally. The test cycle was repeated until the sample got stabilized and attained equilibrium.

Preparation of fresh-cut bitter gourd

Fresh good quality and uniformly sized bitter gourd were selected and prepared by slicing with sharp sterile stainless steel knives and sliced into 1 cm thick cubes. Fresh-cut bitter gourd were soaked in to sodium hypochlorite solution of 100 ppm dipping was used as pre-treatment for 3 min at room temperature because it acts as a surface disinfectant which reduces the microbial growth. Treated samples were shade dried for 15 min in room temperature to remove the surface moisture and approximately 100 g of slices were packaged in different packaging materials. The treated and control samples (without packaging) were stored under refrigeration condition 8±2°C.

Packaging of fresh-cut bitter gourd

Passive and active modified atmospheric packagings are the two systems used for packaging of fresh-cut bitter gourd. Passive modification (atmospheric condition – 21% O_2, 0.01% CO_2, 79% N_2) was done by placing the fresh-cut vegetables in the package film (LDPE and PP) and then it was sealed using the heat sealer. A desired atmosphere develops naturally inside the package as a consequence of respiration of products and the diffusion of gases through the film. The gas was analyzed using gas analyzer (PBI Dansensor). Active modification was done by placing the fresh-cut vegetables in to the pouch and then the air inside the pouch (LDPE and PP) were replaced by a desired mixture of gases using gas mixing unit (MAP mix 8000 EL, PBI Dansensor). The fresh-cut bitter gourds were flushed with 3% O_2, 5% CO_2 and 92% N_2.

Head space gas analysis

The selected polymeric films (LDPE and PP) were made into pouch of

size 20.5 cm length and 15.5 cm breadth. The silicon septum was pasted on the surface of the pouch for drawing the gas samples. The fresh-cut vegetables of approximately 100 g were taken in the pouch and it is sealed for passive atmosphere where as for active atmosphere, the desired mixture of gases are filled and sealed. At particular interval the gas was measured in the package using gas analyser (PBI Dansensor).

Physiological loss in weight (PLW)

Fresh-cut vegetables were weighed with the help of an electronic balance (Make: Avery; Model: OC-51) at regular intervals. The initial and final weights of the samples were recorded and the loss in weight was calculated (Mathad, 2003).

Physiological loss in weight (%) = [(Initial Weight – Final Weight) / Initial weight] × 100 (1)

Physico-chemical and microbiological characteristics of vegetables

Chlorophyll

The chlorophyll content in the fresh-cut bitter gourd at different atmosphere and at storage periods were determined by using 80% acetone (Ranganna, 1995).

Hundred milligrams of finely cut and well mixed representative sample of vegetables were taken into a clean mortar and ground into a fine pulp by adding 20 ml of 80% acetone. The pulp was centrifuged and the supernatant was collected in a 50 ml volumetric flask. The residue obtained was collected and again extracted with acetone. This procedure was repeated till the residue become colorless. The volume was made into 50 ml. The absorbance of the solution at 645 and 663 nm against the solvent (80% acetone) blank was recorded.

The amount of chlorophyll present in the extract (mg chlorophyll per 100 mg tissue) was calculated using the following equation:

Chlorophyll (mg/100 g) = [20.2 (A645) + 8.02 (A663) × V/100 × W] (2)

Where A = absorbance at specific wavelengths (nm), V = final volume of the chlorophyll extract in 80% acetone and W = fresh weight of sample (g).

Ascorbic acid content

Ascorbic acid content were determined by visual titration using 2,6-dichlorophenol- indophenol (Ranganna, 1995). One gram of vegetable was made in to pulp and extracted using 10 ml of 4% oxalic acid solution, made up to 50 ml. Then 5 ml of this made up solution was pipetted out in to a concial flask and titrated against dye. The titration was repeated for the concordant values.

Quantity of ascorbic acid (mg) present in 100 g of sample was calculated as follows.

Ascorbic acid (mg / 100 g) = [0.5/V_1 × V_2/5 ml × 50 ml/ wt of sample × 100] (3)

V_1= volume of dye occupied by the working standard (ascorbic acid); V_2= volume of dye occupied by the sample (bitter gourd).

Titratable acidity

Titratable acidity was determined by titrating a known volume of vegetable juice (by extracting the juice from 10 g of the sample using pestle and motor) with 0.1 N NaOH to an end point of permanent pale pink color using phenolphthalein as indicator. The NaOH required to neutralize the juice and the titratable acidity was calculated and expressed as % citric acid.

Titratable acidity = (N× V× Equivalent weight of acid× 100) / (Weight of the sample taken ×100) (4)

N= Normality of the NaOH; V= Volume of the NaOH required to neutralize the juice (bitter gourd).

Microbial analysis

The qualities of fresh-cut vegetables are based on the number and kind of microorganisms present, which was assessed by standard plate count method (Allen, 1953). Commonly used media for the enumeration of bacteria and fungi are nutrient agar medium and Martin's Rose Bengal Agar medium. One gram of the fresh-cut vegetable was taken and added into a test tube containing 10 ml of sterile water. The test tubes were shaken well for 10 to 15 min for uniform distribution of microbial cell in the water blank. This will give a dilution of 1:10 (10^{-1}). One ml from (10^{-1}) dilution was transferred to 9 ml of sterile water with a sterile one ml pipette, which gave a dilution of 10^{-2}. The process was repeated up to 10^{-5} dilutions with the serial transfer of the diluents. One ml aliquots from 10^{-3} and 10^{-5} dilutions were transferred to the sterile petri dishes for the enumeration of fungi and bacteria, respectively. Three replications were maintained for calculating the population as a mean of four replications.

Sensory evaluation

Sensory evaluation of the vegetables was done by the panel of semi-trained judges (10 members) for appearance, color, flavor, texture, taste and overall acceptability using 9-point Hedonic scale varying from like extremely (rated as 9) to dislike extremely (rated as 1).

Statistical analysis

All the analysis was carried out in four. Statistical analysis was carried out to study the effect of different parameters on all the dependent variables. Analysis of variance (ANOVA) was conducted with Factorial Completely Randomized block Design (FCRD) using the software AGRES version 7.01.

RESULTS AND DISCUSSION

Permeability of the packaging material

The permeability of low density polyethylene (LDPE) and polypropylene (PP) packaging materials of different thickness was assessed and is shown in the Figure 1. From the figure it was observed that, the permeability decreased with thickness of the packaging film for both O_2 and CO_2. The permeability of O_2 in the films leads to more respiration and deteriorate the quality of the product. Hence to maintain the quality of the product, the films (LDPE-100 µ, PP-100 µ) with low permeability to O_2

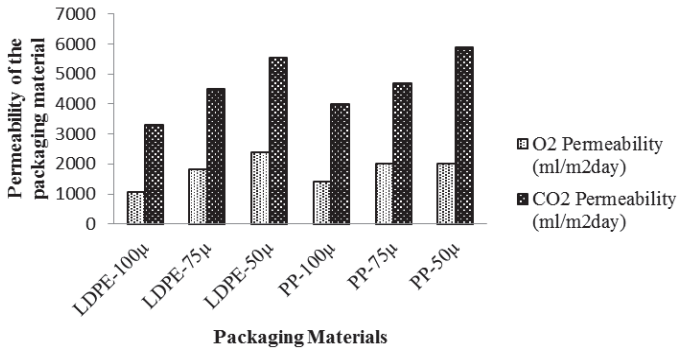

Figure 1. Permeability of the packaging film. LDPE- Low density polyethylene, PP- Poly propylene.

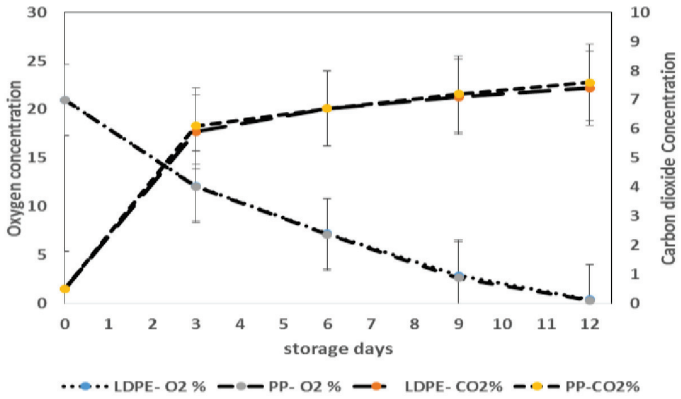

Figure 2. Head space gas analysis of fresh-cut bitter gourd in passive MAP condition. LDPE- Low density polyethylene packaged sample, PP- Poly propylene sample. O_2%- Oxygen concentration, CO_2%- Carbon dioxide concentration

and CO_2 were selected for further study. Ati and Hotchkiss, (2002) reported that LDPE and PP films with a thickness of 25 to 100 µ are most commonly used for storage of minimally processed vegetables.

Respiration rate of fresh-cut bitter gourd

During respiration, the fresh-cut bitter gourd consumes O_2 and produces CO_2 a result of metabolic activity. Meyer et al. (1973) reported that the plant materials during respiration takes oxygen and break the organic reserves to simpler molecules of CO_2 and water with release of energy. The respiration rate of pre-treated fresh-cut bitter gourd at 8±2°C was determined experimentally in a closed system.

Head space gas analysis

The effect of gas concentration on the head space of the pouches (LDPE and PP) containing fresh-cut bitter gourd stored at 8±2°C are shown in the Figure 2. The initial concentration of passive MAP were 21% O_2 and 0.01% CO_2 and at active MAP were 3% O_2, 5% CO_2 and 92% N_2.

The gas concentration of fresh-cut bitter gourd packaged under passive MAP in a LDPE pouch (Figure 2) showed the decrease of O_2 concentration from 21 to 0.423% and increase of CO_2 from 0.01 to 7.4% whereas in PP pouches, the O_2 concentration was decreasing from 21 to 0.321% and CO_2 production was increasing from 0.01 to 7.6% till the 12th day of storage. The PP film showed more concentration of O_2 (0.321%) and CO_2 (7.6%) than LDPE owing to higher permeability to the gases. In active MAP, the fresh-cut bitter gourd stored in LDPE pouch showed the decrease of O_2 from 3 to 0% (Figure 2) and increase of CO_2 from 5 to 13.5% whereas in PP pouches the decrease of O_2 from 3 to 0% and increase of CO_2 from 5 to 13.8%.

After 12 days of storage in passive MAP and 15 days of storage in active MAP, it started producing off-odor. This may be due to low O_2 content which would have facilitated anaerobic condition. Low oxygen concentrations, in combination with temperature fluctuations, have been reported to result in the production of off-flavour (Forney and Jordan, 1999). Mannapperuma et al. (1989) reported that 3 to 4% of O_2 and 4 to 5% of CO_2 were more suitable for maintaining the quality and extending shelf life of fresh-cut produces at refrigerated condition.

The shelf life of fresh-cut bitter gourd extended up to 15 days when it was stored under active MAP whereas in passive MAP it was only 12 days. The increase in shelf life was due to the lesser respiration rate at lower concentration of O_2. Fonseca et al. (2002) also reported the increase of shelf life in shredded galega kale under active MAP.

Physiological loss in weight for MAP of fresh-cut bitter gourd

The effects of storage period on physiological loss in weight of fresh-cut bitter gourd stored in MAP conditions are shown in the Table 1. There was a significant effect of treatment (packaging material × active and passive MAP) at $p \leq 0.01$ on physiological loss in weight. The respiration and the transpiration of water from the product attributed to PLW of the samples (Wills et al., 1989).

The maximum loss of about 5% was found in control sample after 4 days. This may be due to less humidity in atmospheric air. The minimum loss in weight with maximum storage of 15 days was observed as 4.2% in LDPE pouches under active MAP. This may be due to less respiration rate at lower temperature and more humidity inside the package which would have resulted in minimum loss in weight. In passive atmosphere, loss in

Table 1. Effect of storage period on physiological loss in weight of fresh cut bitter gourd stored in MAP condition.

Treatments	Physiological loss in weight (%)				
	8±2°C (Storage days)				
	0	4	8	12	15
Control (T1)	0	5.0^{e}	*	*	*
Passive atmosphere -LDPE (T2)	0	2.7^{c}	3.8^{c}	4.7^{c}	*
Passive atmosphere -PP (T3)	0	3.5^{d}	4.4^{d}	5.4^{d}	*
Active atmosphere -LDPE (T4)	0	1.5^{a}	2.4^{a}	3.2^{a}	4.2^{a}
Active atmosphere - PP(T5)	0	2.0^{b}	3.1^{b}	4.1^{b}	5.3^{b}

Means are the average of 3 determinations, and means in a column followed by same letter are not significantly different at $p \leq 0.05$ among treatments. * indicates sample got spoiled.

Table 2. Effect of storage period on chlorophyll content of fresh cut bitter gourd stored in MAP condition.

Treatments	Chlorophyll Content (mg/100 g)				
	8±2°C (Storage days)				
	0	4	8	12	15
Control (T1)	19.56	12.3^{e}	*	*	*
Passive atmosphere -LDPE (T2)	19.56	16.3^{c}	15.2^{c}	13.8^{c}	*
Passive atmosphere -PP (T3)	19.56	14.2^{d}	12.1^{d}	11.0^{d}	*
Active atmosphere -LDPE (T4)	19.56	19.0^{a}	18.6^{a}	17.2^{a}	16.4^{a}
Active atmosphere - PP(T5)	19.56	17.4^{b}	16.7^{b}	15.5^{b}	14.6^{b}

Means are the average of 3 determinations, and means in a column followed by same letter are not significantly different at $p \leq 0.05$ among treatments. * indicates sample got spoiled.

weight was 3.2% in LDPE pouches which can be stored up to 12 days. The LDPE showed 4.2 % (T4) loss in weight at 8±2°C under active atmosphere in 15 days which was found to be less than PP pouch with 5.3%. This may be due to less permeability of LDPE to the water vapor transmission. Kudachikar et al. (2011) reported that for robusta banana packaged in LDPE pouches showed lesser PLW due to low water vapor transmission rate. By comparing both active and passive MAP it was concluded that minimum weight loss (4.2%) was in active MAP of LDPE pouches with maximum storage period.

Physico-chemical characteristics for MAP of fresh-cut bitter gourd

The physico-chemical analysis of fresh-cut bitter gourd was carried out for color, chlorophyll, ascorbic acid, titratable acidity, bacterial and fungal growth.

Changes in chlorophyll content of MAP fresh-cut bitter gourd

The effect of storage period on chlorophyll content of fresh-cut bitter gourd stored in MAP condition are shown in the Table 2. There was significant effect of treatment (packaging material × active and passive MAP) at ($p \leq 0.01$) on the chlorophyll content. The initial chlorophyll content of the fresh-cut bitter gourd was 19.56 mg/100 g. The control sample (T1) had maximum loss of chlorophyll content (12.3 mg/100 g) in 4 days of storage. The chlorophyll content decreased with increase of storage period. Roura et al. (2000) reported that processing induced the decrease of chlorophyll content during storage in swiss chard leaves.

Minimum loss of chlorophyll was observed in T4 (16.4 mg/100g) under 8±2°C in 15 days of storage. The active MAP showed less loss of chlorophyll content in LDPE (17.2 mg/100 g) and PP pouches (15.5 mg/100 g) at 8±2°C compared to passive MAP for both LDPE (13.8 mg/100 g) and PP (11.0 mg/100 g) in 12 days of storage. Zagory and Kader (1988) reported that low O_2 concentration reduced the breakdown of chlorophyll to phaeophytin. The loss of chlorophyll content in fresh-cut bitter gourd was 19.2%. Similar trend of result was also reported by Wang et al. (2007) for the fresh-cut bitter gourd with a loss of 20% chlorophyll content in 7 days of storage under 8±2°C. The reduction in the loss of chlorophyll content in the present study may be due to the variation in the variety of the bitter gourd selected.

Table 3. Effect of storage period on ascorbic acid of fresh cut bitter gourd stored in MAP condition.

Treatments	Ascorbic acid (mg/100 g)				
	8±2°C (Storage days)				
	0	4	8	12	15
Control (T1)	77.17	59.4^{e}	*	*	*
Passive atmosphere -LDPE (T2)	77.17	65.7^{c}	63.2^{bc}	60.4^{c}	*
Passive atmosphere -PP (T3)	77.17	63.3^{d}	60.6^{d}	58.2^{cd}	*
Active atmosphere -LDPE (T4)	77.17	69.32^{a}	68.2^{a}	67.10^{a}	65.8^{a}
Active atmosphere - PP(T5)	77.17	67.1^{b}	65.4^{ab}	63.24^{b}	60.5^{b}

Means are the average of 3 determinations, and means in a column followed by same letter are not significantly different at $p \leq 0.05$ among treatments. * indicates sample got spoiled.

Table 4. Effect of storage period on titratable acidity of fresh cut bitter gourd stored in MAP condition.

Treatments	Titrable acidity (%)				
	8±2°C (Storage days)				
	0	4	8	12	15
Control (T1)	0. 68	1.6^{e}	*	*	*
Passive atmosphere -LDPE (T2)	0. 68	0.98^{c}	2^{c}	2.9^{b}	*
Passive atmosphere -PP (T3)	0. 68	1.2^{d}	2.6^{d}	3.6^{c}	*
Active atmosphere -LDPE (T4)	0. 68	0.74^{a}	0.93^{a}	1.4^{a}	2^{a}
Active atmosphere - PP(T5)	0. 68	0.82^{b}	1.8^{b}	2.8^{ab}	3.2^{b}

Means are the average of 4 determinations, and means in a column followed by same letter are not significantly different at $p \leq 0.05$ among treatments. * indicates sample got spoiled.

Changes in ascorbic acid for MAP of fresh-cut bitter gourd

The effect of storage period on ascorbic acid content of fresh-cut bitter gourd stored in MAP condition is presented in the Table 3. There was significant effect of treatment of fresh-cut bitter gourd (packaging material × active and passive MAP) at $p \leq 0.01$ on the ascorbic acid content. The initial ascorbic acid content of fresh-cut bitter gourd was 77.17 mg/100 g. The minimum loss of ascorbic acid was seen in T4 (54.4 mg/100 g) in 15 days of storage compared to other treatment and the maximum loss was observed in control (57.4 mg/100 g) after 4 days of storage. In 8±2°C, the shelf life of fresh-cut bitter gourd was 15 days under active MAP and it was only 12 days under passive condition. The active MAP showed a minimum loss of 17.2% in 15 days of storage whereas in passive condition, the loss was 15% in 12 days. The reduction in loss of ascorbic acid in active MAP over the passive system may be due to low O_2 content that would have prevented the oxidation of ascorbic acid to dehydro-ascorbic acid. Peterson and Berends, (1993) reported that for sweet green peppers, the low O_2 content in the package retarded the dehydro-ascorbic acid during storage.

The ascorbic acid content of fresh-cut bitter gourd under MAP decreased with storage period. This result is in agreement with Wang et al. (2007) for minimally processed bitter gourd where there was a decrease in ascorbic acid content (58%) over storage under 8±2°C.

Changes in Titratable acidity for MAP of fresh-cut bitter gourd

The effects of storage period on titratable acidity of fresh-cut bitter gourd stored in MAP condition are shown in the Table 4. It was observed that the treatments (packaging material × active and passive MAP) had significant effect on the titratable acidity at $p \leq 0.01$. The initial titratable acidity of fresh-cut bitter gourd was 0.68 mg/100 g. The titratable acidity increased with storage period. Wang et al. (2007) also reported that cutting of bitter gourd lead to the accumulation of titratable acidity. The minimum increase of titratable acidity was observed in T4 (2.0%) in 15 days of storage under 8±2°C compared to other treatments and maximum increase was seen in T1 (3.2%) after 4 days of storage.

Increase in acidity will lead to sour taste of bitter gourd. The titratable acidity of fresh-cut bitter gourd in LDPE and PP pouches increased under passive MAP by 11.7 and 16. 1% respectively at the end of 12 days of storage

Table 5. Effect of storage period on bacterial growth of fresh cut bitter gourd stored in MAP condition.

Treatments	Bacteria (10^5 cfu/g)				
	8±2°C (Storage days)				
	1	4	8	12	15
Control (T1)	3.12	5.6[e]	*	*	*
Passive atmosphere -LDPE (T2)	3.12	4.4[c]	5.3[c]	6.8[c]	*
Passive atmosphere -PP (T3)	3.12	4.8[d]	6.2[d]	7.6[d]	*
Active atmosphere -LDPE (T4)	3.12	3.4[a]	4.2[a]	5.4[a]	6.3[a]
Active atmosphere - PP(T5)	3.12	3.9[b]	4.8[b]	6[b]	7.1[b]

Means are the average of 4 determinations, and means in a column followed by same letter are not significantly different at $p \leq 0.05$ among treatments. * indicates sample got spoiled.

Table 6. Effect of storage period on fungal growth of fresh cut bitter gourd stored in MAP condition.

Treatments	Fungi (10^3 cfu/g)				
	8±2°C (Storage days)				
	1	4	8	12	15
Control (T1)	4.2	7.4[e]	*	*	*
Passive atmosphere -LDPE (T2)	4.2	6.2[c]	7.5[c]	7.9[c]	*
Passive atmosphere -PP (T3)	4.2	6.9[d]	8.2[d]	8.6[d]	*
Active atmosphere -LDPE (T4)	4.2	4.8[a]	5.6[a]	6.4[a]	7.3[a]
Active atmosphere - PP(T5)	4.2	5.6[b]	6.7[b]	7.3[b]	8.1[b]

Means are the average of 4 determinations, and means in a column followed by same letter are not significantly different at $p \leq 0.05$ among treatments. * indicates sample got spoiled.

whereas in active MAP, the increase were 66% (LDPE) and 78.7% (PP) at end of 15th day.

From the results, it was concluded that the samples stored under 8±2°C in LDPE with active MAP was the best with respect to minimum increase (66% in T4) of titratable acidity. Piga et al. (2003) also reported increase of titratable acidity (59%) during the storage of fresh-cut bitter gourd under 8±2°C (10°C) for 7 days. The variation in the increase of titratable acidity reported may be due to different variety that was used for the study.

Microbial growth in MAP fresh-cut bitter gourd on storage

The effect of storage period on microbial growth for MAP of fresh-cut bitter gourd is shown in Tables 5 and 6. There was significant effect on treatment (packaging material × active and passive MAP) of fresh-cut bitter gourd at ($p \leq 0.01$) on the bacterial and fungal growth. The initial load of bacteria and fungi seen in fresh-cut bitter gourd after pre-treatment was 3.12×10^5 cfu/g and 4.2×10^3 cfu/g respectively. Nguyen and Carlin (1994) also reported that bacterial (10^3-10^6 cfu/g) and fungi counts (10^3-10^4 cfu/g) were seen in fresh-cut vegetables. It was evident from the figure that the bacteria and fungi count were maximum in control sample for fresh-cut bitter gourd. This may be due to cross contamination of product from the atmospheric air and the higher temperature would have facilitated the growth of micro-organism.

The less bacterial (6.3×10^5cfu/g) and fungi count (7.3×10^3cfu/g) were found in T4 (LDPE packaged sample) under active atmosphere at 8±2°C. Corbo et al. (2004) reported that for cactus pear fruit, lower storage temperature significantly reduced the microbial growth. Active atmosphere showed lesser bacterial and fungal growth than passive atmosphere. Oliu et al. (2008) reported that in fresh-cut melon, the microbial growth was less in active atmosphere than passive. In the present study, the shelf life was 15 days in active MAP whereas in passive condition it was only 12 days. Atmospheres with low O_2 (1 to 5%) and high CO_2 (5 to 10%) have shown the maximum shelf-life of fresh-cut fruits (Gorny et al., 2002).

Sensory evaluation for MAP of fresh-cut bitter gourd

The shelf life of the product is mainly depending on the microbial and sensory quality. Based on the results obtained for the microbial analysis, it was observed that the samples (T2, T3, T4 and T5) were within the safe microbial limit and hence the samples were taken for conducting the sensory evaluation. The dishes were

Table 7. Sensory evaluation of fresh-cut bitter gourd stored under MAP condition.

Treatments	Appearance	Color	Texture	Flavour	Taste	Overall acceptability
Fresh Sample	8.2	8.4^{a}	8.2^{a}	8.3^{a}	8.1^{a}	8.21^{a}
Active MAP- LDPE (T2)	8.1	8.1^{b}	7.6^{b}	8^{a}	7.6^{ab}	7.88^{ab}
Active MAP- PP (T3)	7.8	7.7^{bc}	7.2^{bc}	7.4^{b}	7.2^{bc}	7.46^{bc}
Passive MAP-LDPE (T4)	7.6	7.5^{dc}	6.8^{c}	7^{b}	6.8^{cd}	7.14^{cd}
Passive MAP-PP (T5)	7.1	7.1^{d}	6.2^{d}	6.4^{c}	6.4^{d}	6.64^{d}

Means are the average of 4 determinations, and means in a column followed by same letter are not significantly different at $p \leq 0.05$ among treatments. * indicates sample got spoiled.

prepared from the selected samples after keeping them for a maximum period of storage and sensory evaluation was done using a 9-point hedonic scale and the results of the study are presented in the Table 7.

From the Table 7, it was observed that, the fresh sample scored overall acceptability of 8.2. Among the samples, active MAP of fresh-cut bitter gourd packaged in LDPE (T7-7.88) was the best followed by T3, T4, and T5. The active MAP extended the product shelf life by lowering the O_2 concentration and retained the color and texture. Gomez and Arte (2005) also reported that MAP packaged cerely sticks scored maximum in sensory attributes. There was significant effect on treatment (packaging material × active and passive MAP) of fresh-cut bitter gourd at $p \leq 0.01$ on sensory evaluation.

The fresh-cut bitter gourd packaged in LDPE film extended the shelf life up to 15 days whereas in PP film it was 12 days by storing it at low temperature (8±2^{e}C) with minimum change in its quality by modified atmospheric packaging.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Evaluation of different seed dormancy breaking techniques on okra (*Abelmoschus esculentus* L.) seed germination

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Okra (*Abelmoschus esculentus* L.) is one of the horticultural crops commonly grown in Zimbabwe but the productivity of the crop is hampered by poor erratic seed germination due to dormancy. A study was carried out at Bindura University of Science Education to determine the best method and treatment combination of breaking okra seed dormancy. Viability tests and germination tests were conducted first to ascertain that failure of germination was due to dormancy. The study consisted of 3 laboratory experiments arranged as factorial treatment structure laid in a completely randomised design with 3 replications. The 3 experiments consisted of 3 methods of breaking seed dormancy (water soaking, acid scarification and dry heating). Each of the different methods was employed at different exposure duration and at different temperature/concentration levels. Germination was measured for 14 days to determine the total final percentage seed germination. Acid scarified seeds for 3 min at 80% H_2SO_4 concentration level had the best germination percentage of 96.6% followed by dry heating for 5 minutes at 70°C and soaking for 12 h at 30°C which had 92.2 and 91.3% germination respectively. However, H_2SO_4 scarification for 5 min at 60% concentration gave the least germination of 44% followed by soaking for 48 h at 30°C and dry heating for 5 min at 80°C which all resulted in 50% germination. Based on the research findings, 80% H_2SO_4 for 3 min can be used by okra farmers to break dormancy while dry heating for 5 min at 70°C and soaking for 12 h at 30°C are equally good alternatives.

Key words: Dormancy, germination, okra, scarification.

INTRODUCTION

Okra (*Abelmoschus esculentus* L. Moench) of the family Malvaceae is a vegetable crop that has achieved tremendous popularity over the last century (Modi et al., 2006). It is grown practically in every country of the world

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and being an important horticultural crop in Zimbabwe, it is grown in the fields, greenhouses and back yard gardens. The crop is tolerant to Zimbabwean mid-season dry spells and its association with the local food in the different regions of the country is creating a great stable demand for it. It can be consumed after cooking as green pods and it is also used after dehydration (dried) and the whole pod is eaten. According to Baskin et al. (2001), aside from being tasty, okra is a very good source of vitamin A and C which are important for bone growth, cell division, and differentiation and are also important in formation of collagen, a protein that gives structures to bones, cartilage, muscles and blood vessels respectively.

Okra plants are mainly propagated by seed. Keller and Kollmann (1999) reported that germination is a critical stage in the life cycle of weeds and crop plants and often controls population dynamics with major practical implications. However, hard seed coats in okra may cause slow and erratic germination and emergence which is exacerbated at sub-optimal conditions (Demir, 2001). Poor and delayed seed germination due to dormancy is one of the major challenges in the propagation of this crop. According to Mohammadi et al. (2012), okra crop exhibits seed hardness that complicates its management, and this seed hardness interferes with seed germination, weed control, harvesting and other management factors. The percentage of seed germination of okra is relatively low, due to occurrence of seed hardness in this plant (Luis-Felipe et al., 2010).

Early germination and plant establishment on the field is essential for timely harvesting and marketing of the vegetable (Denton et al., 2013). Several methods, including heat treatment, chemical (acid) and mechanical scarification can be used to open the seed coat (Mavengahama and Lewu, 2012). Various pre-treatments, such as chemical and physical treatments were tried and reported that only scarification at the radicle end improved the germination of seeds (Ochuodho et al., 2004). Demir (2001) also reported that mechanical scarification is tedious and time-consuming while heat treatments have greater potential for commercial application and have been found to be effective in improving both germination rate and capacity of okra.

A. esculentus growers in Zimbabwe both communal and commercial farmers continuously face challenges from the poor and erratic seed germination of this cultivar, where some of the seed germinate and the other remained in the soil for weeks and sometimes months. This lack of uniformity in germination in most cases forced the farmers to re-sow. Since physical dormancy in okra results in poor germination, crop stand is in turn affected, yield is also affected hence productivity is reduced which leads into losses. The present study was therefore undertaken with the main objective of determining the best method of breaking okra seed dormancy which can be utilised by both smallholder and commercial farmers.

MATERIALS AND METHODS

Study site

The experiment was carried out in 2012 at Bindura University, Astra Campus, in the Biology Laboratory (altitude 1100 m a.s.l.; latitude 17°8'S and 31°19'E), located about 88 km north-east of Harare. The site lies in Natural Region IIa of Zimbabwe's Agro-ecological Zones, characterized by mean annual rainfall of 750 to 1000 mm and mean annual temperature of between 15 and 20°C.

Experimental design and procedure

The study consisted of 3 laboratory experiments, arranged as factorial treatment structure laid out in a completely randomised design (CRD). Each of the treatments of the 3 experiments was replicated thrice.

Seed viability and dormancy tests

Prior to the 3 experiments, a tetrazolium test was conducted to estimate seed viability of all accessions before proceeding with dormancy-breaking treatments. Thirty seeds from the sample were preconditioned by soaking in distilled water at 28°C for 3 h and dissected longitudinally and medially through the embryo. The seeds were then soaked in 1% tetrazolium solution for 1 h at 40°C in the dark, and then washed several times with distilled water to remove excess solution. Seeds were considered viable when the embryo was completely stained, or when the only extremities of the scutellum and/or the tip of the radicle remained unstained. Seed viability was determined at 90%. Seed dormancy was determined by germination of intact seeds in 9 cm Petri dishes lined with filter paper and with distilled water, in an incubator at a temperature of 30°C. The germination of seeds was monitored daily over a period of 14 days. Germination was scored as the emergence of the radicle that reached 2 mm. The seeds were considered to be strongly dormant since 18 seeds out of 30 seeds germinated so the determined germination rate was 60%.

The okra seeds used in the experiments were obtained from local farmers which were harvested between November 2011 and February 2012. The seeds were field dried and kept at room temperature. The acquired seeds were kept in the laboratory for 7 days in the open for them to equilibrate at room temperature of about 28°C and 60 to 80% relative humidity. Seeds were assessed for quality by taking note of the seed size, colour, physical damage and physiological maturity. Seeds which were not damaged physically, of the same size and looked healthy were selected and from this group a working sample was taken.

Experiment 1 (Water soaking)

The first experiment evaluated the effect of soaking on breaking okra seed dormancy. It had 2 factors namely water temperature and soaking duration. Temperature factor had 4 levels (15, 20, 25 and 30°C) whilst soaking duration factor had 3 levels (12, 24 and 48 h) hence a 3×4 factorial arrangement. For each treatment combination, 90 seeds were soaked in 100 ml beakers with water at a constant appropriate temperature for different durations; these were placed in the water bath at which the temperatures were controlled. The dishes were being kept in darkness. After the required time seeds were removed from water then surface dried. Seeds were sun dried for 5 h then stored.

Experiment 2 (Acid scarification)

The second experiment evaluated the effect of sulphuric acid

(H_2SO_4) scarification on breaking okra seed dormancy. It had 2 factors namely acid concentration and exposure duration. H_2SO_4 concentration had 3 levels (60, 70 and 80%) while exposure duration had 3 levels as well (3, 5 and 8 min) hence a 3×3 factorial arrangement. For each treatment combination, 90 seeds were placed in beakers and the different concentrations of the acid were added to them. A stop watch was used to measure the time to which these were exposed to the H_2SO_4. After exposure the seeds were removed from the acid just before any acid penetrated the seed coats. When the allocated time was finished, the seeds were removed promptly and washed thoroughly in several changes of water to neutralize completely all remaining acid. After treatment and a thorough washing, the seeds were dried and stored awaiting germination tests.

Experiment 3 (Dry heating)

The third experiment evaluated the effect of dry heating on breaking okra seed dormancy. It had 2 factors namely temperature and exposure duration. Temperatures had 3 levels (60, 70 and 80°C) while exposure duration had 3 levels as well (3, 5 and 8 min) hence a 3×3 factorial arrangement. Dry heat was used, and the temperatures required were more suitable to an oven. For this seed coat treatment the seeds were placed in shallow containers in a preheated incubator oven. After the treatment, the seeds were cooled immediately and then stored. In this experiment the seeds were exposed to varied temperatures at different times in which a stop watch was used to measure the time.

Germination tests

Seeds from the three different methods of breaking dormancy were taken and subjected to germination tests to determine whether the treatments would improve germination percentage. The intact seeds were germinated by putting them in 9 cm Petri dishes lined with filter papers. Distilled water was added to moisten the filter paper and placed in an incubator at a temperature of 30°C. The germination of seeds was monitored daily over a period of 14 days. Germination was scored as the emergence of the radicle that reached 2 mm. Each germinated seed was removed from the dishes in order to avoid mix-up in counting.

Data collection and analysis

Preceding recording of germinated seeds was done on daily bases and the data of the replicates was recorded on different columns for analysis. The final numbers of germinated seeds were collected as germination percentages. The data was subjected to an analysis of variance using GenStat statistical package at 5% significance level.

RESULTS

There were significant differences ($p<0.05$) in the percentage of germinated okra seeds among the different treatment combinations in all the 3 experiments. Significant variations ($p=0.048$) were observed on the first experiment; soaking okra seeds in water for 12 h at 30°C resulted in highest seed germination of 91.3% followed by soaking the seeds for 12 h at 25°C which had 75.22%. On the other hand, soaking the seeds in water for 48 h at 30°C gave the least seed germination of 50% (Table 1).

On the second experiment, significant variations ($p=0.037$) in seed germination were noted among the different treatment combinations when chemical scarification using H_2SO_4 was employed to break okra seed dormancy at different concentrations for different exposure durations. Highest percentage okra seed germination (96.6%) was observed when 80% H_2SO_4 concentration was used for 3 minutes followed by exposing the seeds for 5 minutes in 80% H_2SO_4 which gave 75.6% seed germination. Least seed germination was recorded when 60% H_2SO_4 was exposed to the seeds for 5 min (Table 1).

Significant differences ($p=0.028$) in percentage of germinated okra seeds was also noted when dry heating was used to break okra seed dormancy at different temperatures and different exposure times. Highest seed germination (92.2%) was observed when dry heating was used at 70°C for 5 min while least germination (44.4%) was recorded when the seeds were dry heated for 5 min at 80°C (Table 1).

DISCUSSION

In the water soaking method (Experiment 1), soaking okra seeds in warm water at 30°C for 12 h was the most effective treatment combination for enhancing germination of *A. esculentus*, with germination of 91.33%, thus 31.33% better than the baseline germination of 60%. Higher soaking time at the same duration resulted in a dramatic reduction in germination. This is consistent with Naidu et al. (1999) who reported that a temperature of 30°C was most suitable for germination since most of the enzymes in okra are activated and are at optimum under temperature conditions of between 28 and 30°C. These findings are similar to Ekpong (2009) where soaking *Cleome* seeds for 12 h gave best germination as compared to 24, 36 and 48 h. The soaking for 12 h treatment seems to have promoted the leaching of germination inhibitors on the tastae of okra seeds (Xia and Kermode, 2002). However, soaking the okra seed for longer period (48 h) tended to decrease germination. This may be attributed to water trapped in tissue between the embryo and seed coat creating an oxygen barrier (Reisman-Berman et al., 1989). Moreover, Norton (1986) concluded that anoxia caused by prolonged soaking of seeds may result in irreversible injury due to accumulation of toxic metabolites hence poor germination.

In the H_2SO_4 soaking method (Experiment 2), soaking the seeds in 80% H_2SO_4 for 3 min resulted in highest percentage germination. These findings are similar to those by Pahla et al. (2014) who observed that H_2SO_4 promoted highest germination in *Acacia angustissima*. Germination increased with the duration of exposure to H_2SO_4. As also the case with hot water treatments, it seems the length of time that seeds need to be soaked in H_2SO_4 depends on the hardness of the seed (Velempini

Table 1. Effect of different methods of breaking seed dormancy on okra seed germination.

Experiment 1		Experiment 2		Experiment 3	
H_2O soaking	Germination %	H_2SO_4 scarification	Germination %	Dry heating	Germination %
12 h*15°C	62.22^{cde}	3 min*60%	53.30^{ab}	3 min*60ºC	55.60^{b}
12 h*20°C	72.78^{f}	3 min*70%	56.70^{abc}	3 min*70ºC	55.60^{b}
12 h*25°C	75.22^{f}	3 min*80%	96.60^{f}	3 min*80ºC	70.00^{c}
12 h*30°C	91.33^{g}	5 min*60%	50.00^{a}	5 min*60ºC	50.00^{a}
24 h*15°C	68.89^{ef}	5 min*70%	61.10^{cd}	5 min*70ºC	92.20^{d}
24 h*20°C	70.00^{f}	5 min*80%	75.60^{e}	5 min*80ºC	44.40^{a}
24 h*25°C	67.78^{def}	8 min*60%	57.80^{bcd}	8 min*60ºC	50.00^{a}
24 h*30°C	58.89^{bc}	8 min*70%	64.80^{d}	8 min*70ºC	51.10^{a}
48 h*15°C	57.78^{abc}	8 min*80%	64.80^{d}	8 min*80ºC	56.60^{b}
48 h*20°C	60.00^{bcd}	---	---	---	---
48 h*25°C	52.56^{ab}	---	---	---	---
48 h*30°C	50.00^{a}	---	---	---	---
SED	2.569	***SED***	8.14	***SED***	5.13
p-value	0.048	***p-value***	0.037	***p-value***	0.028
LSD	7.928	***LSD***	7.26	***LSD***	10.87
CV%	14.3	***CV%***	11.2	***CV%***	4.2

Means with the same superscript in the same column are not different. Means with different superscripts in the same column are different.

et al., 2003). The effectiveness of H_2SO_4 concentration of 80% could be attributed to successful removal of several lignified layers in the testae, which are packed tightly together and contain water repelling compounds (Baskin, 2003). These layers act as a mechanical (physical) barrier to water absorption and gaseous exchange (Colling, 2009). This improved the germination capacity of the seeds and the time of 3 min, probably, made sure that no other seed structure was damaged by over exposure. Scarification using acid may also enhance germination capacity by increasing the leaching of growth inhibitors from the seed. Baskin (1998) noted that the whole idea behind treating the seeds is to either completely remove the germination impeding seed coat or to reduce its thickness so that the seed could emerge. Removal or reduction in thickness of the seed coat allows the seed to take up water and respiratory gases thus the germination process can be initiated. It is highly probable that treating seeds with H_2SO_4 reduced the thickness of the seed coat compared to the other scarification techniques. Exposing the seeds to concentrated levels of H_2SO_4 can also have a negative effect as it can end up damaging the seed, when the acid can penetrate into the seed via its exposed micropyle (Ells, 1963). This could possibly explain why seeds that were exposed to 80% H_2SO_4 for a longer period of 8 min recorded a lower emergence rate as compared to those exposed for 3 min in the same concentration.

In the dry heating treatment (experiment 3), dry heating for 5 min at 70°C was the most successful since it had mean germination of 92% and significantly different from other means. This shows an increase in the germination from the baseline germination rate of 60% that was found in the control experiment of the research. Dry heat is a form of thermal scarification that causes the rupturing of the seed coat (Serrato-Valenti et al., 1999; Budy et al., 1986). This could have caused the seeds to imbibe water and hence higher germination percentage. It is likely that heat treatment induced disruption of the palisade cells in the chalazal region and that water was absorbed through these cracks, as recorded for some other hard-seeded species (Egley, 1987). These results are similar to the findings of Demir (2001) who observed that heat treatment improved okra seed germination. Exposure for 3 minutes reduced okra seed germination in this experiment. It could be that the okra seeds exposed to dry heat took longer to heat up to the target temperatures than they could have if they were placed in hot water, and there was probably some heat loss when the oven door was opened. Higher temperatures of 80°C also, rather than cause the seed coat to crack, dehydrated the seeds too much, which in turn affected enzyme activation leading to the decline in germination. Baskin (2000) found that dry-heat treatment decreased germination of dormant pearl millet seeds. However, dry heat has been successful in breaking dormancy in some other species.

Conclusion

Okra seed is dormant. Acid scarification of okra seed for 3 min in 80% H_2SO_4 is the most effective treatment

combination of breaking dormancy and enhancing germination since it had the highest germination rate of 96.6% of the three treatment combinations selected from each method. Soaking okra seed in water for 12 h at 30°C and dry heating for 5 min at 70°C also promotes high germination rates but germination is delayed to a period of 12 days. Acid scarification and dry heating are effective methods of breaking okra seed dormancy which can be utilised by smallholder farmers.

Conflict of Interest

The authors have not declared any conflict of interest.

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