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Full Length Research Paper

Physico-chemical characterization and kinetics of drying of organic yellow bell pepper (*Capsicum annuum* L.)

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The bell pepper has many qualities, but it has a high water content, favoring the occurrence of deteriorating reactions and the growth of microorganisms; however, it is possible to use drying as a conservation method. The objective of this study is to perform the kinetics of organic yellow bell pepper drying at different drying air temperatures, to adjust the data obtained to the empirical models and to evaluate the effect of the applied temperatures on its physicochemical characteristics. The fruits were subjected to drying under the temperatures of 50, 60, 70 and 80°C. In order to understand the drying process, kinetics and modeling were applied using Henderson and Pabis, Lewis, Page, Peleg, Silva et al. and Wang and Singh models. The physical-chemical characterization was performed in the *in natura* samples and after drying. The Page model was the one that best described the drying kinetics at all applied temperatures. The effectiveness of the drying process in the reduction of water activity and in the increase of the ash concentration in all treatments was verified. The samples dried at 50°C presented the highest values for protein content, vitamin C and phenolic compounds.

Key words: Conservation, dehydration, organic vegetables, quality.

INTRODUCTION

The cultivation of organic vegetables has prospered all over the world, because this system of production provides benefits to the producer, consumer and the environment. Organic fertilization expands productivity, minimizes the occurrence of corrosive processes in the soil, allows greater aggregation of particles, provides more nutrients and allows the increase of water and phosphorus contents, resulting in obtaining a product of high quality and nutrient-rich (Sediyama et al., 2014; Celestrino et al., 2017; Salles et al., 2017).

The bell pepper (*Capsicum annuum* L.), belonging to the family Solanaceae originated in Central America and was one of the first seasonings used to provide foods with more attractive color, aroma and flavor. In the sixteenth century an expansion of its cultivation became popular in practically all the continents (Hachmann et al., 2017). In Brazil, the pepper has high economic value, standing out as one of the ten vegetables most consumed in the national territory. The existing cultivars have different shapes, sizes and colors that are correlated to the maturation stage (Lahbib et al., 2017). The green peppers are characterized by being harvested before reaching full maturity, presenting slight bitterness. The yellow and orange chilies have intermediate maturation, whereas the red chilies are harvested at full maturity, presenting sweet taste (Trecha et al., 2017).

The peppers are part of the gastronomy of several countries, and can be consumed *in natura*, in the preparation of salads or used industrially as raw material in the production of sauces, condiments, colorings or concentrated aromas (Bogusz Júnior et al., 2015). Besides the aroma, pungency and attractive color, the pepper pericarp has several nutrients that are beneficial to human health, such as calcium, phosphorus, iron, B vitamins, carotenoids and flavonoids that are substances associated with the prevention of diseases such as cancer (Lahbib et al., 2017; Trecha et al., 2017).

In spite of the innumerable qualities previously reported, the *in natura* pepper has a high water content, which is one of the parameters responsible for the occurrence of deteriorating reactions and the development of microorganisms, resulting in a short shelf life. However, the viability of using the drying process as a conservation method, which consists in the removal of water from the product and aims to reduce losses related to the post-harvest stages, development of a product with higher added value and reducing weight and volume, implying less need for spaces for transportation, storage, and reduction in packaging costs (Alves and Nicoleti, 2016). The drying process entails in the product variations that are observed in the texture, taste, aroma, color and reduction of the nutritional quality. Substances are degraded by light, oxygen and high temperatures. Carrying out studies on drying processes and systems, through mathematical modeling, enables the design, optimization and evaluation of the application of the commercial scale drying process. It is possible to observe a higher quality final product (Hernandez-Carrion et al., 2013) by means of the physical-chemical parameters.

In this context, the objective of this study is to carry out drying kinetics of organic yellow pepper at different drying air temperatures, to adjust the data obtained to the empirical models and to evaluate the effect of the applied temperatures on its physicochemical characteristics.

MATERIALS AND METHODS

The organic yellow bell peppers (*C. annuum* L.) were purchased at a fair of organic products located at the Federal University of Campina Grande, in the city of Campina Grande, Paraiba, Brazil. The work was developed in the Laboratory of Storage and Processing of Agricultural Products of the Federal University of Campina Grande.

Kinetics of drying

The yellow peppers were selected, sanitized and cut manually into thin slices; then the initial water content of the product was determined according to the methodology proposed by AOAC (2005). The drying was performed in air circulation oven with air velocity of 2.0 ms^{-1}, Tecnal brand TE-394/4, at temperatures of 50, 60, 70 and 80°C, in which the samples were uniformly distributed in trays, forming a layer of approximately 0.5 cm thickness. The experimental data were expressed in terms of the water content ratio (X*), given by the relationship between the water content differences in time, t, and equilibrium water content ($X(t) - X_{eq}$) of initial and equilibrium water (X_i-X_{eq}). As described in Equation 1:

$$X^*(t) = \frac{X(t)-X_{eq}}{X_i-X_{eq}} \quad (1)$$

Where: X^* = ratio of water content (dimensionless); X_{eq} = equilibrium water content (dry basis); X (t) = water content (dry basis); X_i = initial water content (dry basis).

The six empirical functions *f*(t,a,b) presented in Table 1 were fitted to the experimental data sets using nonlinear regression with the LAB Fit Curve Adjustment Software (Silva and Silva, 2008). The results from the empirical models were evaluated through the statistical indicators chi-square, χ^2 and coefficient of determination, R^2 (Bevington and Robinson, 1992; Da Silva et al., 2008; Taylor, 1997; Silva et al., 2018a).

Physical-chemical characterization and thermosensitive compounds

The determinations of moisture, ash, lipid and protein contents were performed according to the methodology described by AOAC (2005). Water activity (Aw) was determined using the Decagon® Aqualab CX-2T device at 25°C; the total carbohydrate content was calculated by difference to obtain 100% of the total composition

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Table 1. Empirical models to describe drying kinetics.

Model name	Empirical expression	Reference
Handerson and Pabis	$X^* = ae^{-bt}$	Diamante et al. (2010)
Lewis	$X^* = e^{-at}$	Kaleta and Górnicki (2010)
Page	$X^* = e^{-at^b}$	Diamante et al. (2010)
Peleg	$X^* = t(a + bt)$	Mercali et al. (2010)
Silva et alii	$X^* = e^{-at-b\sqrt{t}}$	Silva et al. (2013)
Wang and Singh	$X^* = 1 + at + bt^2$	Kaleta and Górnicki (2010)

(FAO, 2003). The content of ascorbic acid (Vitamin C) was determined according to the methodology proposed by the Institute Adolfo Luttz (Brazil, 2008) and the results were expressed as mg of ascorbic acid/100 g sample. Total phenolic compounds were quantified using the Folin-Ciocalteau method described by Waterhouse (2006), using gallic acid as standard and water as solvent. The calculations performed for the determination of the phenolic compounds were based on a standard curve with gallic acid and the spectrophotometer readings at 765 nm with the results expressed in $mg.100g^{-1}$ of gallic acid.

Statistical analysis

The results were submitted to analysis of variance (ANOVA), Tukey's test of means comparison at the 5% level of significance, with the aid of the statistical program SAS 9.0 (Statistical Analysis System®) (SAS, 1999).

RESULTS AND DISCUSSION

Table 2 shows the results obtained for the empirical models applied to the drying kinetics of yellow pepper, as well as the statistical indicators, chi-square and coefficient of determination. According to the statistical indicators, all proposed models presented a coefficient of determination (R^2) of more than 0.99 (R^2> 0.99) at all temperatures applied, representing satisfactorily the drying process studied. In the chi-square (χ2) analysis, it can be observed that the Wang and Singh model presented the highest values, ranging from 1.2389 to 4.7295 × 10^{-2} when the air temperature of drying ranged from 50 to 80°C. The Page model was considered as the lowest values for the same function with a variation of 0.3399 to 0.5183 × 10^{-2} between the applied temperatures, being the model chosen to represent the drying process. The Peleg model also presented high R^2 and low χ2, according to Silva et al. (2018b), it can be interpreted as an equation resulting from the law of second-order drying rate, which allows to give a physical meaning to the parameters obtained by adjusting curves (Pan et al., 2011; Tao et al., 2014).

It was also observed that the parameter "a" of the empirical shifts tended to increase with increase of drying air temperature, except for the models of Handerson and Pabis, Lewis, Wang and Singh that decreased with the increase in temperature; and the Silva et al. model that did not show direct relation with the air temperature if drying. A similar pattern was observed for parameter "b" where it increased as the drying air temperature increased; however, only the Wang and Singh model showed different behavior.

Derlan et al. (2013), when evaluating the drying process of cambuci pepper at 40, 50 and 60°C, determined that the Midili model was the best fit for the experimental data. Silva et al. (2018b) found that the Handerson and Pabis model best described the drying process of peppers at temperatures of 60 to 80°C. Figure 1 shows the Page model as the one that best described the drying kinetics of yellow pepper to the drying air temperatures applied. The increase in drying air temperature reduced the drying time of the yellow pepper, whose times were equal to 690, 630, 570 and 450 min, respectively. According to Melo et al. (2015), this behavior is due to the fact that the higher water removal rates of the product occur at higher temperatures, which reduce drying time. Table 3 shows the mean values and standard deviations of the physical-chemical characterization and thermosensitive compounds of yellow pepper (*C. annuum*, L.) *in natura*. The mean moisture content for *in natura* yellow pepper was lower than those obtained by Machado et al. (2017) for yellow pepper (92.40%), as well as those obtained by Oliveira et al. (2016) for green pepper (93.79%), eggplant (93.61%) and chuchu (95.26%). It is worth mentioning that in chilies these moisture values decrease with the maturation stage.

According to Fellows (2006), the *in natura* yellow pepper is classified as a food of high water activity (A_w> 0.90), which justifies drying as an option to the conservation of this product due to its high perishability and susceptibility to attack of microorganisms. Values close to the present study were observed by Meneses et al. (2018) for different fruit residues being 0.985, 0.902 and 0.971 for mango, guava and acerola residues, respectively.

The yellow pepper *in natura* had 0.87% ash content, 1.67% proteins and 0.39% lipids; however, Nascimento et al. (2018) when analyzing fresh green peppers obtained lower levels for ashes (0.4%), proteins (1.5%) and lipids (0.2%). Higher values obtained in the present work are related to the maturation stage, since the green

Table 2. Results obtained for the models.

Model	T (°C)	*a*	*b*	R^2	$\chi^2 \times 10^{-2}$
Handerson and Pabis	50	1.004	0.5597×10^{-2}	0.9984	0.5552
	60	1.003	0.5584×10^{-2}	0.9983	0.5102
	70	1.003	0.5569×10^{-2}	0.9982	0.4730
	80	1.001	0.5507×10^{-2}	0.9981	0.3402
Lewis	50	0.5560×10^{-2}	-	0.9985	0.5646
	60	0.5550×10^{-2}	-	0.9984	0.5178
	70	0.5539×10^{-2}	-	0.9982	0.4786
	80	0.5495×10^{-2}	-	0.9981	0.3410
Page	50	0.4880×10^{-2}	1.0256	0.9988	0.5183
	60	0.4949×10^{-2}	1.0225	0.9987	0.4826
	70	0.5028×10^{-2}	1.0191	0.9986	0.4523
	80	0.5359×10^{-2}	1.0050	0.9989	0.3396
Peleg	50	1.607×10^{2}	0.7328	0.9978	0.6888
	60	1.6338×10^{2}	0.7190	0.9982	0.5252
	70	1.6622×10^{2}	0.7035	0.9985	0.3808
	80	1.7026×10^{2}	0.6796	0.9985	0.2681
Silva et alii	50	0.5698×10^{-2}	-0.1603×10^{-2}	0.9984	0.5482
	60	0.5670×10^{-2}	-0.1377×10^{-2}	0.9983	0.5059
	70	0.5636×10^{-2}	-0.1114×10^{-2}	0.9982	0.4710
	80	0.5501×10^{-2}	-0.6958×10^{-4}	0.9981	0.3410
Wang and Singh	50	-0.3860×10^{-2}	0.3662×10^{-5}	0.9900	4.7295
	60	-0.4011×10^{-2}	0.4040×10^{-5}	0.9917	3.4837
	70	-0.4160×10^{-2}	0.4456×10^{-5}	0.9929	2.5803
	80	-0.4493×10^{-2}	0.5568×10^{-5}	0.9949	1.2389

pepper appears as a stage inferior to the yellow pepper. In relation to the total carbohydrate content, the yellow pepper *in natura* presented low value, since the material presented higher moisture content and consequently high water activity (A_w).

High percentages of ascorbic acid (Vitamin C) in sweet peppers (234.64 mg of ascorbic acid/100 g sample), as well as moderate total phenolic compounds content (38.49 mgGAE.100g^{-1}) were quantified. Pereira et al. (2016) quantified ascorbic acid content of 22.29, 5.13 and 5.00 mg of ascorbic acid/100g sample for chard, lettuce and cabbage leaves, respectively. Table 4 shows the mean values of the physico-chemical and thermosensitive compounds for yellow pepper convectively dehydrated in an air circulation oven at temperatures of 50, 60, 70 and 80 °C, respectively.

The moisture content in the samples submitted to drying showed statistically significant variations for all evaluated temperatures, and the higher the drying temperature, the lower the final moisture content of the product. However, the final moisture content of each treatment was satisfactorily met by the Brazilian legislation that establishes a maximum of 15% (Brazil, 2005). Meneses et al. (2018) obtained moisture content of 13.42, 6.09 and 11.31% for mango, guava and acerola residues, respectively, dehydrated at 55°C. As can be seen in Table 4 the drying process was effective in reducing Aw in all evaluated conditions. The lowest Aw (0.189) was obtained with the highest temperature (80°C) applied in the process; however, it is convenient to evaluate factors such as energy expenditure in the conservation process and nutrient degradation since the milder temperatures obtained satisfactory results. Santos et al. (2017) obtained water activity between 0.353 and 0.318, when drying pitaya shells at temperatures between 50 and 70°C.

In the analysis of the ash content, there was a significant increase from 0.87 to 9.26% when the *in natura* chili was subjected to drying between temperatures of 50 to 80 ºC. This behavior must have occurred due to the decrease of the humidity of the samples, consequently causing an increase in the ashes.

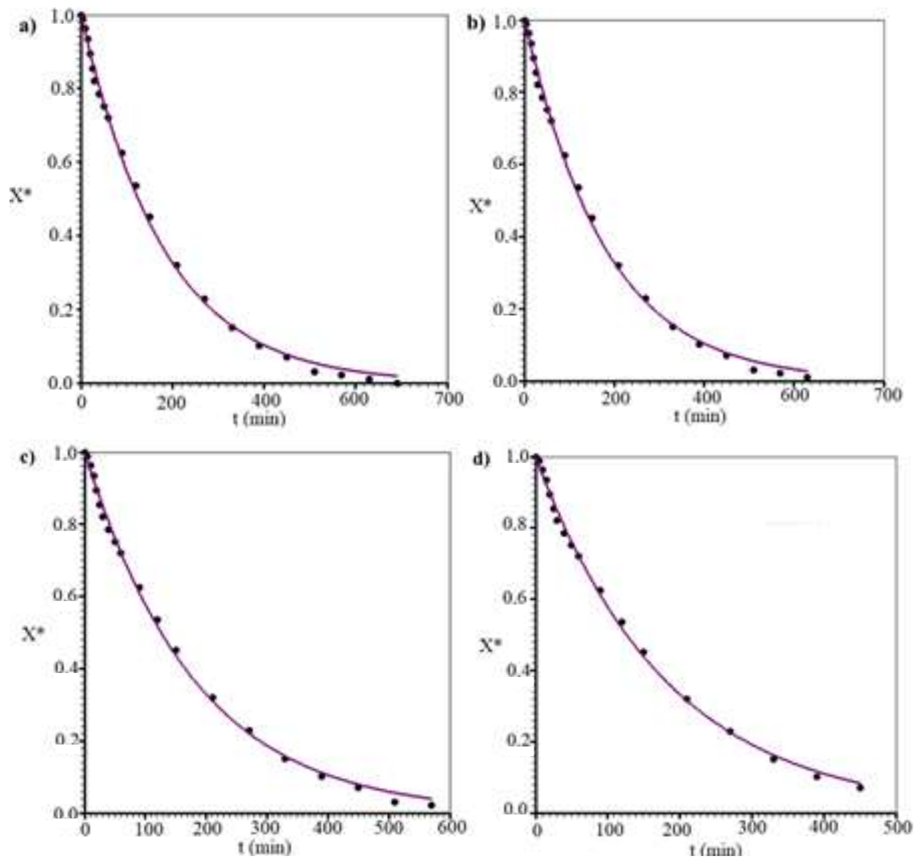

Figure 1. Drying kinetics simulations using the empirical model page at temperature T: (a) 50°C; (b) 60°C; (c) 70°C; (d) 80°C.

Table 3. Physical-chemical characterization and thermosensitive compounds of yellow pepper before drying.

Parameter	**Mean and standard deviation**
Moisture[1] (%, u.b)	90.88 ± 0.155
A_w	0.982 ± 0.006
Ashes (%)	0.87 ± 0.041
Proteins (%)	1.67 ± 0.053
Lipidis (%)	0.39 ± 0.031
Carbohydrates (%)	6.19 ± 0.135
Vitamin C (mg of ascorbic acid/100g sample)	234.64 ± 0.546
Total phenolic compounds (mgGAE.100g^{-1})	38.49 ± 2.491

[1] umid base.

Chouaibi et al. (2019) quantified ash contents of 3.05% in red pepper seeds. The temperatures obtained for the temperatures of 70 and 80°C do not present statistical difference, as well as those obtained for the temperatures of 50 and 60°C.

In the quantification of the protein content, it was verified that the highest protein content was obtained for the dried pepper at 50°C; and that temperatures above 60°C caused degradation of this. Although there was a variation between the *in natura* pepper and the drying temperatures, this parameter presented similar behavior to the ash content, in which the temperatures of 50 and 60°C; 70 and 80°C did not differ statistically from each other. Silva et al. (2018) in green pepper studies obtained

Table 4. Physico-chemical characterization and thermosensitive compounds of dehydrated peppers.

Parameter	Temperatures (°C)				CV (%)
	50	60	70	80	
Moisture (%, d.b[1])	13.69[a]	10.95[b]	8.98[c]	7.90[d]	1.50
A_w	0.388[a]	0.302[b]	0.284[b]	0.189[c]	3.04
Ashes (%)	7.63[b]	8.45[b]	9.84[a]	10.13[a]	4.64
Proteins (%)	2.15[a]	2.10[a]	1.96[b]	1.84[b]	2.35
Lipids (%)	4.59[b]	4.85[a]	4.88[a]	4.33[c]	1.16
Carbohydrates (%)	71.94[c]	73.65[b]	74.34[b]	75.80[a]	0.62
Vitamin C (mg of ascorbic acid/100g sample)	220.89[a]	218.36[b]	214.57[c]	209.63[d]	0.18
Total phenolic compounds (mgGAE.100g^{-1})	34.68[a]	32.20[b]	31.19[bc]	30.79[c]	1.64

[1]Dry base; Letter superscripts equal in the same line do not present significant difference at the 5% probability level. CV: Coefficient of variation.

protein contents ranging from 2.36 to 2.46% when the drying air temperature ranged from 60 to 80°C. Considering the dehydrated material, it is possible to observe that the milder temperatures resulted in better values for this parameter, evidencing that the use of high temperatures in the drying process, can cause a degradation of the proteins.

Regarding the lipid content, the treatments at 60 and 70°C presented the highest values for this parameter, followed by treatments of 80 and 50°C, respectively. The choice of drying method should be well studied since the use of temperatures higher than 50°C and high pressures can degrade important components of the product. For example, drying with greenhouse, which uses heating for a longer time, can modify the physical and chemical properties of the material, especially the ability to retain lipids, which interferes with the quality of the final product (Fornaiser et al., 2018).

In relation to the total carbohydrate content, it was observed that the increase was directly proportional to the temperature increase and inversely proportional to the water content, since these did not suffer thermal degradation and increased with the least amount of water available in the material. Carbohydrate values for the treatments at 60 and 70 °C did not differ statistically from each other. According to Fennema et al. (2010), carbohydrates, alongside water, are more abundant and better distributed in foods of plant origin, and can vary widely among them, and besides their nutritional value help to make food palatable and more pleasant looking.

Higher percentages of Vitamin C were quantified in the pepper of the lower temperature treatment, and for all temperatures, there were significant differences between them. The increase of the drying temperature caused a reduction of 25.01% of the ascorbic acid. Agostini-Costa et al. (2017) quantified ascorbic acid levels for yellow japonica pepper ranging from 136 to 222 mg of ascorbic acid/100g sample. According to Rebouças et al. (2013) and Silva et al. (2018a) vitamins are very sensitive compounds and can be degraded by several factors, such as temperature, oxygen presence, light, humidity, pH, duration of treatment to which the food was submitted, among others.

The highest index of total phenolic compounds was presented in the chili peppers submitted to the lowest temperatures until the highest temperature (80°C), which presented lower value (30.79 mgGAE.100g^{-1}), since drying promotes degradation of the components thermosensitive food. The values of the treatments 60 and 70°C did not present significant differences among themselves, as well as between 70 and 80°C. Lahbib et al. (2017) quantified in the pericarp of 11 different pepper cultivars levels of total phenolic compounds ranging from 6.82 to 4.06 mgGAE.100g-1.

Conclusion

In all applied temperatures, the proposed models presented determination coefficients superior to 0.99, representing adequately the drying process studied. Page's model was the one that best described the drying kinetics of yellow pepper for the drying treatments applied. The chili *in natura* presented high moisture content and high water activity, higher values for protein content, vitamin C and total phenolic compounds. The treatment of 80°C presented lower moisture content, low water activity, high ash content and carbohydrates, also causing a degradation of Vitamin C and total phenolic compounds.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of cropping system, seed treatment and planting date on *Striga hermonthica* infetstaion and growth and yield of sorghum

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***Striga hermonthica* is a serious biotic constraint to sorghum production in sub-Saharan Africa but the use of cropping system, seed treatment and appropriate planting dates might help to control the weed. Two years trial was conducted at the Federal University of Technology Minna research farm. The objective was to evaluate the effect of intercropping system, seed treatment, and planting date in integrated management of *S. hermonthica* in sorghum. Treatments comprised two varieties of sorghum (resistance ICSV 1002 and susceptible Gwari Local variety), three different concentrations of *parkia* pulp powder (0, 66 and 100 g/L), soyabean variety TGX 1448-2E and two sowing dates (15 June and 21 July) in two cropping season (2012 and 2013). These were evaluated in a randomized complete block of three replicates. Data in both years were collected on days to first *Striga* emergence and *Striga* count per stand of sorghum plant and per plot of sorghum plant, severity score, sorghum plant height and grain yield were collected in both years. The results show that *Striga* emergence was significantly delayed in sorghum variety ICSV1002, sorghum intercropped with soyabean and sorghum soaked with 66g/L *Parkia* concentrations compared to other treatments. *Striga* count was fewer in sorghum variety ICSV1002, sorghum intercropped with soyabean and sorghum soaked with 66 g/L *Parkia* concentrations compared to other treatment. Severity score, plant height and grain yield showed the same trend as *Striga* emergence and *Striga* count. In conclusion, program of integrated *Striga* control could provide sustainable *Striga* control**

Key words: Sorghum, *Striga hermonthica,* integrated management.

INTRODUCTION

An estimated cereal production area of 50 million hectare shows different levels of *Striga* infestation in Africa (Westwood et al., 2010). In total, 25 African countries reported *Striga* infestations in 2005 (De Groote et al., 2008). The socioeconomic consequences are difficult to measure, but a few estimations have suggested that

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Striga affects the life of more than 100 million people in Africa and causes economic damage (Labrada, 2008; Waruru, 2013). Controlling the production of new *Striga* seeds is therefore an important component of a long-term control program. Farmers in Africa have limited resources to invest in *Striga* control practices and longer term, low-input approaches are needed. Cropping systems remain traditional and the methods mostly used in controlling *Striga* are hand-pulling, land fallowing, crop rotation, crop seeds treatment with the powder of *Parkia biglobosa* (African locust bean tree) peels before the planting (Traoré and Yonli, 2001). Unfortunately, these cultural practices do not lead to significant reduction of the density of *S. hermonthica* in affected-fields (Traoré and Yonli, 2001). Besides, some of these control methods are labour intensive to the capital deficient farmers (Mashark et al., 2006). The land fallowing method is less used because of the reduction of arable land due to the population growth. Regarding crop cultivars, the national programme of cereal breeding has attempted to identify *Striga* resistant varieties of sorghum, based on the number of emerged *Striga* plants in cultivation plot. Long-term *Striga* control focus approaches on controlling the production of new *Striga* seeds and on reducing the number of seeds in the soil. Several seasons of hand weeding are required before the beneficial effect on the cereal crop can be observed. Intercropping with trap crops can reduce *Striga* seed banks but selection of a trap crop should be based on their ability to stimulate *Striga* seeds to germinate. The use of plant products for the control of *S. hermonthica* is limited, though the effect of plant materials especially neem (*Azadiracthaindica)* products have been reported to significantly control some organisms e.g insects, fungi and to some extent nematodes (Gahukar, 2002; Agbenin, 2002; Abdel-Razek and Gowen, 2002).The use of powder from the fruit of *P. biglobosa* has been reported to improve the soil agrochemical properties and to inhibit the germination of *S. hermonthica* seed. In Nigeria, Marley et al. (2004) reported 29.1% less *Striga* emergence under field conditions when *Parkia* products were used. Integrating yield protecting technologies like the seed dressing technology with practices that provide returns in the longer term may be one way to longer-term approach. The objective of this study is to evaluate the effect of intercropping system, seed treatment, and planting date in integrated management of *S. hermonthica* in sorghum;

MATERIALS AND METHODS

Experimental area

Field experiment was conducted at the Federal University of Technology Minna, (09° 39’ N and 06° 28’ E) in the Southern Guinea Savannah ecological zone of Nigeria with mean annual rainfall of 1300 mm. The experiment was carried out on sandy clay loamy in a field with a history of high *Striga hermonthica* infestation. The soil was characterized as an acidic (pH 5.2) sandy clay loamy (640 g/kg sandy 100 g/kg silt and 260 g/kg clay) with organic matter content of 8.9 g/kg. Total nitrogen was 0.5 g/kg, phosphorus of 4.2 mg/kg and cation exchange capacity of 6.09 cmol/kg.

Preparation of *parkia* pulp powder

Parkia fruits were obtained from Bosso town in Bosso local government area, Minna. The pulp was separated from the seeds by pounding in mortar with pestle and sieved. A weighing scale was used to measure 5 g of the pulp powder put in containers and diluted with distilled water at different volumes.

Experimental design, treatments and agronomic practice

The treatment design was a randomized complete block with three replicates. Three concentrations of *P. biglobosa* pulp powder at 0, 66 and 100 g/L was used to prime two sorghum cultivars (resistance ICSV1002 and Gwarri local varieties) and two sowing dates (15 June and 21 July) was assigned to main plot and sowing in July was considered late. Planting distance was 75 cm between rows and 30 cm between plants. Seed were socked for 16 h and sown two to three seeds of sorghum per hill on the chosen dates and stands with excess seedling were thinned to two plants per hill at two weeks after sowing. Hand pulling of weeds other than *S. hermonthca* seedling was done at four weeks and second weeding was carried out at 8 weeks after sowing. Harvesting of sorghum panicles was done at 22 and 23 weeks after sowing for June and July dates respectively; panicles were dried threshed and grain yield determined.

Data analysis

Data collection and analysis include days to first *Striga* emergence, *Striga* count per stand and per plot, severity score of maize using a scale of 1-5, where 1 indicates no *Striga* damage and 5 indicating a very high severely level, plant height from tagged stand using tape rule and measuring from the soil surface to neck of last leaf, grain yield per plot using weighing balance. Data were statistically treated with analysis of variance (ANOVA) using the computer software Genstat (2010). Statistical differences between variables means were compared using least significant difference ($P < 0.05$).

RESULTS

Striga emergence and count

Sorghum variety ICSV 1002 intercropped with soyabean at 66 g/L *Parkia* concentration significantly ($P < 0.05$) delayed *Striga* emergence (63.33 days) compared to other treatment combinations. In the local sorghum variety, intercropped with soyabean at 66 and 100 g/L *Parkia* concentration delayed *Striga* emergence (58.67 days) compared to other treatment combinations in 2012 (Table 1). In 2013, ICSV1002 variety intercropped with soyabean at 100 g/L *Parkia* concentration significantly ($P < 0.05$) delayed S*triga* emergence (66.00 days) compared to other treatment combinations. Delayed infestation was observed in the local sorghum variety intercropped with soyabean at 66 g/L *Parkia* concentration compared to other treatment combinations

Table 1. Interaction effect of sorghum, soyabean and *Parkia* concentration on days to first *Striga* emergence, *Striga* shoots count per stand and per plot.

Sorghum	Soyabean	*Parkia* concentration (g/l)	2012							2013						
			DFE	SCS (WAS)			SCP (WAS)			DFE	SCS (WAS)			SCP (WAS)		
				10	14	18	10	14	18		10	14	18	10	14	18
ICSV 1002	Sole	0	59.83	3.50	5.67	6.67	5.67	9.83	10.67	60.50	2.17	4.33	6.67	4.50	7.17	8.17
ICSV 1002	Sole	66	61.83	2.00	3.50	4.67	3.33	7.17	8.17	63.00	1.40	2.50	4.00	2.50	4.50	5.83
ICSV 1002	Sole	100	62.00	3.17	5.17	5.67	4.50	8.00	9.67	62.50	2.00	3.83	4.67	3.83	5.67	7.00
ICSV 1002	Soyabean	0	60.67	2.00	3.00	4.17	3.17	6.33	6.83	62.00	2.19	2.83	4.83	2.67	4.83	6.00
ICSV 1002	Soyabean	66	65.33	1.67	2.83	3.00	2.30	4.17	5.17	65.83	1.93	1.45	3.00	0.12	2.17	3.00
ICSV 1002	Soyabean	100	63.67	1.83	3.00	3.00	2.33	4.67	5.67	66.00	3.09	3.67	5.17	3.94	4.83	8.17
Local variety	Sole	0	55.33	10.00	15.17	16.00	14.83	22.33	23.67	59.00	7.50	9.50	11.67	11.00	13.33	14.83
Local variety	Sole	66	57.67	4.83	7.67	9.00	8.33	13.17	14.30	59.00	4.33	5.83	8.67	6.33	8.50	10.83
Local variety	Sole	100	57.40	5.50	9.17	10.00	9.67	13.83	14.83	59.67	4.33	6.83	8.50	6.67	8.50	10.83
Local variety	Soyabean	0	57.50	5.10	8.83	10.33	8.67	13.67	13.17	59.83	5.50	3.83	6.17	5.83	7.50	9.17
Local variety	Soyabean	66	58.67	2.83	4.83	5.50	5.17	7.83	9.33	59.83	2.00	4.17	5.57	3.83	5.83	7.50
Local variety	Soyabean	100	58.67	4.67	8.67	8.50	8.33	11.00	13.67	59.17	3.00	4.67	6.50	5.00	7.00	8.67
Mean			59.97	3.92	6.45	7.21	6.36	10.17	11.26	61.36	3.29	4.45	6.29	4.69	6.65	8.33
$LSD_{(0.05)}$			0.82	1.22	1.46	1.64	1.72	2.26	2.35	1.16	NS	1.40	NS	1.23	NS	NS

DFE, Day to first *Striga* emergence; SCS, *Striga* shoot count per stand; SCP, *Striga* shoot count per plot; NS, Non-significant; LSD, probability level at 0>.05; WAS, weeks after sowing.

Table 1). Irrespective of year of planting and in all the sampling periods, priming at 66 g/L *Parkia* concentration significantly (P < 0.05) supported fewer *Striga* count per stand and per plot compared to other treatment combinations (Table 1).

There were significant (p < 0.05) differences in sorghum intercropped with soyabean and treated with 66 g/L *Parkia* concentrate, as the treatment significantly suffered less *Striga* damage (2.17 and 2.00 in 2012 and 2013 respectively) compared to other treatment combinations. The Local variety showed same trend with ICSV 1002 variety (Table 2). In 2013 the interaction effect of sorghum, soyabean and *Parkia* concentration on plant height was significantly affected (p<0.05) at 10 WAS but not at 14 WAS. Intercropped sorghum at 66 g/L *Parkia* concentration produced taller plants (56.83 cm) in the ICSV 1002 variety compared to 100 and 0 g/l treatments. In the Local sorghum variety, the intercropped at 66 g/L *Parkia* concentration significantly (p<0.05) produced tallest plant height (45.17 cm) compared to 100 and 0 g/L *Parkia* treatments, 2012 which were not significantly different. There was no significant (P <0.05) differences in grain yield among the cropping system and *Parkia* treatments.

Sorghum variety ICSV1002 intercropped with soyabean and planting in July delayed *Striga* emergence (66.44 days) compared to most treatment combinations in 2012, while in local sorghum variety, soyabean intercropped and planting in June and July delayed *Striga* emergence (58.33 days and 58.33 days) compared to other treatments (Table 3). There were no significant differences in 2013. *Striga* count per stand was not significantly (P < 0.05) different in all cases where sorghum varieties were combined with soyabean and sowing date in 2012 and 2013 (Table 3). *Striga* counts per plot were not significant on number of *Striga* shoots (P < 0.05) in 2012; however, in 2013, fewer *Striga* count per plots were recorded in July planting compared to planting in June at 10 and 14 WAS irrespective of sorghum varieties and cropping system.

The interaction effect of sorghum varieties,

Table 2. Interaction effect of sorghum, soyabean and *Parkia* concentration on severity score, plant height (cm) and grain yield (kg/ha) of sorghum.

Sorghum	Soya bean	*Parkia* concentration (g/l)	2012 SC	2012 PH (cm) (WAS) 10	2012 PH (cm) (WAS) 14	2012 GY(k/ha)	2013 SC	2013 PH (cm) (WAS) 10	2013 PH (cm) (WAS) 14	2013 GY (k/ha)
ICSV 1002	Sole	0	3.17	37.33	47.33	1385.30	2.83	44.83	53.00	1572.90
ICSV 1002	Sole	66	2.83	46.33	55.00	1535.00	2.00	50.83	56.67	1623.30
ICSV 1002	Sole	100	2.50	41.67	50.83	1514.00	2.33	45.50	54.33	1599.00
ICSV 1002	Soyabean	0	3.00	49.50	58.33	1507.80	2.67	48.50	59.17	1630.80
ICSV 1002	Soyabean	66	2.17	56.67	65.00	1702.70	2.00	56.83	63.33	1833.90
ICSV 1002	Soyabean	100	2.27	56.17	64.33	1613.90	2.50	52.67	59.33	1615.50
Local variety	Sole	0	5.00	23.67	31.83	965.80	5.00	36.17	39.50	1088.10
Local variety	Sole	66	5.00	35.33	43.50	1183.40	5.00	40.33	43.00	1169.40
Local variety	Sole	100	4.83	32.33	43.33	1294.80	5.00	40.33	46.33	1161.40
Local variety	Soyabean	0	4.83	28.83	38.00	1152.70	4.83	42.17	47.00	1220.10
Local variety	Soyabean	66	3.50	40.17	49.00	1329.60	4.67	45.17	50.50	1351.10
Local variety	Soyabean	100	3.67	38.83	48.00	1336.70	5.00	40.50	47.83	1288.10
Mean			3.82	40.57	49.54	1376.80	4.00	45.32	51.67	1429.47
LSD(0.05)			0.42	NS	NS	NS	0.70	3.23	NS	NS

SC, Severity Score; PH**,** Plant height (cm), GY**,** Grain yield (k/ha); NS**,** Non-significant; LSD**,** Probability level at 0> 05; WAS, Weeks After Sowing.

Table 3. Interaction effect of sorghum, soyabean and sowing date in days to first *Striga* shoot emergence, shoot count per stand and per plot.

Sorghum	Soya bean	Sowing date	2012 DFE	2012 SCS (WAS) 10	2012 SCS (WAS) 14	2012 SCS (WAS) 18	2012 SCP (WAS) 10	2012 SCP (WAS) 14	2012 SCP (WAS) 18	2013 DFE	2013 SCS (WAS) 10	2013 SCS (WAS) 14	2013 SCS (WAS) 18	2013 SCP (WAS) 10	2013 SCP (WAS) 14	2013 SCP (WAS) 18
ICSV 1002	Sole	June	59.22	3.78	5.78	6.67	5.00	9.00	10.33	60.50	2.50	4.89	6.78	4.56	6.44	8.00
ICSV 1002	Sole	July	63.22	2.00	3.78	4.67	4.00	7.67	8.67	63.44	1.22	2.22	3.44	2.67	5.11	6.00
ICSV 1002	Soyabean	June	60.00	2.22	3.11	3.67	2.67	5.00	5.89	61.67	3.66	3.37	5.56	4.11	5.44	7.00
ICSV 1002	Soyabean	July	66.44	1.44	2.78	3.11	2.56	5.11	5.89	67.56	1.14	1.93	3.11	0.37	2.44	4.44
Local variety	Sole	June	57.11	8.00	11.67	12.78	11.56	16.22	16.56	59.78	6.89	1.11	11.22	9.44	11.56	13.56
Local variety	Sole	July	57.22	5.56	9.67	10.56	10.33	16.67	18.67	59.33	3.89	5.67	8.00	5.78	7.67	9.89
Local variety	Soyabean	June	58.33	4.89	8.44	9.11	7.44	10.67	11.22	59.33	3.67	5.22	7.00	5.78	7.67	9.89
Local variety	Soyabean	July	58.33	3.56	6.44	7.11	7.33	11.00	12.89	59.89	2.00	3.22	5.11	4.00	5.89	7.00
Mean			59.98	3.93	6.46	7.21	6.36	10.17	11.26	61.44	3.12	3.45	6.28	4.59	6.53	8.22
LSD(0.05)			0.67	NS	NS	NS	NS	NS	NS	NS	0.90	NS	NS	1.00	1.30	NS

DFE, Day to first *Striga* emergence; SCS, *Striga* shoot count per stand; SCP, *Striga* shoot count per plot; NS, Non-significant; LSD, probability level at 0>.05; WAS, weeks after sowing.

Table 4. Interaction effect of sorghum, soyabean and sowing date on severity score, plant height and grain yield (k/ha) of sorghum.

Sorghum	Soya bean	Sowing date	2012				2013			
			SC	PH (WAS)		GY (k/ha)	SC	PH (WAS)		GY(k/ha)
				10	14			10	14	
ICSV 1002	Sole	June	3.22	40.56	49.33	1396.60	2.44	47.44	58.11	1577.10
ICSV 1002	Sole	July	2.44	43.00	52.78	1559.60	2.33	46.67	51.22	1619.80
ICSV 1002	Soyabean	June	2.67	53.44	62.33	1497.70	2.52	54.00	61.89	1648.80
ICSV 1002	Soyabean	July	2.22	54.78	62.78	1718.60	2.26	51.33	59.33	1738.00
Local variety	Sole	June	5.00	26.44	35.89	1057.70	5.00	37.22	41.11	984.30
Local variety	Sole	July	5.00	34.44	43.22	1238.30	5.00	40.67	44.78	1295.00
Local variety	Soyabean	June	4.56	33.56	42.44	1203.20	5.00	44.67	49.89	12.73
Local variety	Soyabean	July	3.44	38.33	47.56	1342.90	4.56	40.56	47.00	1355.50
Mean			3.82	40.57	49.54	1376.83	4.00	45.32	51.67	1278.90
LSD(0.05)			NS	NS	NS	NS	0.57	2.64	2.05	55.46

SC, Severity Score; PH, Plant height (cm); GY, Grain yield (k/ha); NS, Non, significant; LSD, Probability level at 0>0.05; WAS, Weeks After Sowing.

cropping system and sowing date on severity score did not attain any level of statistical significance in 2012, but did in 2013 (Table 4).

Intercropping resistant ICSV 1002 sorghum variety and planting in July significantly ($P < 0.05$) suffered less *Striga* damage compared to other treatments; same trend was observed in the local sorghum variety (Table 4). There were no significant ($P < 0.05$) differences in interaction effect of sorghum varieties, cropping system and sowing date on plant height in all the sampling periods in 2012 (Table 4) . Generally intercropping the sorghum varieties with soya bean in June produced significantly higher plant height than planting in July in 2013. In 2013, ICSV1002 sorghum variety intercropped with soyabean and sowing in July produced highest grain yield of sorghum compared to other treatment combinations. The local variety showed the same trend with ICSV 1002 variety.

DISCUSSION

Striga emergence

The observed difference in the days to first *Striga* shoot emergence between varieties ICSV 1002 (resistant) and local sorghum variety (susceptible) could be due to low germination stimulant production commonly found in *Striga* resistant sorghum genotypes, as observed by Matuasova et al. (2005). The delayed *Striga* emergence in sorghum intercropped with soyabean relative to sole sorghum could be due to the ability of soyabean to increase soil moisture and reduce soil temperature needed for the *Striga* seed to germinate. A similar observation was made by Oswald et al. (2002) that intercropping maize with cowpea and sweet potato can significantly affect *Striga* germination. The delayed *Striga* emergence following the priming of sorghum with 66 g/L *Parkia* concentration compared to 100 and 0 g/L in 2012 and 2013 might be due to allele chemical in the *Parkia* pulp which inhibited Striga development at that concentration or level. A similar observation was made by Kolo and Mamudu (2008) that dressing of maize seed with *P. biglobosa* pulp gave better maize development both vegetative and in grain yield especially with the resistant varieties

Sorghum planted in July delayed *Striga* emergence compared to those planted in June could probably be due to high soil moisture which is caused by *Striga* seeds to undergo wet dormancy. This is also in agreement with work of Dugje et al. (2008) that sowing maize in mid-July reduced Striga infestation compared to sowing in mid-May or mid-June in parts of the Northern and Southern Guinea Savanna of Nigeria.

Striga count

The significance of sorghum and soyabean intercropping in reducing Striga count compared to those sown without soyabean in 2012 and 2013 could be attributed to the effect of soyabean cover with lowering soil temperature and increasing relative humidity which are unfavorable for Striga seed germination. This is in agreement with the findings of Teasdale and Daughtry (1993) that cover crop absorbs red-light and reduces red: far-red ratio sufficiently to inhibit phytochrome mediated seed germination. Also, Dembele and Kayentao (2002) in Mali found a reduction of Striga biomass by 92% in the intercropped plot of sorghum with cowpea.

Fewer Striga count in 66 g/L Parkia concentration in 2012 and 2013 compared to 100 and 0 g/L confirms the ability of Parkia concentration in controlling Striga; although the mobility of Parkia pulp phytochemical in sorghum has not been documented, it is likely that the Parkia pulp concentration has an indirect mechanism by which it reduces level. This is similar to the findings of Marley et al. (2004) that all plant materials like neem and Parkia extract significantly reduced Striga emergence.

Fewer Striga count observed in July sowing date compared to June might be due to the lower weed pressure in July because of cooler soil temperature, high relative humidity and regular rainfall which cause the *Striga* seeds to undergo wet dormancy and fail to germinate. Dugje et al*.* (2008) had also reported that sowing maize in mid-July reduced *Striga* infestation compared to sowing earlier in mid-May or mid-June in parts of the Northern and Southern Guinea Savanna of Nigeria.

Severity score

The lower *Striga* damage in the ICSV1002 (resistant) compared to Local sorghum variety (susceptible) could be attributed to the delayed emergence and reduced attachment to the host root. This conforms with the report of Wilson et al*.* (2000) that resistant host genotype may limit the number of *Striga* plants that infest host plant or may reduce the impact of *Striga* on the host plants.

The less *Striga* damage in sorghum intercropped with soyabean compared to sole sorghum confirms the effectiveness of soyabean as trap crop to induce suicidal germination of *Striga* seed. As cover crop, soyabean interfered with the sun radiation and chemical environment of *Striga* seed, lowering the light and daily temperature and inhibiting emergence of *Striga* seed, as well as increasing soil fertility through nitrogen fixation. All these caused unfavorable condition for *Striga* seed germination and resulted in less attack and damages. This is similar to observation by Carsky et al*.* (2000); Schulz et al*.* (2003) that varieties of cowpea, groundnut and soyabean have potential to cause suicidal germination of S. *hermonthica* and improve soil fertility.

The significance of the lower *Striga* damage in 66 g/l compared to 100 and 0 g/l *Parkia* concentration could be due to lower *Striga* population in the former which decreased severity of attack on host. This is in agreement with the work of Ndungu (2009) that coating sorghum seed with herbicides reduced *Striga* infestation.

Reduction in *Striga* infestation accounted for fewer *Striga* damages.

The reduced *Striga* damage in planting in July compared to June could be attributed to less weed pressure and unfavorable environmental condition of low temperature and high humidity which inhibited *Striga* emergence and population and reduced attack on host. This is similar to observation by Odhiambo and Ariga (2004) that when planting is delayed *Striga* seeds are unable to germinate and seedlings fail to attach to host root systems due to unfavorable low soil temperature during the middle of the rainy season. This translated into less *Striga* damages.

Plant height

The taller plant height in ICSV1002 (resistant) sorghum compared to Local variety (susceptible) sorghum could be attributed to the ICSV1002 producing little or no root exudates to stimulate *Striga* seeds, hence reducing *Striga* population, which translates into higher performance over local variety. This is agreement with the findings of Rodenburg et al. (2006) that cultivation with resistant crops result in fewer *Striga* plant and higher crop yield than susceptible genotypes of the cultivated plant would do.

The taller plant height in sorghum intercropped with soyabean compared to sole sorghum in 2012 and 2013 might be due to combined effect of soyabean *Striga* inhibition by inducing *Striga* seed suicidal germination and reducing *Striga* attachment and growth covering effect of soyabean creating unfavorable environment for *Striga* germination and growth and nitrogen fixation and increased soil fertility. All these gave the intercropped sorghum plant good establishment and development compared to sole sorghum and this translated into higher plant height. This is similar to observation by Khan et al*.* (2002), that intercropping of cereal and cowpea reduced *Striga* infestation significantly, due to the soil cover of cowpea that created unfavorable conditions for *Striga* germination.

The taller plant height following priming with 66 g/L

Parkia concentration compared to 100 and 0 g/L *Parkia* treatment could be attributed to reduced *Striga* infestation and severity of attack on host crop at of 66 g/L *Parkia* treatment which gave the plant a better growth and development. This is similar to observation by Marley et al*.* (2004) that *P. biglobosa* releases allele chemicals that suppress the growth of other plant species.

The taller plant height in July compared to planting in June may however be attributed to delayed attack in relation to phenological development and reduced competition for the host nutrient and food with consequent luxuriant growth. This supports the findings of Van deft (1997) that early attachments and final growth reduction on the plant are a strong indication that control practices based on a reduction in the *Striga hermonthica* problem.

Grain yield

The higher grain yield in the ICSV1002 resistant sorghum variety compared to Local susceptible variety in 2012 and 2013 could be due to ICSV1002 variety good establishment and growth hence higher grain yield. This is in agreement with the finding of Rodenburg et al*.,* (2006) that in *Striga* infested areas cultivation with resistant crops results in fewer *Striga* plants and higher crop yield than a non-resistant genotype of the cultivated plant would do.

The higher grain yield from intercropping compared to sole sorghum in 2012 and 2013 might be due to effect of soyabean on soil conservation, nitrogen fixation and reduction in *Striga* emergence. Babiker et al*.* (1987) reported that intercropping sorghum with Dolichos lab-lab (labia) suppressed *Striga* emergence and growth and increased number of heads and straw yield of sorghum in the Sudan.

The higher grain yield at 100 g/L *Parkia* treatment in 2012 compared to 66 and 0 g/L *Parkia* treatment in that year, while in 2013 66 g/L *Parkia* treatment gave the highest grain yield compared to 100 and 0 g/L. The highest grain yield in the treated seeds compared to the control could be due to inhibition of *Striga* emergence, less parasitism by *Striga* which had allowed adequate quantities of both water and nutrients required by sorghum plant for yield and yield components.

Ndungu (2009) noted that coating sorghum seed with herbicide reduced *Striga* infestation, *Striga* flowering and *Striga* seed set, and it is considered as the most effective approach as it does not affect sorghum biomass.

The highest grain yield in July planting compared to June plant might be attributed to the combined effect of delayed infestation/attachment, low *Striga* population and good establishment and growth hence higher yield. This is in agreement with the findings of Berner and Ikie (1994) that delaying infection of *S. hermonthica* on both maize and sorghum until 4-6 weeks after planting significantly reduced emergence and reproduction of the parasite, and significantly increased host yield.

CONCLUSION AND RECOMMENDATION

The results demonstrate resistant sorghum varieties to reduce the impact of *Striga,* the high potentiality of using *Parkia* based products for *S. hermonthica* control by seed soaking at high concentration and the intensifying cropping by integrating soyabean variety. The relatively low *Striga* count and high yield in ICSV1002 resistant sorghum variety at 66 g/L *Parkia* concentration and under intercropping system indicate a reduced potential for flowering and capsule production and consequently a reduced capacity of increasing the *Striga* seed bank in the soil. *Parkia* pulp powder might be used in *S. hermonthica* control to reduce dependence on herbicides.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Light effects on growth and essential oil quantity and constituents in some Apiaceae plants

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The Apiaceae family known for vegetable crops rich in essential oils, includes numerous genera of high medicinal and economic value. This study investigates the effects of red and far-red light treatments through the dark period (night-break), on the growth characteristics, essential oil quantity and composition, in *Coriandrum sativum* L., *Anethum graveolens* L., and *Petroselinum crispum*. Treatments began 20 days after sowing, with exposure to red or far-red light for 4 h, nightly, from 10 pm to 2 am. Control plants had no treatment. The plants shoots were harvested after 30 days of treatment. The fresh and dry weight, height, petiole length, internode length, leaf number, leaf area, and total chlorophyll of plant samples were measured. Essential oils were evaluated and then analyzed using gas chromatography–mass spectrometry. The results showed that the red and far-red light led to non-significant increase in fresh and dry weight, plant height, petiole length, leaf number, leaf area, essential oil content, and concentration of individual oil components, while the internode length and total chlorophyll showed a significant increase in all treated plants. Therefore, the controlled use of red light and far-red light may be useful for initiating a response in plants, and enhancing their nutritional value.

Key words: Apiaceae, light, night-break, essential oil constituents.

INTRODUCTION

The Apiaceae family contains vegetable crops that are rich in secondary metabolites and essential oils. The family includes numerous genera of high medicinal and economic value (Margaris et al., 1982). The family has a wide global distribution consisting of about 300 genera and 3000 species, mostly of temperate herbs (Hassan and Elhassan, 2017). Dill (*Anethum graveolens* L.) is a member of the Apiaceae family and is an aromatic herb used as a seasoning in different foods such as seafood, sauces, soups, and salads (Huopalahti and Linko, 1983). Parsley (*Petroselinum crispum* (Mill.) Fuss) and cilantro (*Coriandrum sativum* L.) are two herbs used to enhance the flavor of many cuisines, including in South America, China, India, Mexico, and South East Asia (Wong and Kitts, 2006).

The light spectrum plays an important role in regulating the growth processes, morphology and photosynthesis activities in planta or *in vitro* (Wang et al., 2016). Most

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plant species can modify and develop their anatomical structure, morphology, physiology and biochemical makeup in response to light (Gonçalves et al., 2005). Furthermore, most plant species can develop acclimation systems to cope with different light regimes (Zhang et al., 2003), including adjusting their essential oil content, which could be one of the ways in which plants respond to stress (Mench and Martin, 1991). Increasing oil content in plants can increase their economic value (Hälvä et al., 1992b), consequently, plant survival, growth, and adaptation.

Studies have indicated that exposure to red light (RL) and far-red light (FRL) during the middle of the night (night-break; NB) has effects on multiple morphological and physiological parameters in plants. Vince-Prue (1977) showed that treatment by RL and FRL at NB led to a non-significant increase in stem and internode elongation of *Fuchsia hybrid*. Furthermore, FRL fluorescent and low red to far-red ratio (R:FR ratio) at NB promoted internode elongation in the stems of *Eustoma grandiflorum* (Yamada et al., 2008, 2011), and *Chrysanthemum morifolium* (Liao et al., 2014). NB treatment every 4 h with RL for 8 weeks led to a non-significant increase in plant height and total dry weight in *Solanum lycopersicum* L. (Cao et al., 2016). Chia and Kubota (2010) reported that a low RL:FRL ratio, or FRL at end-of-day, led to a significant increase in stem elongation, with no significant effects on leaf area in tomato plants (*S. lycopersicum*). A low RL/FRL ratio has also been found to increase the growth and internodes elongation in rosemary (*Rosmarinus officinalis* L.) (Mulas et al., 2006). An end-of-day RL and FRL treatment increased internode elongation in dill plants (Hälvä et al., 1992b), and *Populus tremula* $_X$ *tremuloides* (Olsen and Junttila, 2002). RL and FRL led to fast growth, elongation of stem, and an increase in the petiole length in silver birch (*Betula pendula* Roth) seedlings (Tegelberg et al., 2004), and increased the internode and petiole length in chrysanthemum (*C. morifolium* Ramat.) (Dierck et al., 2017).

RL, in normal conditions has a greater effect than FRL on plant growth because it is a major energy source for photosynthesis in plants. Under normal conditions, RL enhances shoot and root biomass of *Lactuca sativa* L. (Son and Oh, 2013), promotes shoot elongation in rice (*Oryza sativa* L). (Chen et al., 2014), and shoot and root length, biomass, and leaf number of artichoke (*Cynara cardunculus*) seedlings (Rabara et al., 2017). RL caused a significant increase in fresh and dry weight, leaf number, petiole length, and leaf area of strawberry *Fragaria* × *ananassa* (cv. Queen Elisa) plants (Norouzi et al., 2017). RL treatment also increased the fresh weight of peppermint (*Mentha piperita* L.) (Heydarizadeh et al., 2014), and stimulated an increase in the weight and height of *Taraxacum officinale* L. (Ryu et al., 2012), and *Rehmannia glutinosa* Gaertn. (Manivannan et al., 2015). Red shade cloth stimulated stem elongation in *Pittosporum variegatum* (Oren-Shamir et al., 2001), and increased shoot fresh weight in sweet basil (*Ocimum basilicum* L.), cilantro (*C. sativum*), and parsley (*P. crispum*) plants (Appling, 2012).

In normal conditions FRL led to increased plant height and stem mass in pepper (*Capsicum annuum* L.) (Brown et al., 1995), increased stem elongation in *R. officinalis* (Whitelam and Halliday, 2008), increased stem elongation in chrysanthemums (Rajapakse et al., 1993), and increased the fresh and dry weight, and stem length in baby lettuce (*L. sativa*) (Li and Kubota, 2009; Kubota et al., 2012). FRL was more effective in maintaining growth in *Picea abies* L. compared to RL (Molmann et al., 2006). FRL:RL ratio has effects on plants, where the shoot size and whole biomass ratio increased in Corn (*Zea mays* L.) seedlings that received a high FRL:RL ratios of reflected from near plants or soil surface (Kasperbauer and Karlen, 1994). Low RL:FRL ratio can induce stem and petiole elongation in *Arabidopsis thaliana* (Wang et al., 2015), and increase plant height in *Chenopodium album* L., *Amaranthus retroflexus* L., and *S. lycopersicum* (Ma and Upadhyaya, 2016). Molmann et al. (2006) reported that FRL was more effective at maintaining growth in *P. abies* compared to RL.

Other studies have reported different results on the effects of RL and FRL. For example, Brown et al. (1995) reported that plant biomass and leaf number was reduced in pepper (*C. annuum*) under RL treatment. Liu (2013) showed that leaf area in *Anoectochilus roxburghii* was not different unde a 12 h photoperiod with red LEDs. Su et al. (2014) showed that RL inhibited plant height, leaf area, and fresh weight of cucumber seedlings. Holmes and Smith (1975) showed that a high level of FRL reduces leaf area. Hälvä et al. (1992b) reported that petiole length, and leaf area decreased significantly, but that leaf number decreased non-significantly, in dill grown under R and FR lights for 4 h at end-of-day. Mulas and Craker (2005) reported that leaf number reduced in rosemary *(R. officinalis*) under FRL. The treatment of *Ficus benjamina* with FRL led to a negative effect on biomass production (Werbrouck et al., 2012).

In higher plants, chlorophyll is the most important pigment, it is responsible for capturing light for photosynthesis, and converts light energy into the chemical energy needed for the growth and development of the plant. Chlorophyll content is used to assess plant growth and vigor (Ni et al., 2009). Chlorophyll content and composition changed in plants in response to light quality (Manivannan et al., 2015), which may affect the growth of plants in terms of the accumulation of biomass, chlorophyll, and other plant products of economic importance (Ye et al., 2017).

Several reports have declared that RL and FRL have an effect on chlorophyll pigments in plants. RL is essential for stimulating chlorophyll synthesis, but this stimulating effect is cancelled out by subsequent FRL pulses (Lamparter et al., 1997). RL promotes chlorophyll synthesis in marigold (*Tagetes erecta* L.) and salvia (*Salvia splendens* F.) seedlings (Heo et al., 2002), kale (*Brassica oleracea* L.) (Lefsrud et al., 2008), *Cattleya loddigesii* Lindley (Galdiano et al., 2012), rice (*O. sativa* L.) (Chen et al., 2014), *R. glutinosa , Triticum aestivum* L. (Dong et al., 2014; Manivannan et al., 2015), lettuce (*L. sativa* 'Creipa') (Chen et al., 2016) and artichoke *C. cardunculus* seedlings (Rabara *et al*., 2017). Other studies have shown that chlorophyll content decreases under RL in some plants, for example in three hybrid grapes; *Vitis riparia* , *V. ficifolia* and *V. vinifera* (Hybrid Franc, Ryuukyuuganebu and Kadainou R-1) under pure red-light-emitting diodes (Poudel et al., 2007), and (*Cucumis sativus)* plants under RL (Wang et al., 2010). FRL decreased the concentrations of anthocyanin, carotenoids, and chlorophylls compared with white light alone (Li and Kubota, 2009; Brouwer et al., 2014), but Paradiso et al. (2011) showed that FRL could improve plant photosynthesis in rose plants 'Akito' and Lettuce (*L. sativa* 'Green Towers') (Zhen and van Iersel, 2017).

Plant essential oil content and composition is affected by many factors, including environmental conditions (Fernandes et al., 2013; İzgı et al., 2017), light spectrum (Hälvä et al., 1992a; Li and Kubota, 2009), light period (Hälvä et al., 1992a; Malayeri et al., 2010), and light intensity (Hälvä et al., 1992a; Shafiee-Hajiabad et al., 2016). Hälvä et al. (1992b) showed that essential oil content increased and composition changed in dill plants that were treated with 4 h of RL and FRL at end-of-day light. RL and FRL treatments increased the essential oil content of rosemary (*R. officinalis*) (Mulas et al., 2006). Heydarizadeh et al. (2014) showed that RL increased the essential oil content in peppermint (*M. piperita*) fourfold compared to natural light conditions, and increased it in *M. piperita*, *M*. *spicata*, and *M*. *longifolia* compared to blue or white light (Sabzalian et al., 2014). Red, blue, and ultraviolet (UV) lights enhanced the concentration of essential oils in various herbs (Dou et al., 2017). Ivanitskikh and Tarakanov (2014) showed that the essential oil content was highest in *O. basilicum* and *Salvia officinalis* grown under white and red and blue LED light, while it was three times lower when under just RL LEDs. The essential oil composition of plants is very sensitive and can be affected and modified under various conditions of light, nutrition, water, and temperature (Fernandes et al., 2013). Shafiee-Hajiabad et al. (2016) reported that light intensity affected the essential oil composition in *Origanum vulgare* L.

Many studies have shown that environmental factors have plants effects on plants and their essential oil content and composition. However, the role of most of these factors, including the effects of light quality on the synthesis of essential oils, is still not clearly understood; especially the factor of light quality during the dark period. Therefore, the objective of this study is to investigate the effects of light (RL and FRL) in a limited period during the dark period on some growth characteristics, and essential oil quantity and composition in parsley, dill, and cilantro.

MATERIALS AND METHODS

Plant material and treatments

Cilantro (*C. sativum*), dill (*A. graveolens* 'Dura Sv') and parsley (*P. crispum*) were used in this study. Seeds were sown in plastic pots (size 1.5 L) containing a commercial potting mixture, pro Mix BX (peat moss 60: vermiculite 20: perlite 20 parts, by volume; N: P_2O_3: K_2O, 5:10:5; pH 6.0). The plants were thinned after cotyledon emergence to 5 seedlings per pot, and were grown in a glasshouse (Botany and Microbiology Department, College of Science, King Saud University, Riyadh, KSA). Average day and night temperatures were 23 and 19°C, respectively. Plant watering included weekly treatment with 0.2% water soluble fertilizer (Peters Professional, N: P_2O_3: K_2O, 24:8:16).

All plants received full daylight during the experimental period, while at night, all plants were covered with black cloth to prevent light from external sources, and concentrate the treatments. Plant treatments were as follows, Red light (RL): 40 W red fluorescent tubes from General Electric Co. (F 40 R) + Red Filter (Roscolux 19) for 4 h at 1.2 mW/m^2, RL: FRL 2.08; Far-red light (FRL): 75 W incandescent bulbs + Plastic Filter (Roscolux 358) for 4 h at 1.4 mW/m^2, RL: FRL 0.7; Control: untreated. Each treatment consisted of 18 pots (6 cilantro, 6 dill, and 6 parsley). Light treatments were started 20 days after sowing with 18 pots treated with either RL, or FRL, or control. Additional light exposure was for 4 h nightly, from 10 pm to 2 am. Control plants were not exposed to any treatment during the night. Experimental duration was 50 days: 20 days' pretreatment, and 30 days of treatment. All plants were harvested 30 days after the start of treatment. The natural day length increased during the experiment from 13 h 20 min, to 13 h 35 min. Light levels were measured every 5 days at canopy height by a digital photometer LI 250 a light meter (Li-Cor Biosciences, Lincoln, Nebraska, USA). The RL: FRL ratio was measured with a cosine corrected sensor (SKR 100 660/730 measuring unit, SKR 110 sensor head, Skye Instruments Ltd., Llandrindod, Wells, UK).

Measurements

The plant samples were harvested at a vegetative stage (prior to flower bud formation) by cutting the vegetative parts above ground. Plant fresh weight, height, petiole length, internode length, leaf number, and leaf area were determined by measuring 10 randomly selected plants from each treatment. An LI-3100 meter (Lambda Instruments Corp., Lincoln, Nebraska, USA) was used to measure leaf area. The plant material was dried to a constant weight in an oven at 55°C to determine dry weight.

Chlorophyll analysis

Chlorophyll was extracted using 80% acetone in the dark at 22-25°C. Chlorophyll concentration was calculated as mg g^{-1} FW according to the equations described by Porra (2002).

Essential oil isolation

Air-dried plant samples (200 g) were placed in a 0.5 L round-bottom distillation flask and 300 ml of distilled water was added. The essential oils were obtained by steam distillation for approximately 3 h with Clevenger's apparatus, according to the European Pharmacopoeia method (Commission, 2010). The oils were separated, dried over anhydrous sodium sulphate, filtered, and stored in a closed bottle at 4°C until used. The essential oil yield for each treatment was calculated as the ratio of oil to dry vegetative biomass (oil µg/g DW).

GC-MS analysis of essential oil

The essential oils were analyzed by gas chromatography coupled with mass spectrometry (GC-MS) (QP2010 Ultra, Shimadzu, Kyoto, Japan). The sample was dissolved in dichloromethane (1%) and injected at 250°C (injector temperature) into a capillary column type HP-1 (30 m, 0.25 mm i.d, 0.25 µm film thickness, stationary phase (95% diethyl-5% diphenyl poly siloxane)), using helium as a carrier gas at a flow rate of 1.2 ml/min. The injected volume was 1 µl and the injection mode used was split (split ratio 300), the injection temperature was 250°C. The oven temperature was raised from 35°C (hold for 3 min) to 240°C at the rate of 5°C/min, then at the rate of 3°C/min, raised to 280°C, hold for 3 min. Interface temperature was 250°C; the ion source temperature was 200°C. The MS system was operated in electron ionization mode at 70 eV. The mass and scan range was set at m/z 35-800. Identification of the essential oil compounds was based on the comparison of their spectral fragmentation with data reported in NIST 14 (National Institute of Standards and Technologies, Mass Spectra Libraries) (Adams, 2007; NIST, 2017).

Statistical analysis

Each pot was treated as one replicate and all the treatments had 6 replicates. The data were analyzed statistically with SPSS-17 statistical software (SPSS Inc., Chicago, Illinois, USA). Means were statistically compared with Duncan's Multiple Range Test at $p < 0.05$.

RESULTS AND DISCUSSION

Effects of RL and FRL on vegetative traits

The growth and development of cilantro, dill, and parsley plants in response to RL and FRL treatments (Table 1) was similar to that reported for other plants. RL and FRL showed effects on the morphological and physiological parameters under study in the experimental period. The effects of RL and FRL treatments appeared in all species under study, some significant variations were observed in treated plants. Plant species differed in their responses to light quality, the variation in effects was low between RL and FRL. The effect of RL was slightly greater than FRL in some traits. Fresh and dry weight increased non-significantly, compared to the control plants in all species under RL and FRL treatment, and FRL treatment decreased them non-significantly compared with RL plants.

Our results in Table 1A, B, and C show that fresh and dry weight in all plants treated with RL and FRL showed no significant changes, but generally, the traits tended to increase in the RL and FRL treatments compared to control plants. RL showed greater effects compared to FRL. The slightly increased biomass in study plants can be attributed to the short exposure to RL and FRL. Our results are generally in line with previous studies which indicate that treating plants with RL, or RL and FRL, at midnight (Cao et al., 2016), or under normal conditions (Norouzi et al., 2017), leads to an increase in fresh and dry weight. However, the results are contrary to Su et al. (2014) and Werbrouck et al. (2012) who reported that RL and FRL have negative effects on biomass. The increase in biomass in our study can be attributed to increased carbohydrate content and starch accumulation, due to the increased amount of chlorophyll, thus increasing the frequency of photosynthesis. Photosynthesis is responsible for the accumulation of most, or all, dry matter in plants (Kang and van Iersel, 2004). This explanation is consistent with previous studies, which reported that the concentration of starch increased in seedlings grown under RL (Li et al., 2012).

In all plants treated with RL or FRL, internode length increased significantly, while plant height and petiole length increased non-significantly. The response of plants to the effects of RL and FRL varied depending on the species. In general, plants tended to increase in height compared to control plants (Table 1A, B, and C).

In the present study, the elongation of stems, height of plants and petiole length in plants treated with RL and FRL may be due to changes in indole-3-acetic acid (IAA) and gibberellic acid (GA3) levels. IAA and GA3 may alter plant tissues and cells through conversion of phytochromes (phys) from Pr form to Pfr form, or vice versa. Pr is the biologically inactive form and absorbs RL, whereas the Pfr form is biologically active and absorbs FRL (Smith, 2000). Conversion between the Pr and Pfr forms may be occurring, and therefore leading to plant growth and adaptation to the light environment. In daylight, phys exists mainly in the Pfr form, which may cause inhibition of genes involved in growth and elongation. During the night period, Pfr slowly converts into the inactive Pr form, which may lead to the stimulation of genes involved in growth and elongation (Soy et al., 2012). Phys has a variety of photomorphogenic effects in plants including effect on leaf and stem traits (Nobel, 2009). This explanation is supported by several of reports, which indicate that IAA and GA levels in plants are related to the state of Pr, Pfr and the conversion between them. This may be due to exposure of the plant to RL or FRL, and therefore lead to effects on the growth and development of the plant (Hisamatsu, 2005; Kurepin et al., 2010; Liao et al., 2014).

Generally, our results are consistent with several results of previous studies on plants treated with RL, or FRL, or both. For instance, RL and FRL at NB lead to non-significantly increased stem and internode elongation of *Fuchsia hybrida* (Vince-Prue, 1977), treatment by a low RL:FRL ratio or end-of-day FRL led to a significant increase in stem elongation in tomato (*S. lycopersicum*) (Chia and Kubota, 2010), also, in tomato (*S. lycopersicum*) NB treatment with RL led to a non-significant increase in plant height and total dry weight (Cao et al., 2016) , RL led to stimulated an increase in the height of *T. officinale* (Ryu et al., 2012), and *R. glutinosa* (Manivannan et al., 2015). The red shade cloth stimulated stem elongation in *P. variegatum* (Oren-Shamir et al., 2001), sweet basil (*O. basilicum*),

Table 1. Effects of red light (RL.) and far-red light (FRL.) for a limited time (10 pm - 2 am) during the dark period on the growth and development of cilantro Ci (*C. sativum*), dill Di (*A. grveolens*, and parsley Pa (*P. crispum*).

Plant	Treat	Weight		Height (cm)	Length		Leaf		Total Chlo (mg g^{-1} FW)
		Fresh (g)	Dry (g)		Internode (mm)	Petiole (cm)	Number per plant	Area (mm^2)	
					A				
	Con.	7.31^{a}	0.63^{a}	23.87^{a}	1.57c	8.55^{a}	11.75^{a}	133.60^{a}	2.68^{b}
Ci	RL	7.55^{a}	0.76^{a}	25.45^{a}	2.55^{b}	8.57^{a}	11.48^{a}	132.07^{a}	2.73^{a}
	FRL	7.47^{a}	0.74^{a}	25.63^{a}	3.60^{a}	8.58^{a}	11.25^{a}	131.86^{a}	2.73^{a}
					B				
	Con.	3.98^{a}	0.49^{a}	25.67^{a}	1.23^{b}	13.93^{a}	9.53^{a}	22.29^{a}	2.44^{b}
Di	RL	4.30^{a}	0.57^{a}	28.42^{a}	3.33^{a}	13.95^{a}	9.42^{a}	21.22^{a}	2.48^{a}
	FRL	4.20^{a}	0.54^{a}	29.50^{a}	4.67^{a}	13.97^{a}	9.40^{a}	21.20^{a}	2.47^{a}
					C				
	Con.	3.22^{a}	0.33^{a}	18.60^{a}	0.95^{b}	8.88^{a}	8.72^{a}	42.08^{a}	2.72^{b}
Pa	RL	3.48^{a}	0.44^{a}	19.92^{a}	2.00^{a}	8.90^{a}	8.47^{a}	41.43^{a}	2.77^{a}
	FRL	3.45^{a}	0.43^{a}	20.20^{a}	2.35^{a}	8.93^{a}	8.42^{a}	40.67^{a}	2.76^{a}

Different letters in a column represent significance at 0.05 level. Control (Con.) and (Chlo) chlorophylls.

cilantro, and parsley (*P. crispum*) (Appling, 2012).

The results also concur with results of previous studies about effects of the FRL on plant growth, where it has been suggested that FRL increased plant height and stem mass in pepper (*C. annuum*) (Brown et al., 1995), caused increased stem elongation in *R. officinalis* L. (Whitelam and Halliday, 2008), and increased the stem length, in baby lettuce (*L. sativa*) (Li and Kubota, 2009), and FRL was more effective than RL at maintaining growth in *P. abies* (Molmann et al., 2006). Leaf number and leaf area decreased non-significantly in plants treated with RL and FRL, compared to the control (Table 1A, B and C). This may be because the period of exposure to RL or FRL was not enough to cause significant effects. Norouzi et al. (2017) reported that 8 h of RL led to an increase in the number of leaves and leaf area of strawberry plants. Some previous studies reported similar results to the current study. Hälvä et al. (1992b) reported that leaf number and leaf area decreased non-significantly in dill plants that grew under RL or FRL for 4 h at end-of-day. Mulas et al. (2006) reported that leaf number reduced in rosemary (*R. officinalis*) under FRL. Holmes and Smith (1975) showed that a high level of FRL reduced leaf area. Chia and Kubota (2010) and Kurepin et al. (2010) reported that the tomato plants treated with a low RL:FRL ratio, or were treated with end-of-day FRL showed no differences in leaf area. Liu (2013) reported that the leaf area in *A. roxburghii* was not different under a 12 h photoperiod with red LEDs. Su et al. (2014) showed that RL inhibited the expansion of leaf area of cucumber seedlings.

Chlorophyll pigments in plants are important for capturing light energy and converting it into chemical energy needed for the growth and development of plants. Chlorophyll content is used as an indicator to assess the growth and vigor in plants (Ni et al., 2009). Plants change their chlorophyll content and composition in response to light quality (Manivannan et al., 2015), which may affect the growth of the plant in terms of accumulation of biomass, chlorophyll, and products of economic importance (Ye et al., 2017).

In the current study, light quality had a positive effect on the chlorophyll content in the leaves of all treated plants (Table 1A, B and C). Total chlorophyll content increased significantly in plants treated with RL and FRL. This increase is likely to be because wavelengths of RL are fully proportional to the peak absorption of chlorophyll and phytochromes. In our study, the increase in chlorophyll content was in line with the other trait results, such as increases in biomass, and petiole and internode length. The results of the current study are consistent with previous reports, which declared that RL and FRL have an effect on the chlorophyll pigments in plants. RL is essential for chlorophyll synthesis (Lamparter et al., 1997), and promotes chlorophyll synthesis and its content in plants, such as in marigold and salvia seedlings (Heo et al., 2002), kale (*B. oleracea* L.) (Lefsrud et al., 2008), and *C. loddigesii* (Galdiano et al., 2012). Similar results have also been reported for *R. glutinosa* and *T. aestivum* L. (Manivannan et al., 2015), lettuce (*L. sativa* 'Creipa') (Chen et al., 2016) and artichoke (*C. cardunculus*) *(Rabara et al.*, 2017). FRL can lead to an increase in photosynthetic efficiency through increases in photochemical and photosynthetic efficiency of light

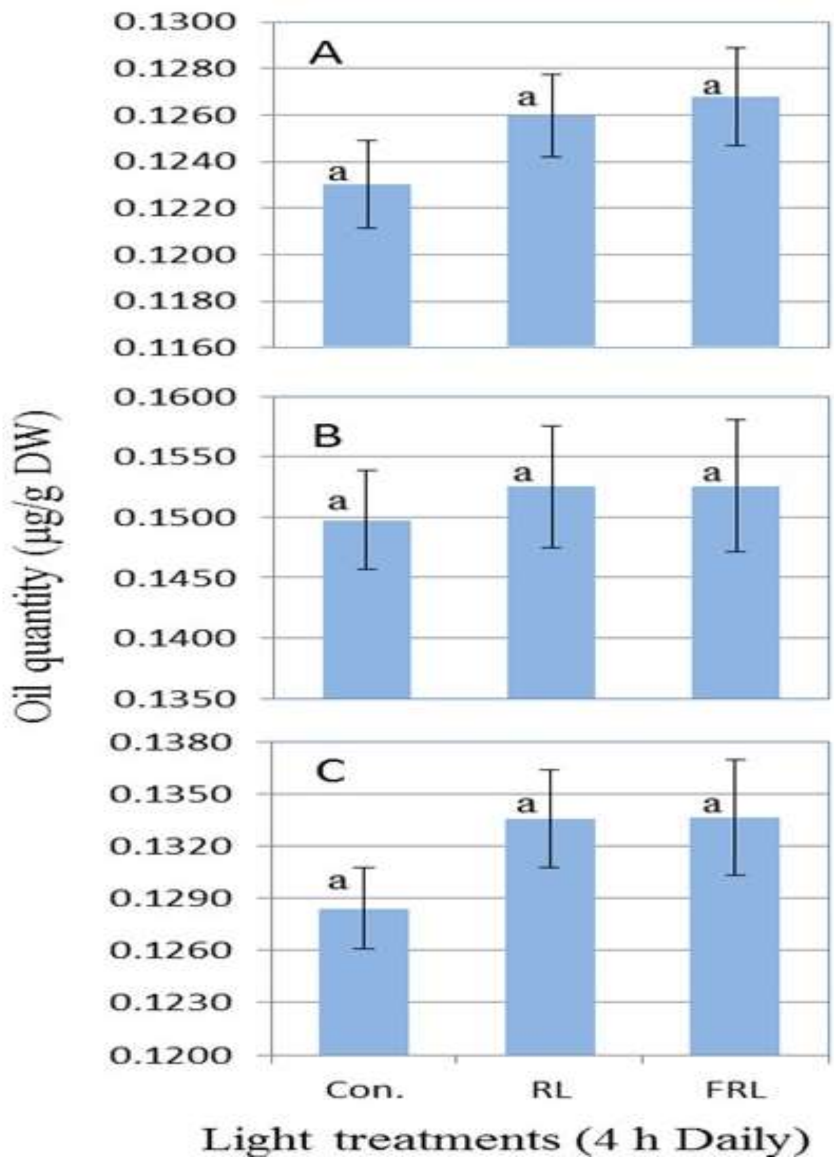

Figure 1. The effects of red light (RL) and far-red light (FRL) for a limited time (10pm-2am) during the dark period on essential oil quality in cilantro (A), dill (B), and parsley (C), control (control).

(Zhen and van Iersel, 2017). However, some studies have indicated contrary results. RL and FRL may decrease the chlorophyll content in some plants, for instance, chlorophyll content decreased in three grape hybrids (Hybrid Franc, Ryuukyuuganebu and Kadainou R-1) under pure red-light-emitting diodes (Poudel et al., 2007), and cucumber plants under RL (Wang et al., 2010). FRL decreased the concentrations of anthocyanin, carotenoids, and chlorophylls compared with white light alone (Brouwer et al., 2014), but Paradiso et al. (2011) showed that FRL could improve plant photosynthesis in rose and lettuce (*L. sativa* 'Green Towers') (Zhen and van Iersel, 2017).

Essential oil quantity

The results (Figure 1) show that all species treated with RL and FRL had higher percentages of essential oil content in the dry sample than in control plants. The percentage and difference between light treatments effects, was non-significant statistically, compared to the control plants; this may be due to insufficient exposure to the light treatments. In general, the results tend to indicate that the light spectra used in our study have a positive effect on the essential oil content in the plants under study. The results of the study are in line with the results of a number of previous studies which indicate

Table 2. The effects of red light (RL.) and far-red light (FRL.) for a limited time (10 pm to 2 am) during the dark period on the composition of essential oil in cilantro Ci (*C. sativum*), dill Di (*A. graveolens*), and parsley Pa (*P. crispum*), and Control (Con.).

Plant	Light treatment	Name of chemical compounds							
		α-Phellandrene	Cymene	Limonene	Linalool	Myristicin	Myrcene	α-Pinene	β-Pinene
		(µg/g)							
					2A				
Ci	Con	4.4	0.26	0.31	13.97	-	-	2.1	-
	RL	4.77	0.28	0.32	15.3	-	-	2.2	-
	FRL	4.8	0.28	0.33	15.36	-	-	2.3	-
					2B				
Di	Con	10.58	1.5	0.64	9.8	0.37	3.71	4.24	2.62
	RL	11.63	1.59	0.67	10.2	0.38	3.88	4.39	2.8
	FRL	11.67	1.63	0.69	10.4	0.39	3.95	4.47	2.85
					2C				
Pa	Con	-	1.63	4.85	0.46	41.4	4.36	6.26	2.44
	RL	-	1.77	5.2	0.47	44.3	4.77	6.81	2.64
	FRL	-	1.79	5.26	0.48	44.8	4.83	6.83	2.67

that the RL and FRL treatment have effects on the content of essential oil in some plants, where Hälvä et al. (1992b) indicated that the oil content increased in dill (*A. graveolens*) that was treated for 4 h with RL and FRL at end-of-day. Mulas et al. (2006) indicated that RL and FRL treatment led to a significant increase of essential oil in rosemary (*R. officinalis*). RL and other light wavelengths also have an effect on essential oil content in plants. Heydarizadeh et al. (2014) showed that RL increased the content of essential oil fourfold in peppermint (*M. piperita*), compared to that in the field. RL increased essential oil content in *M. piperita*, *M. spicata*, and *M. longifolia* compared to blue or white light (Sabzalian et al., 2014). Red, blue, and UV light enhanced the concentration of essential oils in various herbs (Dou et al., 2017).

In our study, the increase in essential oil contents was consistent with other vegetative characteristics, and the correlation with biomass seems clear. Our results concur with previous studies which indicate that essential oil synthesis and its increased production is associated with the traits of growth, function, and biomass in plants, and influenced by several factors (El-Zaeddi et al., 2016). including environmental conditions (İzgı et al., 2017). Essential oils are one of the most important compounds in plants. Researchers have reported that light can have a direct or indirect effect on the production and accumulation of essential oils through the increase of plant biomass; for example, in chamomile (*Matricaria recutita* L.) Verzár-Petri et al. (1978), sage (S. *officinalis*), thyme (*Thymus vulgaris*) (Li et al., 1996), *M*. *piperita* (Pegoraro et al., 2010), *Ocimum gratissimum* L. (Fernandes et al., 2013), and cell cultures of *Melastoma malabathricum* (Chan et al., 2010).

Essential oil constituents

After essential oil isolation from cilantro, dill, and parsley shoots, eight compounds were identified to investigate the essential oil components using GC-MS (Table 2). All eight compounds were observed in the essential oils of the plants under study, except for α-phellandrene in parsley, and Myrcene, Myristicin and β-Pinene in cilantro. The eight compounds were found in different amounts in the three species, this may be due to the differences in plant species. Table 2 shows slight differences in the quantities of essential oils in the study species.

In cilantro (Table 2), the essential oil constituents included α-phellandrene, cymene, limonene, linalool, and α-pinene. Our results revealed there to be various effects on the essential oil components in plants under RL and FRL treatments compared to control plants. With the exception of linalool, the light treatments had little effect on other essential oil components, including α-phellandrene, cymene, limonene, and α-pinene. The highest concentration of linalool was observed in plant tissue that was treated with RL and FRL, while the lowest concentration was cymene. The highest essential oil percentage increase was observed in linalool, whereas the lowest was observed in limonene.

The essential oil components of dill included α-phellandrene, cymene, limonene, linalool, myristicin, myrcene, α-pinene, β-pinene (Table 2). The four major components were α-phellandrene, linalool, myrcene, and α-pinene. The effects of the treatments on the concentrations of essential oil constituents was to increase them slightly but non-significantly.

Finally, the essential oil components of parsley were cymene, limonene, linalool, myristicin, myrcene, α-pinene, and β-pinene (Table 2). The three major components were myristicin, limonene, and myrcene. Our results showed no differences in the proportions of essential oils, but quantities tended to increased.

In general, the effects of RL and FRL treatments on concentrations of essential oil constituents increased, but not significantly. This may be because the period of plant exposure to the treatments was insufficient to cause a significant increase. The eight compounds tended to be in higher concentrations in plants treated with FRL, then RL, then control. The increase in the total oil content in plant tissues and the effect on its components may be due to the effects of RL and FRL on the pathways of building these components. The RL and FRL may also have an effect on the enzymes induced to build the compounds. The biosynthesis of aromatic compounds occurs through two complex chemical pathways, involving different enzymatic reactions which depend on a large group of enzymes known as terpene synthases (Rehman et al., 2015). Ivanitskikh and Tarakanov (2014) reported that light spectrum variations can be used for the biosynthesis of substances in plants including essential oils. Light intensity can also affect essential oil production through the stimulation of photosensitive enzymes involved in the mevalonic acid pathway (Gobbo-Neto and Lopes, 2007). Thus, irradiance can directly influence the production of essential oils, or indirectly, through the increase of plant biomass (Pegoraro et al., 2010). Plant essential oil composition is very sensitive and can be affected and modified under various conditions of light, nutrition, water, and temperature (SimÕes and Spitzer, 2000; Lima et al., 2003; Fernandes et al., 2013). Shafiee-Hajiabad et al. (2016) reported that light intensity affected the essential oil composition in *O. vulgare*. Based on our study, there seems to be consistency between our results and the results of previous studies on essential oil components.

Conclusion

The present study shows the effect of RL was slightly greater than FRL in traits, fresh and dry weight that increased non-significantly, compared to the control plants in all species under RL and FRL treatment; and they increased the essential oil content and dry matter of all three species. In our study, the increase in chlorophyll content was in line with the other trait results, such as increases in biomass, and petiole and internode length. The concentrations of individually volatile compounds in cilantro, dill, and parsley essential oils were slightly affected by the different light spectra. Light spectrum that used in present study increased the essential oils content may be due to the effects of RL and FRL on the pathways of building these components. The RL and FRL may also have an effect on the enzymes induced to build the compounds. In general, most of studied traits in the study species subjected to RL and FRL tended to increase slightly. Therefore, the use of light spectra may be useful for inducing plant responses, and for enhancing the nutritional value of plants.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Effects of conservation tillage on maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.) chlorophyll, sugars and yields in humic nitisols soils of Embu County, Kenya

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An experiment was conducted to determine the effects of conservation tillage (CT) practices on leaf chlorophyll content, sugars and yields of *Zea mays* L. and *Phaseolus vulgaris* L. for two consecutive cropping seasons at the Kenya Agricultural and Livestock Research Organization farm in Embu County, Kenya. The experimental design was a Randomized Complete Block Design with 9 treatments replicated 3 times. The treatments were, conventional tillage sole maize, zero tillage sole maize, Furrows/Ridges sole maize, conventional tillage sole bean, zero tillage sole bean, furrows and ridges sole bean, conventional tillage maize-bean intercrop, zero tillage maize-bean intercrop, furrows/ridges maize-bean intercrop. *Zea mays* L. and *Phaseolus vulgaris* L. plants grown under the CT plots had significantly more chlorophyll content, more sugar content and more grain weight than those under conventional tillage practices (CVT). The results provided a physiological basis for the observed increase in yields. They led to a conclusion that the CT method is suitable for improving crop productivity through enhancing physiological functions in the leaf.

Key words: Conservation tillage, chlorophyll, grain weigh.

INTRODUCTION

Approximately 65% of agricultural land in Sub-Saharan Africa (SSA) is degraded (Rockstrom et al., 2009). A major cause is intensive soil tilling and removal of crop residues (Rockstrom et al., 2009). Arable agriculture across sub-Saharan Africa is exposed to climate stress and climate change is predicted to further increase risks of both extreme temperatures and drought (Niang et al., 2014). Negative impacts on crop yields are therefore expected (Schlenker and Lobell, 2010; Lobell et al., 2011).

According to Chivenge et al. (2007), tillage practice plays an important role in the manipulation of nutrient

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storage and release from soil organic matter (SOM). Conventional tillage (CVT) induces rapid mineralization of SOM and potential loss of soil carbon (C) and soil nitrogen (N). Several agricultural systems have been established to be climate-smart, and this includes conservation tillage (CT), (Rosenstock et al., 2016; Thierfelder et al., 2017). The benefits of CT include increased water infiltration, reduction in soil moisture evaporation and reduced soil erosion (Thierfelder et al., 2017).

Despite the yield benefits accruing from the CT practices in Sub-Saharan Africa (Twomlow and Bruneau, 2008), majority of smallholder farmers' fields are still under conventional tillage methods. Furthermore in SSA, the gaps in *Zea mays* L. yields are high with yields having trends of stagnation or decline (Ray et al., 2012; van Ittersum et al., 2013). This low productivity is associated with frequent dry spells and soil fertility depletion (Recha et al., 2012; Ngetich et al., 2012). According to Lobell et al., 2014, closing these yield gaps and reversing this yield decline is a priority. Improved soil and crop yields increase are reported elsewhere in the world as a result of CT practices (Kabirigi et al., 2015; Thierfelder et al., 2017). However, the physiological basis of the observed yield increases as a result of CT practices has not yet been reported. The objective of this study was therefore to determine the effects of CT practices on the chlorophyll content, sugar content and yields of *Z. mays* L. and *Phaseolus vulgaris* L.

MATERIALS AND METHODS

Study site description

The study was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) farm in Embu County, Eastern Kenya (latitude 00°33.18'S; longitude 037°53.27'E; altitude 1420 meters above sea level, in the upper midlands (UM) ecozone, 125 km North-East of Nairobi (Jaetzold et al., 2007). According to Nicholson (2000), annual rainfall is 1250 mm; the mean max. temperatures are 28°C and min. temperatures are 21°C (Jaetzold et al., 2007). Soils in the study site are Humic Nitisols.

The treatments included; three tillage methods, CVT, Furrows/Ridges (F/R), Zero Tillage (ZT) and three cropping patterns (sole *Zea mays* L. (SM), *P. vulgaris* L. (SB) and Maize-Bean intercropping (MB). The experiment was laid out on a Complete Randomized Block Design and replicated 3 times giving a total of 27 plots. The plot dimensions were 7.5 m wide × 10 m length each with 2.0 m path between the plots. For CT tillage practices, 75% of crop residues were applied on the plots by spreading them between the rows at the rate of 2.5 tons ha^{-1} per season on the soil surface. *Z. mays* L. spacing was 75 cm between the rows and 50 cm within the rows. Two seeds were sown and this gave a plant population of 53333 plants ha^{-1}. *P. vulgaris* L. spacing was 50 cm between the rows and 15 cm within the rows while maintaining one plant per hill. The spacing for intercropped bean was 50 cm between the rows and 20 cm within the rows while maintaining two plants per hill to give a plant population of 133333 plants ha^{-1}. Weeds in the CT practices were controlled using the appropriate pre-emergence and post- emergence herbicides. Weeds in the conventional tillage were controlled by tilling the plots using hand hoes twice per season.

Data collection

The chlorophyll concentration was measured three times per season (before flowering, at flowering and after flowering for bean and maize using a SPAD-502 chlorophyll meter (Konica Minolta Sensing Inc., Tokyo, Japan) five randomly selected plants per plot were sampled.

Leaf sugar content

This was measured three times per crop growing season (before flowering, at flowering and after flowering) on bean and maize leaves using the anthrone method (Li, 2000).

Bean and maize grain yields

The bean plants in the net plots were uprooted. The bean pods were manually separated from the stover, sun- dried and packaged into sacks before threshing the grain from the residues. The grains were then dried in the sun to approximately 12.5% moisture content which was determined using a moisture meter before taking the final weight. The total bean grain yield per hectare was then calculated.

All the maize plants on the net plots were harvested by cutting at the ground level after 50% physiological maturity. The maize ears were manually separated from the husks and were dried in the sun. Maize grain was then separated from cobs by hand shelling. After shelling the grains were then dried in the oven for 48 h to adjust the grain moisture content to 12.5% which was determined by the use of a moisture meter. The total grain yield per hectare was then calculated. All data obtained were subjected to analysis of variance (ANOVA) according to the general linear model (GLM) procedure of the Statistical Analysis System (SAS Institute Inc., 2003). The differences between treatment means were considered significant when ($p \leq 0.05$).

RESULTS AND DISCUSSION

Chlorophyll concentration

Bean plant's chlorophyll content varied significantly ($p \leq 0.05$) in all the cropping seasons due to tillage practices (Table 1). Maize chlorophyll content was not affected significantly ($p \leq 0.05$) before and at anthesis (Table 2). However, there was a significant difference ($p \leq 0.05$) on the chlorophyll content after anthesis in the SR 2015 (Table 2). The maize chlorophyll content differed significantly only at anthesis for LR 2016 due to tillage practices ($p = 0.0003$). The highest chlorophyll concentration in all the seasons was recorded at the flowering stage. This is due to increased development of chloroplasts which increases the rate of photosynthesis as the plants manufactures more photosynthetic assimilates to be translocated to the grains for grain filling. The lowest chlorophyll content concentrations were observed at the crop physiological maturity stage (Tables 1 and 2). This could be attributed to the fact that the plants had reached senescence and the loosening of the chloroplasts in the plant leaves.

The CT practices recorded higher chlorophyll content in

Table 1. Effects of tillage practices on bean sugar content (%) at different stages of crop development during short rains SR 2015 and LR 2016.

Tillage practice	Leaf sugar content SR 2015			Leaf sugar content LR 2016		
	Before anthesis	At anthesis	After anthesis	Before anthesis	At anthesis	After anthesis
Conventional tillage	1.9	3.2	1.5	2.0	3.3	1.6
Zero tillage	2.3	2.9	1.5	2.2	3.1	1.3
Furrows/ridges	2.2	3.2	1.7	2.2	3.3	1.7
LSD (0.05)	0.6	0.5	0.5	0.5	0.5	0.6
p-value	0.3	0.4	0.16	0.5	0.5	0.4

Values followed by the same letter along the column are not significantly different p≤0.05. LSD = Least significant difference; SR = short rains; LR = long rains.

Table 2. Effects of tillage practices on maize sugar content (%) at different stages of crop development during SR 2015 and LR 2016.

Tillage practice	Leaf sugar content SR 2015			Leaf sugar content LR 2016		
	Before anthesis	At anthesis	After anthesis	Before anthesis	At anthesis	After anthesis
Conventional tillage	1.7[b]	2.6[b]	1.3[b]	2.1[b]	2.7[b]	1.4[b]
Zero tillage	2.4[a]	2.9[a]	16[b]	2.4[a]	3.3[a]	1.3[b]
Furrows/ridges	2.4[a]	3.4[a]	1.9[a]	2.6[a]	3.6[a]	2.0[a]
LSD (0.05)	0.4	0.4	0.3	0.3	0.5	0.2
p-value	0.005	0.004	0.0005	0.02	0.01	0.0001

Values followed by the same letter along the column are not significantly different p≤0.05. LSD = Least significant difference; SR = short rains; LR = long rains.

comparison with the CVT practice after flowering in the two crop growing seasons (Tables 1 and 2). Higher chlorophyll concentration shows how better a crop is performing and this is an indication of the potential yield (Namuco et al., 2009). The chlorophyll concentration determines the level of photosynthesis and primary productivity according to Egli and Rucker (2012). Studies that were done by Agamy et al. (2012) reported that improved plant nutrients have a positive impact on the growth of a plant and yield factors including chloroplasts in leaf cells. The results of this study are in agreement with their observations (Figures 1 to 4).

Leaf sugar content

Sugar content in beans was highest at the flowering stage for both seasons (Table 1). Maize leaf sugars differed significantly (p≤0.05) at all stages of growth due to tillage practices (Table 2). In comparison, crops grown under CT practices had more sugar content as compared to those grown under CVT (Tables 1 and 2).The sugars were highest at the point of maximum chlorophyll content in both maize and beans (Tables 1 and 2). This could be due to the fact that at maximum chlorophyll content, the plants were actively involved in the manufacture of photosynthetic assimilates in preparation for grain filling. The amount of chlorophyll in the leaves is an indicator of the rate of CO_2 assimilation per unit time and this governs the sugar content in the leaves (Nitasha et al., 2018).

Sugar content was lowest after flowering (Tables 1 and 2). This decrease in sugar content in the leaves could have been as a result of translocation of the photosynthetic assimilates from the leaves to the grains during grain filling. This could also be attributed to the fact that the plant leaves had reached senescence hence the chloroplasts had started aging.

Bean and maize grain weight

The CT practices produced more grain weight in both seasons than in the CVT (Figures 5 and 6). The high bean and maize grain yields under the CT practices could be attributed to increased photosynthetic rates as denoted by the high leaf chlorophyll and sugar content than CVT. Miriti (2010) while working in Makueni sub County in Kenya also found out that there were higher maize yields by 55% in the tied ridged plots than in the CVT plots.

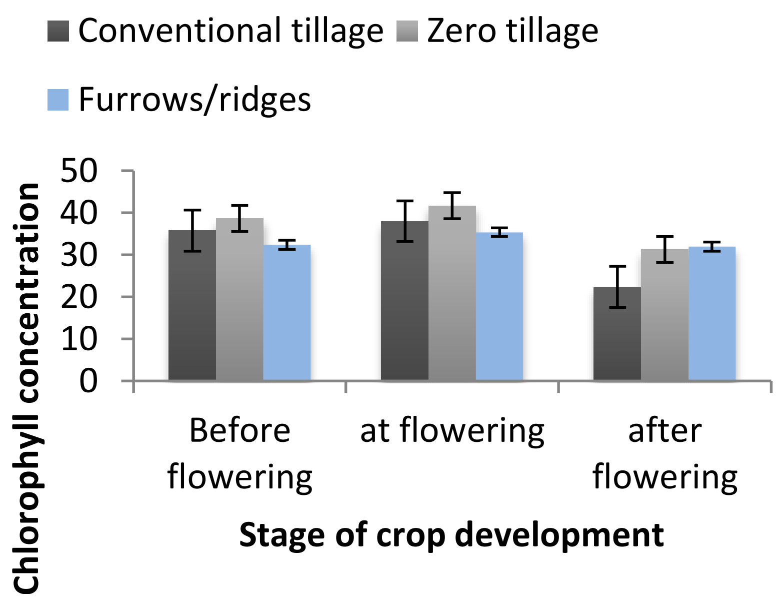

Figure 1. Effects of tillage practices on bean chlorophyll concentration (units of SPAD) taken before, at and after flowering during SR 2015.

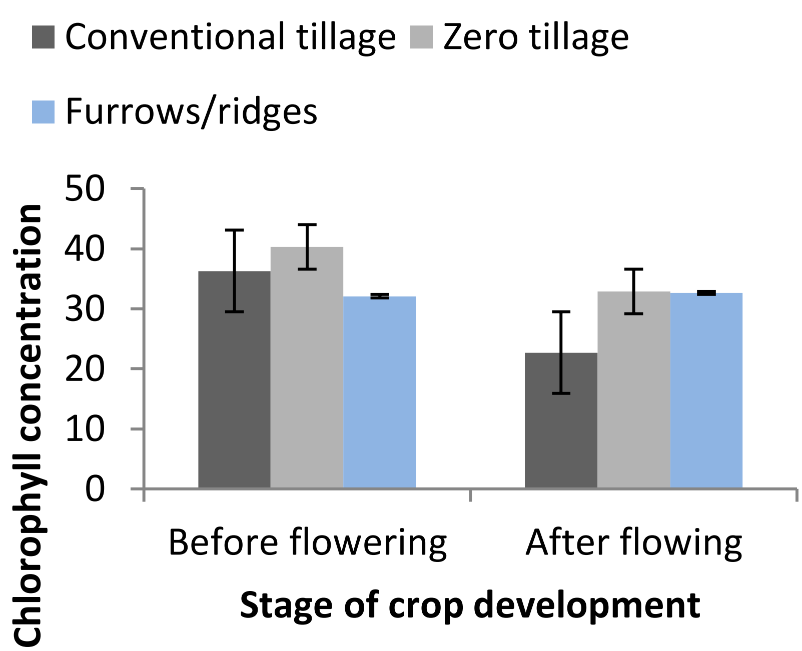

Figure 2. Effects of tillage practices on bean chlorophyll Concentration (units of SPAD) taken before, at and after flowering During LR 2016.

CONCLUSION AND RECOMMENDATIONS

Conservation tillage practices increased the crop's chlorophyll content than the conventional tillage practices. This is an indicator of increased rate of photosynthesis in the *Z. mays* L. and the *P. vulgaris* L. crops grown under the conservation tillage practices than those under the conventional tillage practices. Conservation tillage practices had more *Z. mays* L. and *P. vulgaris* L. leaf sugar content than conventional tillage practices. This led to the observed crop yield increases under the conservation tillage practices than those under

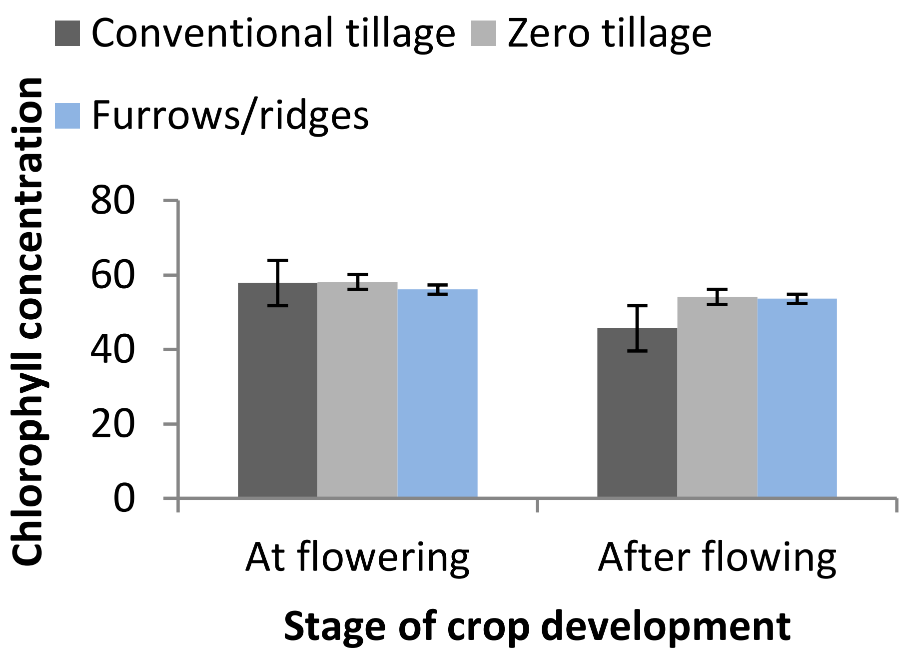

Figure 3. Effects of tillage practices on maize chlorophyll concentration (units of SPAD) at different stages of crop development during short rains SR 2015.

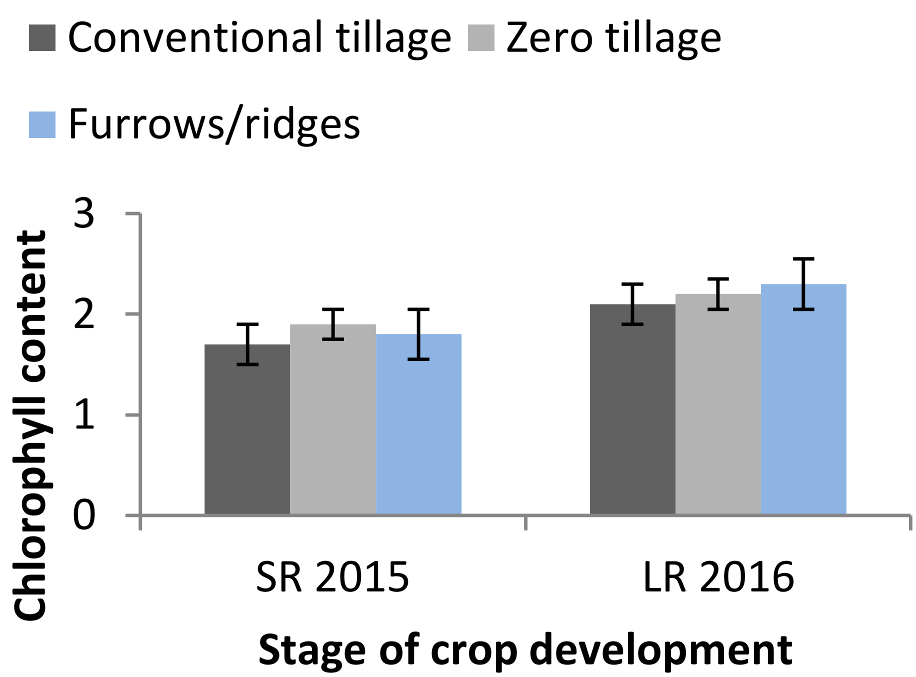

Figure 4. Effects of tillage practices on maize chlorophyll concentration (units of SPAD) at different stages of crop development during short rains LR 2016.

conventional tillage practices. As a result, it will be a good practice to promote conservation tillage practices among farmers for increased crop yields.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

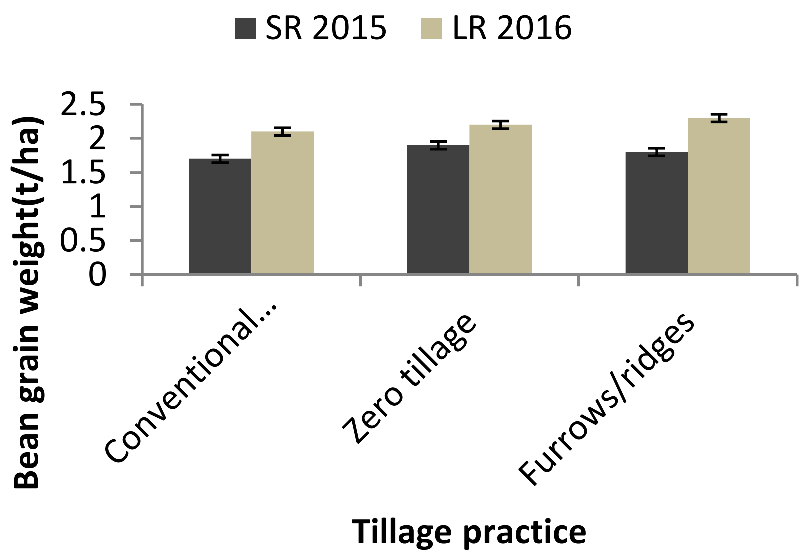

Figure 5. Effects of tillage practices on bean grain weight during short rains 2015 and long rains 2016 seasons.

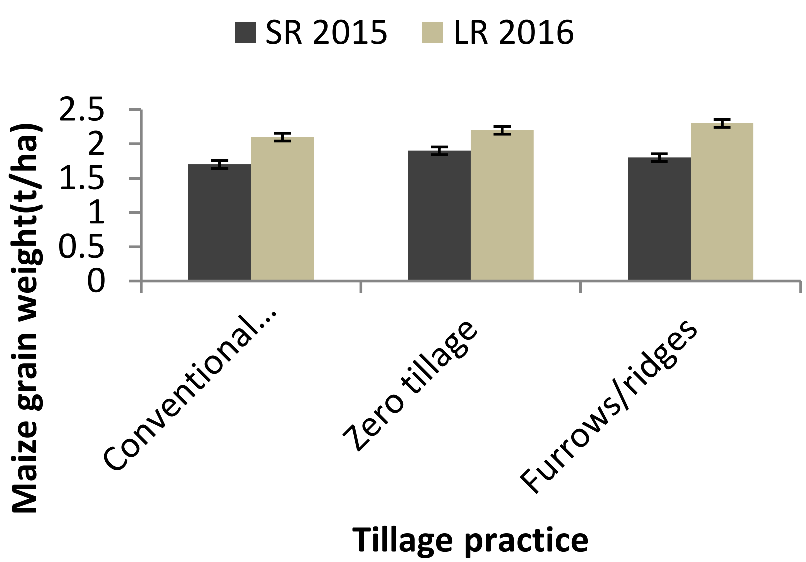

Figure 6. Effects of tillage practices on maize grain yields during short rains 2015 and long rains 2016 seasons.

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