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ORIGINAL ARTICLES

Plastic mulch color and potassium foliar application affect growth and productivity of strawberry (*Fragaria X ananassa* Duch)

[1]A. Abou El-Yazied* and [2]M. A. Mady

[1]*Dept. Hort., Fac. Agric., Ain Shams Univ., Cairo, Egypt.*
[2]*Dept. Agric. Botany, Fac. Agric., Moshtohor, Benha Univ., Egypt.*

ABSTRACT

The field experiment was conducted to study the effect of plastic mulch color (red, red over black and black) and potassium foliar application (0, 500 and 1000 ppm) on some growth aspects, photosynthetic pigments, minerals, endogenous phytohormones, early and total fruit yield and fruit quality of strawberry plants (*Fragaria x ananassa*) cv. Festival during 2009/2010 and 2010/2011 seasons. Results indicated that 1000 ppm potassium foliar application or red and red over black mulches gave significantly the highest values of the plant growth (plant length, number of crowns and leaves, fresh and dry weights, and total leaf area per plant), photosynthetic pigments, NPK, total sugars, total free amino acids and crude protein concentrations in leaves, gibberellins, auxins and cytokinins in strawberry shoots (but the lowest abscisic acid), yield and fruit quality (vitamin C, total soluble solids titratable acidity and anthocyanin). The interactions indicated that the best values of all tested characters were obtained by 1000 ppm foliar K application with red or red over black plastic mulch. Hence, it could be recommended that red and red over black mulches with foliar application of potassium at 1000 ppm can be used to increase the final yield and fruit quality of strawberry plants.

Key words: *Fragaria X ananassa***;** potassium; mulch color; vegetative growth; photosynthetic pigments; endogenous phytohormones; yield; fruit quality.

Introduction

Strawberry (*Fragaria X ananassa* Duch) is one of the most important vegetable crops in Egypt for fresh consumption, processing and exportation. The average area devoted to grow strawberry in Egypt was increased and reached about 13749 fed.; 8418 fed. was for fresh production with an average yield of 18.6 t/ fed. and 5331 fed. was for frigo production with an average yields of 20.7 t/fed. Moreover, the total exportable fruit yield was 23 thousand tons according to Ministry of Agriculture in 2010/2011. The growth and productivity of produced strawberry fruit depend on color of mulches and foliar application with some minerals (Kasperbauer, 2000 and Abo Sedera *et al.*, 2010a and b).

Potassium increases the photosynthetic rates of crop leaves, CO_2 assimilation rate and facilitating carbon movement (Sangakkara *et al.*, 2000). The high concentration of K^+ is thought to be essential for normal protein synthesis. Potassium is the mineral nutrient required in the largest amount by plants. The potassium requirement for optimal plant growth is in the rang 2-5% of the plant dry weight of vegetative parts, tubers and fruits. Potassium is an important component of strawberry fruit and helps the plants regulate water movement and enzymatic reactions. Also, potassium is required for protein synthesis, affects photosynthesis at various levels, stimulated a large number of enzymes and has important functions in phloem transport (Marschner, 1995; Alderfasi and Alghamdi, 2010).

On the other hand, the surface color of plastic mulch can change the quantity of light and spectral balance reaching plants which reflected on growth and fruit production (Brown *et al*., 1992). Plastic mulches are widely used to conserve water by blocking rapid evaporation from the soil surface, enhanced soil biological activity, control weeds with less herbicides, increased plant growth and development, enhanced early yield, increased yield and improved quality and keep fruit clean in the production of tomato, strawberry and other vegetable crops (Decoteau *et al.*, 1990; Lamont, 1993; Kasperbaur and Hunt, 1998). In this respect, Decoteau *et al.* (1988) reported that tomato plants that were exposed to brief periods of FR light at the end of the daily photosynthetic period were taller than those that received brief periods of R light. The effect of FR light on plant length could be reversed by R light and implies phytochrome involvement. Differences in the light spectrum reflected from the plastic, and the similar differential responses to mulch color and light treatments, suggest that tomato plants grown in plastic mulch culture may respond to relatively small changes in light environment induced by the surface color of the mulch.

Corresponding Author: mohamed.mady@fagr.bu.edu.eg, www.bu.edu.eg

Many investigations hypothesized that changing mulch color could keep those benefits, while also reflecting a yield-enhancing morphogenetic light signal to the growing plants (Kasperbauer and Hunt, 1998; Kasperbauer, 2000). Also, Briggs and Olney (2001) concluded that a plant's ability to maximize its photosynthetic productivity is depending on its capacity to sense, evaluate and respond to light quality, quantity and direction. That is the color of light received by a growing plant influences how and where the photosynthetic are used (Kasperbauer, 2000). In the field the amount of red light absorbed and far red light sets the photo-equilibrium of the ratio FR/R, which functions as a regulator of photosynthetic partitioning and allocation. Therefore, the amount of FR received by a growing plant is influenced by FR reflected either from nearby green plants (Oyaert *et al.*, 1999) or from the soil mulch surface (Greer and Dole, 2003). Also, Kasperbauer (2000) reported that yield of strawberry per plant and size per berry were greater over the red mulch than over the black one in the field experiments at a research centre and in a commercial strawberry farm.

The most commonly used plastic color is black. Therefore, we hypothesized that changing mulch color to reflect more far-red (FR) and red (R) light and a higher FR/R ratio with potassium foliar application would keep those benefits and improve not only the quantity of vegetative and reproductive growth of strawberry plant but also the quality of fruits in this plant. In other words, this study aimed to find out the influence of mulch color and potassium level on strawberry productivity.

Material And Methods

The field experiment was carried out during winter seasons of 2009/2010 and 2010/2011 seasons in a private sector farm at Bader Center village, El-Behera Govern., Egypt, to study the effect of colored plastic mulches with potassium foliar application on growth, yield and fruit quality as well as photosynthetic pigments, minerals, endogenous phytohormones, total sugars, total free amino acids and crude protein of strawberry plants (*Fragaria x ananassa*) cv. Festival.

The fresh transplants of the used cultivar were obtained from Strawberry and Non-traditional Crops Improvement Center, Ain Shams University. Transplants were dipped in rhizolex solution at a rate of 2 g/liter for 5 minutes as recommended by Ministry of Agriculture for pathogen disinfection before transplanting. Transplanting was done on 27th and 28th of September in 2009/2010 and 2010/2011 seasons, respectively. Mechanical and chemical analyses of the experimental soil are presented in Table (A). Mechanical and chemical analyses were estimated according to Jackson (1973) and Black *et al*. (1982), respectively.

Table A: Mechanical and chemical analyses of the experimental soil.

	Unit	Seasons	
		2009/2010	2010/2011
	Mechanical analysis		
Coarse sand	%	17.25	18.50
Fine sand	%	37.50	35.70
Silt	%	26.50	28.30
Clay	%	18.75	17.50
Textural class		Sandy loam	Sandy loam
Chemical analysis			
Organic matter	%	2.37	2.16
Available N	ppm	35.9	37.4
Available P	ppm	9.8	7.8
Available K	ppm	22.6	25.2
$CaCo_3$	%	0.51	0.57
Iron	ppm	22.8	24.0
Zinc	ppm	2.27	3.78
Manganese	ppm	12.70	15.80
Copper	ppm	2.42	2.29
Boron	ppm	12.0	16.0
EC	mS/cm	1.21	1.19
pH		7.35	7.20

The experimental design and treatments:

The plastic mulch color treatments were red, red over black, black and bare soil (unmulched) as control. Polyethylene mulch sheets with thickness of 150 µ were used.

Potassium sulfate (K_2SO_4) was used at three levels, i.e., 0 (control, sprayed with distilled water), 500 and 1000 ppm, applied after 40 days from transplanting and every 21-day intervals for four times through the growing season.

This experiment was laid out in a split plot design with four replicates. The plastic mulch color treatments were assigned in the main plots, whereas foliar application of potassium sulfate were distributed in the sub plots. Each plot (10 m^2) was one ridge of 1 m width and 10 m length. The distance between plants was 50 cm on four rows above ridges. There are two ridges of bare soil (unmulched) between each two mulch treatments to provide complete separation of different colors. Before the soil surface of each treatment was covered with mulch, the tubes of trickle irrigation lines were strengthened. The agricultural practices concerning cultivation, fertilization, irrigation and disease control were conducted as commonly followed according to the Ministry of Agriculture for the commercial production of fresh strawberry.

Studied characteristics:

Light reflection was measured for each color of mulch treatment at mid-day on 15^{th} of each of February and March for 2009/2010 and 2010/2011 seasons using an Exotech model 100Ax field hand radiometer. Light reflection measurements included each of green – orange - yellow (500-600 nm), red light (600-700 nm), far-red (700-800 nm) and the invisible near infra-red (800-1100). Then the R photon ratio according to Decoteau *et al.*(1989) and (1990) using the equation of R photon ratio = FR / R ratio was calculated. These values were used because they approach the peaks for phytochrome action spectra in green plants (Kasperbauer *et al.,* 1964), where FR = far-red light, R = red light (Table B).

Table B: Reflection of the visible and invisible light from mulch color under experiment conditions.

Plastic mulch color	Wave length (nm)									
	Visible light (%)								Invisible light (%)	
	Green-orange-yellow 500- 600		Red (R) 600- 700		Far-red(FR) 700-800		FR/R		Near infra-Red (NIR) 800-1100	
	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
	15^{th} of February									
Red mulch	24.80	25.65	43.27	45.70	46.38	53.74	1.072	1.176	48.54	51.89
Red over black	14.56	13.87	51.87	52.64	55.85	58.32	1.077	1.108	53.22	50.43
Black mulch	9.11	11.70	17.84	16.93	9.23	10.89	0.517	0.643	12.85	16.49
Bare soil	6.98	7.24	13.53	13.80	12.64	13.01	0.932	0.953	14.65	15.32
	15^{th} of March									
Red mulch	26.54	26.14	44.18	46.44	49.25	52.86	1.115	1.138	49.87	52.45
Red over black	13.70	12.84	50.78	51.89	54.90	57.95	1.081	1.117	54.32	51.13
Black mulch	10.50	12.45	18.95	19.34	10.44	11.60	0.551	0.599	13.87	17.34
Bare soil	7.24	8.21	13.98	13.90	13.11	13.27	0.938	.941	15.43	15.88

S_1: 2009/2010 season, S_2: 2010/2011 season

Vegetative characteristics: five plants were randomly chosen from central row of each plot at 135 days after transplanting in both seasons to estimate plant length, number of crowns and leaves /plant, fresh and dry weight/plant, and total leaf area using the disk method according to Derieux *et al.* (1973).

Photosynthetic pigments: chlorophyll a, b and carotenoids were calorimetrically determined in fresh leaves of strawberry at 135 days after transplanting in both seasons according to the method described by Inskeep and Bloom (1985).

Chemical composition: total nitrogen, phosphorus and potassium were determined in strawberry leaves at 135 days after transplanting according the methods described by Horneck and Miller (1998), Sandell (1950) and Horneck and Hanson (1998), respectively. Also, total free amino acids, reducing and total sugars were determined according to Rosed (1957) and Thomas and Dutcher (1924), respectively. Crude protein was calculated according to the following equation : Crude protein= Total nitrogen x 6.25 (A.O.A.C., 1990).

Endogenous phytohormones were quantitatively determined in strawberry shoots at 135 days after transplanting in the second season using High-Performance Liquid Chromatography (HPLC) according to Koshioka *et al*. (1983) for auxin (IAA), gibberellic acid (GA_3) and abscisic acid (ABA) while, cytokinins were determined according to Nicander *et al.* (1993).

Fruit yield: early fruit yield was determined as weight of all harvested fruits at the ripe stage during November, December and January. Total fruit yield per plant and per feddan were calculated.

Physical and chemical quality of fruit: ten fruits were randomly chosen from each treatment at full ripe stage to determine fruit length, diameter and weight/plant. Total soluble solids (T.S.S.) was measured using a hand refractometer. Vitamin C, titratable acidity and anthocyanin were determined according to the method described by A.O.A.C. (1990).

Statistical analysis:

Data obtained in this study were statistically analyzed using the least significant differences test (L.S.D.) according to Snedecor and Cochran (1982).

Results And Discussion

Vegetative growth:

The influence of potassium foliar application and plastic mulch color on plant length, number of crowns and leaves, fresh and dry weights, and total leaf area per plant in 2009/2010 and 2010/2011 seasons are shown in Tables (1 and 2). The potassium foliar application at 1000 ppm gave the highest values for all measured vegetative growth traits as compared with other foliar application treatments in the two seasons. The enhancing effect of potassium on plant growth might be attributed to its association with the efficiency of leaf as an assimilator of CO_2 (Rai *et al*., 2002), its essential functions in increasing leaf chlorophyll concentration, delaying leaf senescence (Taize and Zeiger, 2002) and related to the formation of chlorophyll precursor or to the prevention of the decomposition of chlorophyll (Fageria, 2009), activating phyto-hormone, regulation of cellular pH, enhancing N uptake, and acting as an activator for more than 6 enzymatic systems (Marschner, 1995). In this respect, Eshghi *et al*. (2012) found that leaf area was significantly increased after potassium application probably because of a promoting role of potassium in plant growth.

As for the effect of plastic mulch color, the same data in Tables (1 and 2) indicate that red and red over black mulches gave significantly the highest values of plant length, number of crowns and leaves, fresh and dry weights, and total leaf area per plant compared to black mulch or bare soil at any level of foliar application of potassium during both seasons. In harmony with our results, Adams (1977), Fortnum *et al.* (1997) and El-Desouky *et al.* (2005a) reported that tomato plants grown with red mulch resulted in increase of leaf area and dry weight of leaves and branches compared with black mulch or other colors. Leaf area in strawberry was also increased by red mulch when compared with other colors (Wang *et al.*, 1998).

Table 1: Effect of potassium foliar application and plastic mulch color on vegetative growth of strawberry in the first season (2009/2010)

Treatments		Plant length (cm)	Number of leaves/ plant	Number of crowns/ plant	Leaf area/ Plant (cm^2)	Fresh weight/ plant (g)	Dry weight/ plant (g)
		Potassium foliar application					
0 ppm K		13.44	17.79	3.76	314.04	60.86	14.47
500 ppm K		14.87	18.91	3.75	330.59	64.92	15.18
1000 ppm K		15.09	20.90	3.97	352.89	69.04	15.95
LSD at 5%		0.24	1.34	0.23	13.97	1.70	0.33
		Plastic mulch color					
Bare soil		12.39	16.44	2.69	291.80	54.76	12.89
Red		15.11	20.64	4.39	353.50	69.59	16.29
Red over black		16.01	21.96	4.79	367.36	71.57	16.64
Black		14.36	17.76	3.43	317.37	63.84	14.98
LSD at 5%		0.29	1.61	0.22	17.88	1.79	0.37
		Interactions					
0 ppm K	Bare soil	11.83	15.37	2.65	292.86	51.90	12.32
	Red	13.55	19.24	4.29	328.49	64.68	15.34
	Red over black	14.74	20.10	4.68	340.45	66.42	15.89
	Black	13.64	16.45	3.41	294.37	60.45	14.31
500 ppm K	Bare soil	12.53	15.98	2.58	280.49	54.43	13.06
	Red	16.54	20.39	4.31	358.73	69.59	16.10
	Red over black	16.32	21.85	4.73	365.04	71.88	16.41
	Black	14.10	17.42	3.36	318.09	63.77	15.15
1000 ppm K	Bare soil	12.80	17.97	2.84	302.04	57.95	13.28
	Red	15.23	22.28	4.57	373.28	74.51	17.42
	Red over black	16.98	23.94	4.96	396.59	76.40	17.63
	Black	15.35	19.41	3.52	339.64	67.29	15.47
LSD at 5%		0.31	1.83	0.42	31.19	2.37	0.75

It is of interest to note that the increment of vegetative growth characteristics was completely reflected on the dry matter accumulation of these plants. That is of significant value when a great part of this weight being directed towards or allocated to form fruits with onset of flowering and fruiting stages (Tables 8 and 9). Here, the obvious effects of red mulch are including not only significant increases of photosynthetic creation (Tables 3 and 4) but also an alteration of their partitioning and allocation. The black surface reflected less light and a lower ratio of far-red (FR) relative to red (R) light compared to red and red over black surface (Table B). The obtained favorable effect of red mulch on plant growth may be due to that the FR: R ratio plays a major role in assimilate partitioning during influences plant adaptation to competition from other plants (Kasperbauer, 2000). The ratio acts through the phytochrome system to regulate stem elongation, chloroplast development and photosynthate partitioning among shoots, roots and developing fruits. These results are in agreement with those of Mazher *et al.* (2007) and Alderfasi and Alghamdi (2010).

The interaction between potassium and mulch color indicated that red and red over black mulches with foliar application of 1000 ppm potassium gave significantly the highest values of all studied growth characters when compared with other treatments.

Table 2: Effect of potassium foliar application and plastic mulch color on vegetative growth of strawberry in the second season (2010/2011)

Treatments		Plant length (cm)	Number of leaves/ plant	Number of crowns/ plant	Leaf area/ Plant (cm2)	Fresh weight/ plant (g)	Dry weight/ plant (g)
Potassium foliar application							
0 ppm K		12.74	17.84	3.92	309.93	59.92	13.78
500 ppm K		14.42	19.24	3.51	339.12	64.03	16.34
1000 ppm K		15.78	21.20	4.80	355.46	68.79	18.17
LSD at 5%		0.21	1.08	0.30	16.41	1.55	0.51
Plastic mulch color							
Bare soil		12.56	16.84	2.85	305.82	57.83	13.52
Red		14.84	21.09	4.78	350.81	68.54	17.18
Red over black		15.96	21.46	4.92	368.42	69.13	17.94
Black		13.89	18.30	3.76	314.28	61.49	15.74
LSD at 5%		0.25	1.06	0.24	21.04	1.56	0.47
Interactions							
0 ppm K	Bare soil	11.53	15.67	2.74	288.91	50.49	11.78
	Red	12.84	19.04	4.53	314.33	61.34	14.33
	Red over black	14.20	19.92	4.75	336.72	69.54	15.36
	Black	12.38	16.71	3.67	299.77	58.31	13.66
500 ppm K	Bare soil	12.72	16.28	2.24	302.61	60.24	14.23
	Red	15.54	20.97	4.29	362.38	68.88	17.44
	Red over black	15.93	21.59	4.35	372.60	65.17	18.07
	Black	13.48	18.10	3.15	318.87	61.83	15.61
1000 ppm K	Bare soil	13.42	18.57	3.56	325.95	62.75	14.56
	Red	16.14	23.26	5.51	375.72	75.39	19.77
	Red over black	17.74	22.88	5.65	395.94	72.68	20.40
	Black	15.80	20.09	4.47	324.21	64.34	17.94
LSD at 5%		0.34	1.35	0.46	37.57	2.26	0.89

Photosynthetic pigments:

Data in Tables (3 and 4) indicate that potassium foliar application at 1000 ppm gave the highest values for different photosynthetic pigments as compared with other foliar application of potassium in the two seasons. This might be due to the potassium affects photosynthesis at various levels. It is the dominant counterion to the light- induced H^+ flux across the thylakoid membranes (Tester and Blatt, 1989) and for the establishment of the transmembrane pH gradient necessary for the synthesis of ATP (photophosphorylation), in analogy to ATP synthesis in mitochondria (Marschner, 1995).

As for the effect of plastic mulch color, red and red over black mulches gave significantly the highest chlorophyll a, b and carotenoids when compared with other plastic mulch color treatments during the two seasons. Similarly, chlorophyll content was increased in strawberry by red mulch commpared with other colors (Wang *et al.,* 1998). Kreslavski *et al. (*2005) reported that far red light reflected all effects of red light upon wheat seedlings, i.e., increased chlorophyll accumulation and ace-related both coleoptiles and first leaf elongation. In this respect, vigorous growth of strawberry plants grown over red mulch could be attributed to the following facts: (1) providing the common known benefits for mulch (minimizing water consumption, weed control and keeping fruit clean); moreover, changing mulch color to the red one could keep those benefits, while also evocates a growth and yield-enhancing morphogenetic light signal to the growing plants (Kasperbauer and Hunt, 1998; Kasperbauer, 2000). (2) Physiologically, light (including the red one) affects metabolism directly through photosynthesis and growth and development, indirectly (Casal, 2000; Neff *et al.*, 2000; Yang *et al.*, 2001).

On the other hand, different photosynthetic pigments positively responded to the different applied mulch color treatments with foliar application of potassium during both seasons. The red and red over black mulches in the presence of potassium foliar application at the highest level gave the highest values of photosynthetic pigments when compared with other treatments.

Table 3: Effect of potassium foliar application and plastic mulch color on photosynthetic pigments content (mg/g fresh weight) in leaves of strawberry in the first season (2009/2010)

Treatments		Chlorophyll (a)	Chlorophyll (b)	Chlorophyll (a+b)	Carotenoids
Potassium foliar application					
0 ppm K		0.447	0.292	0.739	0.286
500 ppm K		0.445	0.289	0.734	0.314
1000 ppm K		0.525	0.414	0.934	0.434
LSD at 5%		0.027	0.018	0.040	0.024
Plastic mulch color					
Bare soil		0.402	0.296	0.692	0.316
Red		0.523	0.350	0.873	0.347
Red over black		0.541	0.360	0.901	0.354
Black		0.423	0.320	0.743	0.362
LSD at 5%		0.032	0.019	0.035	0.026
Interactions					
0 ppm K	Bare soil	0.361	0.264	0.625	0.264
	Red	0.516	0.308	0.824	0.297
	Red over black	0.537	0.316	0.853	0.304
	Black	0.374	0.278	0.652	0.279
500 ppm K	Bare soil	0.341	0.236	0.577	0.268
	Red	0.522	0.312	0.834	0.301
	Red over black	0.539	0.324	0.863	0.307
	Black	0.379	0.282	0.661	0.381
1000 ppm K	Bare soil	0.503	0.387	0.873	0.415
	Red	0.531	0.429	0.960	0.444
	Red over black	0.547	0.439	0.986	0.451
	Black	0.517	0.399	0.916	0.425
LSD at 5%		0.041	0.032	0.076	0.061

Table 4: Effect of potassium foliar application and plastic mulch color on photosynthetic pigments content (mg/g fresh weight) in leaves of strawberry in the second season (2010/2011)

Treatments		Chlorophyll (a)	Chlorophyll (b)	Chlorophyll (a+b)	Carotenoids
Potassium foliar application					
0 ppm K		0.427	0.253	0.679	0.313
500 ppm K		0.437	0.361	0.716	0.327
1000 ppm K		0.524	0.382	0.893	0.406
LSD at 5%		0.034	0.022	0.071	0.036
Plastic mulch color					
Bare soil		0.400	0.415	0.698	0.330
Red		0.520	0.306	0.826	0.361
Red over black		0.523	0.314	0.836	0.361
Black		0.407	0.293	0.690	0.341
LSD at 5%		0.031	0.028	0.093	0.028
Interactions					
0 ppm K	Bare soil	0.337	0.232	0.569	0.293
	Red	0.501	0.259	0.760	0.321
	Red over black	0.513	0.278	0.791	0.327
	Black	0.355	0.241	0.596	0.309
500 ppm K	Bare soil	0.371	0.636	0.675	0.341
	Red	0.507	0.274	0.781	0.326
	Red over black	0.513	0.287	0.800	0.328
	Black	0.358	0.248	0.606	0.312
1000 ppm K	Bare soil	0.491	0.378	0.849	0.357
	Red	0.553	0.384	0.937	0.435
	Red over black	0.542	0.376	0.918	0.429
	Black	0.509	0.389	0.867	0.402
LSD at 5%		0.067	0.049	0.110	0.053

Minerals and some bioconstituent:

Data in Tables (5 and 6) clearly indicate that foliar application with 1000 ppm potassium increased N, P, K, crude protein, total free amino acids, reducing and total sugars when compared with other foliar application treatments in both seasons. Potassium aids as osmoregulate in photosynthesis by regulation stomata opening and closing, activates more than 60 enzyme system, promotes water uptake and regulates nutrients translocation (Marschner, 1995). Application of K increased CO_2 assimilation and decreased mitochondrial respiration (Peoples and Koch, 1979; Rai *et al.* 2002). Potassium had, also, a favorable influence on photo reduction and photophosphorylation (Mengel, 1997). Also, releasing of K^+ into the xylem sap decreases its water potential and thus favors the uptake of water (Mengel and Haeder, 1977) which is essential for nutrients uptake. This result may be related to K^+ which is needed for stimulating the plasmalemma ATPase that produces the necessary conditions for the metabolites, such as sucrose and amino acids (Barker and Pilbeam, 2007).

As for mulch color, it could be noticed that red and red over black mulches were superior in this respect compared to black mulch and bare soil. Also, Wang *et al.* (1998) indicated that strawberry plants grown on red mulch had the highest content of total sugars compared with plants grown on black mulch color.

Concerning the studied interactions, red and red over black mulches with foliar application of potassium at 1000 ppm gave the highest values of N, P, K, crude protein, total free amino acid, reducing and total sugars when compared with other treatments. In this respect, the high content of total sugars and some bio-constituents may be a direct result for high rates of photosynthesis with great efficiency. That was preceded with large photosynthetic area (Tables, 1 and 2) and high content of photosynthetic pigments (Tables, 3 and 4). These results are in agreement with those of Odeleye *et al*. (2007), Mazher *et al.* (2007) and Alderfasi and Alghamdi (2010).

Table 5: Effect of potassium foliar application and plastic mulch color on some minerals and bio-constituents in leaves of strawberry in the first season (2009/2010)

Treatments		N (%)	P (%)	K (%)	Crude protein (%)	Reducing sugars mg/g (FW)	Non-reducing sugars mg/g (FW)	Total sugars mg/g (FW)	Total free amino acids mg/g (FW)
Potassium foliar application									
0 ppm K		2.13	0.344	2.09	13.33	31.23	18.04	49.27	15.92
500 ppm K		2.26	0.367	2.32	14.11	34.35	18.97	53.32	18.31
1000 ppm K		2.42	0.405	2.41	15.15	35.96	19.87	55.83	19.31
LSD at 5%		0.09	0.010	0.13	0.69	1.09	0.85	3.74	1.13
Plastic mulch color									
Bare soil		2.03	0.324	1.98	12.71	27.64	16.78	44.42	15.44
Red		2.39	0.395	2.38	14.96	35.63	19.73	55.36	18.89
Red over black		2.44	0.402	2.44	15.27	40.58	24.83	65.41	20.45
Black		2.21	0.366	2.28	13.83	31.54	14.49	46.03	16.62
LSD at 5%		0.12	0.010	0.18	0.52	1.31	0.62	4.15	1.06
Interactions									
0 ppm K	Bare soil	1.82	0.294	1.72	11.38	25.30	15.78	41.08	13.37
	Red	2.30	0.367	2.24	14.38	32.60	18.90	51.50	16.91
	Red over black	2.32	0.376	2.29	14.50	37.12	24.29	61.41	19.16
	Black	2.09	0.339	2.11	13.06	29.90	13.17	43.07	14.25
500 ppm K	Bare soil	2.02	0.319	2.03	12.63	28.72	15.79	44.51	15.90
	Red	2.38	0.390	2.42	14.88	35.38	20.08	55.46	19.35
	Red over black	2.43	0.397	2.49	15.19	40.33	25.18	65.51	20.91
	Black	2.20	0.361	2.33	13.75	32.96	14.83	47.79	17.09
1000 ppm K	Bare soil	2.26	0.359	2.20	14.13	28.89	18.77	47.66	17.04
	Red	2.50	0.428	2.47	15.63	38.90	20.22	59.12	20.40
	Red over black	2.58	0.434	2.55	16.13	44.28	25.03	69.31	21.27
	Black	2.35	0.398	2.41	14.69	31.77	15.46	47.23	18.53
LSD at 5%		0.21	0.012	0.20	1.13	2.41	1.19	4.76	1.16

Endogenous phytohormones:

As illustrated in Figure (1), all promoters (gibberellins, auxins and cytokinins) were improved by using mulch color treatments or foliar application of potassium, yet, abscisic acid was decreased. Red and red over black mulches with 1000 ppm potassium foliar application gave the maximum values in gibberellins, auxins and cytokinins while its gave the highest reduction of abscisic acid in shoots of strawberry during 2010/2011 season. These data, could also be of great influence upon different vegetative and reproductive growth. In addition, increasing cytokinin level on the account of auxin could be in favor of increasing the number of formed crowns (Tables, 1 and 2) and improvement of photosynthetic pigments content (Tables, 3 and 4) in strawberry plants.

Also, El-Desouky *et al.* (2005b) reported that tomato plants grown with red mulch resulted in increase of auxins and cytokinins compared with black mulch or other colors.

Table 6: Effect of potassium foliar application and plastic mulch color on some minerals and bio-constituents in leaves of strawberry in the second season (2010/2011)

Treatments		N (%)	P (%)	K (%)	Crude protein (%)	Reducing sugars mg/g (FW)	Non-reducing sugars mg/g (FW)	Total sugars mg/g (FW)	Total free amino acids mg/g (FW)
Potassium foliar application									
0 ppm K		2.26	0.336	2.13	14.10	32.13	16.95	49.07	16.74
500 ppm K		2.34	0.374	2.45	14.63	35.32	19.32	54.64	19.62
1000 ppm K		2.45	0.416	2.47	15.30	37.78	20.82	58.60	20.29
LSD at 5%		0.14	0.012	0.17	0.84	1.13	0.48	3.61	0.74
Plastic mulch color									
Bare soil		2.18	0.336	2.07	13.60	29.52	17.14	46.67	15.36
Red		2.45	0.376	2.45	15.31	37.69	20.08	57.77	20.17
Red over black		2.49	0.411	2.51	15.54	41.57	24.54	66.11	22.29
Black		2.28	0.378	2.36	14.23	31.52	14.35	45.86	17.71
LSD at 5%		0.14	0.011	0.14	0.89	1.84	0.81	3.84	0.63
Interactions									
0 ppm K	Bare soil	2.07	0.301	1.79	12.94	26.81	16.19	43.00	12.77
	Red	2.37	0.318	2.26	14.81	34.89	19.68	54.57	17.53
	Red over black	2.39	0.380	2.32	14.94	39.39	20.29	59.68	20.94
	Black	2.19	0.345	2.16	13.69	27.41	11.63	39.04	15.72
500 ppm K	Bare soil	2.17	0.334	2.17	13.56	29.10	16.93	46.03	16.10
	Red	2.44	0.375	2.55	15.25	37.27	20.53	57.80	20.91
	Red over black	2.48	0.409	2.61	15.50	42.48	25.00	67.48	23.03
	Black	2.27	0.376	2.45	14.19	32.43	14.80	47.23	18.45
1000 ppm K	Bare soil	2.29	0.372	2.26	14.31	32.66	18.31	50.97	17.22
	Red	2.54	0.436	2.55	15.88	40.92	20.02	60.94	22.08
	Red over black	2.59	0.443	2.61	16.19	42.83	28.34	71.17	22.90
	Black	2.37	0.412	2.46	14.81	34.71	16.61	51.32	18.97
LSD at 5%		0.23	0.021	0.22	1.17	3.09	1.21	5.17	1.18

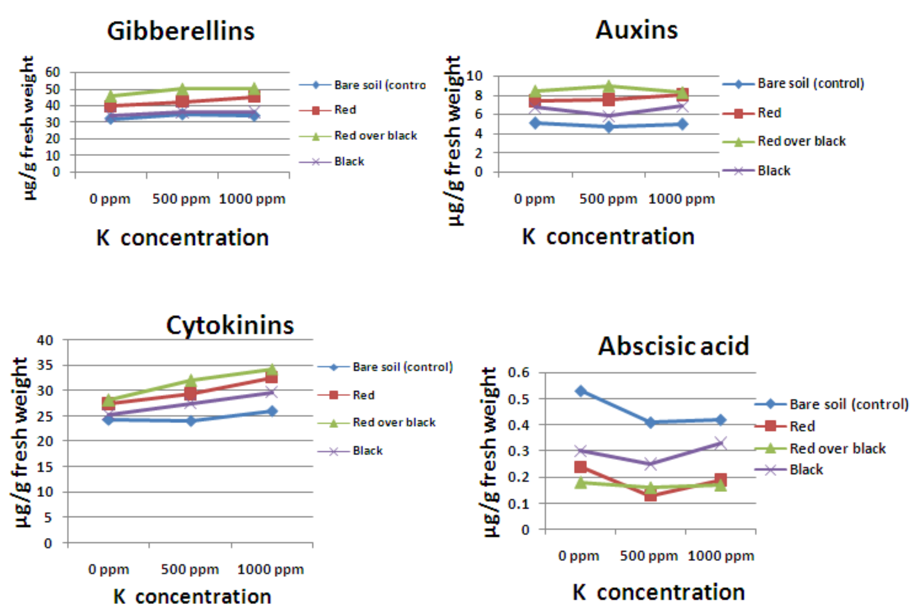

Fig. 1: Effect of potassium foliar application and plastic mulch color on endogenous phytohormones in shoots of strawberry in the 2010/2011season

Fruit yield:

As shown in Tables (7 and 8), the foliar application of potassium at 1000 ppm increased fruit weight, length and diameter, as well as early and total yields per plant or feddan in the two tested seasons compared to other foliar application of potassium. In this respect, Marchand and Bourrie (1999) reported that foliar applications of potassium could also improve yield, especially in heavy clay soils where potassium is not readily available for the plants, or in sandy soils. Also, Khayat *et al*. (2010) reported that early and total yield were increased when strawberry plants were treated with potassium. Moreover, Eshghi *et al*. (2012) on strawberry found that weight of primary and secondary fruits and number of their achenes increased significantly when they were treated with potassium. The favourable influences of potassium on fruit characters and yield might be attributed to its effects on photosynthetic pigments (Tables, 3 and 4), minerals and bioconstitutents (Tables, 5 and 6) and phytohormones (Fig. 1) which could be reflected on plant growth (Tables, 1 and 2) hence increased productivity. Carbohydrates are necessary for growth augmentation of fruits, and since the element K has an important role in loading and unloading of sugars in plant phloem, application of a source of K on plants might increase their fruit weight (Mengel, 2007). Potassium plays a positive role in phloem loading with sucrose and increasing the transport rate of phloem-sap solutes (Herlihy, 1989).

Respecting the plastic mulch color, red and red over black mulches increased fruit weight, length and diameter, early and total yields per plant or feddan in the two tested seasons compared to other mulch color treatments. That means that a large amount of photosynthates are being directed towards the formed fruits. This might be due to the alteration of FR/R light ratio (Table B) which has been reported to affect photosynthates partitioning and allocation (Kraepiel and Miginiac, 1997) resulting in improving biochemical constitutents (Tables, 5 and 6), hence plant growth (Tables, 1 and 2). There are several hypothesis, concepts and theories about the role of phytochrome (the photoreceptor of red and far red light) in the mechanism of plant transition to the generative development.

Concerning the interactions, all mulch color treatments with foliar application of potassium exhibited high significant increases of early and total yields per plant or feddan. Red and red over black mulches with foliar application of potassium at 1000 ppm gave the maximum values during the two seasons. Moreover, fruit characteristics, namely length, diameter and weight, were increased by all mulch color treatments with foliar application of potassium. Red over black mulch with foliar application of potassium at 1000 ppm gave the highest values in fruit characteristics in the two seasons. It could be attributed to the vigorous growth obtained (Tables, 1 and 2) which may be resulted from the high photosynthetic pigments content (Tables, 3 and 4), increasing minerals and bio-constituents (Tables, 5 and 6) as well as auxins, gibberellins and cytokinins and reducing abscicic acid (Fig. 1). Chory *et al.* (1996), Chory and Li (1997), Duchovskis (2004), El-Desouky *et al.* (2005b and c) and Samuloliene *et al.* (2005) suggested that the ratio of phytohormones in plants exposed to the light has substantial influence on flowering initiation especially the increase of gibberellins and auxins and the reduction of abscisic acid. Moreover, potassium has important functions in both loading of sucrose and in the rate of mass flow-driven solute transport in sieve tubes in phloem transport (Marschner,1995).

Table 7: Effect of potassium foliar application and plastic mulch color on physical quality and fruit yield of strawberry in the first season (2009/2010)

Treatments		Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Total yield/ plant (g)	Early yield (ton /fed.)	Estimated total yield (ton /fed.)
Potassium foliar application							
0 ppm K		17.90	4.155	3.11	500.8	4.679	21.07
500 ppm K		18.70	4.343	3.14	530.5	4.919	21.15
1000 ppm K		21.66	5.003	3.55	586.8	5.539	21.43
LSD at 5%		0.50	0.06	0.05	40.6	0.068	0.15
Plastic mulch color							
Bare soil		16.95	4.247	3.16	444.7	3.885	18.71
Red		20.55	4.657	3.29	601.6	5.721	25.34
Red over black		21.38	4.780	3.38	602.5	5.965	25.35
Black		18.80	4.317	3.23	508.7	4.611	21.40
LSD at 5%		0.57	0.08	0.06	44.3	0.081	0.24
Interactions							
0 ppm K	Bare soil	15.41	3.920	3.01	421.4	3.564	17.73
	Red	19.16	4.240	3.16	568.1	5.326	23.90
	Red over black	19.71	4.440	3.21	540.4	5.615	22.74
	Black	17.33	4.020	3.06	473.3	4.210	19.91
500 ppm K	Bare soil	15.95	4.070	3.03	429.0	3.712	18.05
	Red	19.69	4.570	3.13	592.2	5.623	25.00
	Red over black	21.06	4.620	3.26	602.3	5.821	25.34
	Black	18.08	4.110	3.12	498.5	4.519	20.97
1000 ppm K	Bare soil	19.48	4.750	3.45	483.6	4.378	20.35
	Red	22.81	5.160	3.58	644.6	6.215	27.12
	Red over black	23.37	5.280	3.67	664.8	6.458	27.97
	Black	20.99	4.820	3.52	554.3	5.105	23.32
LSD at 5%		0.72	0.12	0.13	67.2	0.108	0.72

Table 8: Effect of potassium foliar application and plastic mulch color on physical quality and fruit yield of strawberry in the second season (2010/2011)

Treatments		Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Total yield/ plant (g)	Early yield (ton /fed.)	Estimated total yield (ton /fed.)
Potassium foliar application							
0 ppm K		18.99	4.250	3.16	510.1	4.640	21.46
500 ppm K		19.39	4.388	3.20	540.5	4.673	21.56
1000 ppm K		22.15	4.939	3.56	586.5	4.713	21.57
LSD at 5%		0.45	0.14	0.07	38.7	0.058	0.09
Plastic mulch color							
Bare soil		17.78	4.293	3.23	453.9	3.742	19.09
Red		21.20	4.683	3.33	608.1	5.706	25.58
Red over black		22.55	4.767	3.40	616.2	5.865	25.92
Black		19.16	4.358	3.27	504.6	4.702	21.23
LSD at 5%		0.62	0.21	0.12	44.1	0.062	0.27
Interactions							
0 ppm K	Bare soil	16.61	4.040	3.08	435.8	3.404	18.33
	Red	19.88	4.330	3.19	579.2	5.352	24.37
	Red over black	21.49	4.500	3.25	561.9	5.518	23.64
	Black	17.97	4.130	3.11	463.6	4.287	19.50
500 ppm K	Bare soil	16.81	4.140	3.13	445.4	3.534	18.74
	Red	20.57	4.630	3.21	580.3	5.513	24.41
	Red over black	21.65	4.600	3.30	617.2	5.666	25.97
	Black	18.51	4.180	3.17	518.9	4.570	21.83
1000 ppm K	Bare soil	19.91	4.700	3.49	480.5	4.289	20.21
	Red	23.15	5.090	3.58	664.7	6.253	27.96
	Red over black	24.52	5.200	3.66	669.5	6.412	28.16
	Black	21.01	4.765	3.52	531.2	5.249	22.35
LSD at 5%		0.95	0.48	0.15	68.3	0.177	0.56

Fruit quality:

Data presented in Tables (9 and 10) show that foliar application of potassium at 1000 ppm, gradually, increased vitamin C content, total soluble solids (TSS), titratable acidity and anthocyanin. This may be due to that the high concentrations of K usually lead to an increase in organic acid concentration, also having a beneficial effect on ascorbic acid levels (Bergmann, 1992). Some experiments showed an increase of vitamin C and in the tubers (Perrenoud, 1993) with potassium application.

Table 9: Effect of potassium foliar application and plastic mulch color on vitamin C, total soluble solids, titratable acidity and anthocyanin of strawberry fruits in the first season (2009/2010).

Treatments		Vitamin C (mg/100g F.W)	Total soluble solids %	Titratable acidity %	Anthocyanin (mg/100g F.W)
Potassium foliar application					
0 ppm K		38.52	5.11	0.56	72.14
500 ppm K		40.53	5.19	0.57	73.96
1000 ppm K		44.77	6.14	0.77	82.05
LSD at 5%		0.69	0.35	0.08	1.06
Plastic mulch color					
Bare soil		38.66	5.14	0.58	72.43
Red		42.96	5.63	0.66	78.14
Red over black		43.65	5.83	0.68	79.38
Black		39.82	5.33	0.61	74.24
LSD at 5%		0.55	0.38	0.12	1.28
Interactions					
0 ppm K	Bare soil	35.58	4.77	0.51	67.22
	Red	39.87	5.25	0.58	74.67
	Red over black	41.25	5.46	0.60	75.23
	Black	37.36	4.96	0.54	71.42
500 ppm K	Bare soil	37.99	4.84	0.52	71.89
	Red	42.64	5.35	0.60	75.52
	Red over black	43.30	5.53	0.62	77.44
	Black	38.20	5.04	0.55	70.98
1000 ppm K	Bare soil	42.41	5.80	0.72	78.18
	Red	46.38	6.29	0.79	84.22
	Red over black	46.40	6.49	0.81	85.46
	Black	43.90	5.99	0.75	80.32
LSD at 5%		1.28	0.92	0.20	3.24

Table 10: Effect of potassium foliar application and plastic mulch color on vitamin C, total soluble solids, titratable acidity and anthocyanin of strawberry fruits in the second season (2010/2011).

Treatments		Vitamin C (mg/100g F.W)	Total soluble solids %	Titratable acidity %	Anthocyanin (mg/100g F.W)
Potassium foliar application					
0 ppm K		40.66	5.08	0.57	73.90
500 ppm K		41.31	5.15	0.61	74.08
1000 ppm K		45.26	6.46	0.76	84.30
LSD at 5%		0.48	0.12	0.07	1.21
Plastic mulch color					
Bare soil		38.81	5.22	0.59	73.29
Red		43.63	5.74	0.67	80.54
Red over black		45.60	5.89	0.71	80.78
Black		41.59	5.38	0.61	75.10
LSD at 5%		0.46	0.12	0.06	1.33
Interactions					
0 ppm K	Bare soil	37.09	4.71	0.52	68.55
	Red	41.82	5.24	0.58	76.48
	Red over black	44.04	5.42	0.63	79.21
	Black	39.67	4.93	0.55	71.34
500 ppm K	Bare soil	38.18	4.84	0.54	70.40
	Red	42.42	5.35	0.65	77.97
	Red over black	44.15	5.47	0.68	75.72
	Black	40.50	4.94	0.56	72.23
1000 ppm K	Bare soil	41.16	6.12	0.70	80.91
	Red	46.64	6.64	0.79	87.16
	Red over black	48.62	6.79	0.83	87.40
	Black	44.61	6.28	0.73	81.72
LSD at 5%		0.79	0.24	0.07	2.08

Respecting the plastic mulch color, red and red over black mulches showed the highest values of vitamin C content, total soluble solids, titratable acidity and anthocyanin compared with other mulch color treatments. Kasperbauer *et al.* (2001) reported also that chemical composition of strawberries developed in sunlight over a specially formulated red plastic were better compared with those that developed over standard black plastic mulch. Also, El-Desuky *et al.* (2005c) attributed the significant increase of tomato and pepper yielded fruits over mulch treatment to those acute alterations in the phytohormones profile and the histological feature in mulched plants as well as repartitioning and allocation of photosynthetic.

As to the studied interactions, in general, applied red and over red mulch color with foliar application of potassium at 1000 ppm gave the highest values of vitamin C content, total soluble solids, titratable acidity and anthocyanin compared with other treatments. In this respect, Marschner (1995) reviewed that environmental factors such as temperature, soil moisture and irradiation (considerably were achieved in mulch treatment) influence both the availability and uptake of nutrients by the roots and the shoot growth rate. These findings are of great economic value because quality as well as the shelf time of such fruits will be increased as confirmed by Wang *et al.*, (1998).

Conclusion:

We could conclude that foliar application of potassium at 1000 ppm and FR and FR/R light ratio, reflected from the red and over red plastic mulch on the soil surface, acted through the natural phytochrome system within the growing plants to modify the productivity enough to increase early and total yields and improve concentrations of vitamin C, total soluble solids, titratable acidity and anthocyanin of strawberry fruit.

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