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Safe Weed Management Methods as Alternative to Synthetic Herbicides in Potato.

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ABSTRACT

Two field trails were carried out to evaluate the effect of different plastic colours (blue, white and black) mulches, biodegradable (plastic and rice straw) mulches, infrared transmitting (IRT) plastic mulch and natural herbicides (acetic acid at 20% (AA), citric acid at 10% (CA) and AA at 10% + CA at 5%) in comparison with hoeing, metribuzin and unweeded check on weed growth and nutrient removal by weeds, tuber physical characters and productivity of potato crop. ,Black plastic mulch, biodegradable mulch and AA (20%) reduced the weed fresh weight by 98.2, 94.1 and 90.7%, respectively, while the lowest reduction (68.6%) was obtained by CA at 10%. The lowest weed density at 90 DAP was recorded in black, blue, biodegradable plastic mulches (3.5-6.9%), while IRT mulch as well as metribuzin and hoeing (9.4-13.4%) came in the second order. Uncontrolling weeds reduced the total yield by 52.5%. All mulches treatments produced yield similar to hoeing. Total tuber yield in the three natural herbicides treatments were insignificant with the metribuzin. The losses of macronutrients by weeds (N, P and K) were 77.3, 5.8 and 66.6 kg/ha and micronutrients (Mn and Zn) were 481.3 and 552.4 g/ha.

Keywords: Potato, Weeds, Natural Herbicides, Mulch, Biodegradable, Infrared Transmitting

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INTRODUCTION

Weed competition with potato plants reduced tuber yield by 32.7% [1], 40.9% [2] and up to 86% [3]. Weeds also had a negative effect on potato tuber quality [4]. Weed infestation removes nutrients from the soil which reflects negatively on crop yield [5].

Metribuzin (Sencor 70% WP) is the recommended herbicide by the Egyptian Ministry of Agriculture for weed control in potato. Although herbicides are highly effective on weed control, inexpensive [6] and have very good selectivity toward crops [7]. They have number of disadvantages include: environmental pollution, reducing potato tuber quality, crop phytotoxicity and the reduction of weed biodiversity [4]. Moreover, the overuse of herbicides has led to the rapid evolution of herbicide-resistant weeds [8]. Hence, there is a new trend to find safe alternative methods for managing weeds without herbicides.

Hoeing is still the most common weed control method in vegetable crops because it has a high weed control efficacy, ranged from 62.9-75% in potato fields [2, 9], 97.6% in tomato [10] and reached 97.8% in onion [11]. On the other side, hoeing is high cost, the labor is unavailable in some regions and it is unsuitable for large farms.

Biodegradable and synthetic mulches have many benefits such as weed and pest management, soil moisture conservation, reducing soil compaction, decreasing nutrient leaching, high quality early and high crop yield [12]. The color of plastic mulch determines its energy radiation behavior and its effect on microclimate around plant, color affects both the surface temperature of the mulch and the underlying soil temperature [13]. White, black and blue plastic mulches decreased weed dry weight by 84.6, 95.3% [14] and 94.2% [15], respectively. Plastic mulch increased yield in different vegetable crops such as potatoes [16- 17], tomatoes [18], pepper [19], cucumber [20] and strawberry [21].

Infrared transmitting (IRT) plastic mulches have been designed in order to filter out photosynthetic active radiation, but allow infrared light to warm the soil [6]. Green and brown IRT plastic films achieved weed density and biomass as well as the black polyethylene mulch, but were significantly less than white film [22]. There was a positive effect on tomato, cucumber and watermelon yields under IRT plastic mulch [23, 24].

Despite multiple benefits, removal and disposal of synthetic polyethylene mulches remains a major agronomic, economic, and environmental constraint [25]. Therefore the use of biodegradable plastic mulch and plant waste mulch were developed. Biodegradable films can be incorporated into the soil at the end of the crop season and undergo biodegradation by soil microorganisms [26]. There were no significant differences in yield responses on the biodegradable mulches as compared with the synthetic polyethylene mulch in different vegetable crops such as tomato, zucchini, pepper and eggplant [27, 28]. The use of rice straw is very common as organic mulch. In Egypt, rice straw is considered one of the most important plant waste problems [29]. Rice straw mulch reduced total weeds number and dry weight and increased weed control percent [1, 11, 30, 31]. Yields of potato, tomato and onion in rice straw mulch were significantly higher than un-mulched soil [1, 11, 18].

Natural herbicides such as acetic acid, citric acid, and essential oils proved effective as nonsynthetic herbicide for controlling broadleaf weeds if applied at an early stage [32,33]. Use of glacial acetic acid at 20% had a potential effect on weed control in potato production when applied at the cotyledon stage of weed growth and pre-potato plants emergence [34].

This study was conducted to examine the effect of different plastic mulches, biodegradable mulches and natural herbicides on weed growth, nutrient uptake by weeds, yield of potato crop and some physical characters of tubers.

MATERIALS AND METHODS

Two field experiments were carried out at the Agriculture Experimental Station of the National Research Centre, El-Nubaria, Beheira Governorate, Egypt, during the two successive seasons of 2015/2016 and 2016/2017 to examine the effect of different colours of plastic mulches, biodegradable mulches and natural herbicides on weed growth, nutrient uptake by weeds, yield of potato crop and some physical characters of tubers. The experiments were conducted in sandy soil, with pH 9.01, organic matter 0.8%, Ec 0.3 dS/m, $CaCO_3$ 2.5%, NO_3 + NH_4 81.3 ppm and total K 0.33%.

The experimental design was randomized complete block design with four replicates. The plot area was 10.5 m^2 (1/400 of fed., contained four rows 3.75 m length and 0.7 m width).

Seeds (tubers) of potato crop (*Solanum tuberosum* L.) Spunta cv. were planted at 1st and 2nd October in the first and the second season, respectively, with space 25 cm between plants. Cultural management and pest control programs were applied according to the recommendations of the Egyptian Ministry of Agriculture. Drip irrigation was applied according to standard recommendations; the irrigation was stopped one week before harvesting.

Organic fertilizer was applied during soil preparation at the rate of 95 m^3/ha + 238 kg/ha sulphur + 167 units of phosphorus of calcium super phosphate (15.5% P_2O_5). Nitrogen fertilizer was applied at the rate of 430 units of N/ha in the form of ammonium nitrate (33.5 % N), divided to equal doses during the growing season, while potassium sulphate (48% K_2O) was added at the rate of 190 kg K_2O/ha and applied during the soil preparation and at 50 and 70 days after planting. The experiment included 12 treatments as following: unweeded check (control treatment), hand hoeing at 3 and 7 weeks after planting (WAP), metribuzin herbicide (Sencor 70% WP) at 714 g (commercial product)/ha, biodegradable blue plastic mulch, IRT white plastic mulch, white plastic mulch, black plastic mulch, blue plastic mulch, rice straw mulch at 10 ton/ha, acetic acid at 20%, citric acid at 10% and acetic acid at 10% + citric acid at 5%.

Biodegradable blue plastic mulch (60 µ thickness) was obtained from Ahram Plastic Group, Shubra El-Kheima, Qalyubia Governorate, Egypt. While, IRT plastic, white plastic, Black plastic and Blue plastic were purchased from Shouman Company for Plastic, El-Marg, Cairo, Egypt. The thickness of all plastics was 60 micron (µ). The mulches were applied by hand after soil preparation and before potato planting.

Acetic acid glacial (99.5%) (CH_3COOH) and Citric acid ($C_6H_8O_7$) were purchased from company of El-Nasr Pharmaceutical Chemicals. Metribuzin was applied at 7 days after potato planting, while acetic acid, citric acid and their mixture were applied before potato plants emergence and directly sprayed towards weeds. Metribuzin and the three natural herbicides treatments using knapsack sprayer at 476 liters water solution/ha.

Recorded data

On weeds

Weed density was recorded at 50 and 90 DAP, and then weed samples were collected randomly from one square meter. Weeds were classified into two groups, *i.e*. annual broad- and narrow-leaves then the number, and fresh weights weeds were determined. Nutrient removal by weeds at 90 DAP were determined by measuring N, P and K elements and Zn, Mn and Fe were determined [35].

At harvest (after 110 DAP)

Fresh and dry weight, diameter, length and specific gravity of tuber were determined. Total yield tuber yield ha^{-1} was determined by harvesting the whole plot area. Physical characters of tubers were measured *i.e*. fresh and dry weights, length, diameter and specific gravity of potato tubers.

Statistical analysis

Data were statistically analyzed using MSTAT and the Duncan multiple range test was used to compare the treatment means. For weeds data, some values were zero; therefore, 1 value was added to each score then data were transformed to square root before conducting the statistical analysis of the data, so each value of x was transformed to $\sqrt{x+1}$. This was carried out to minimize the error term and to fit these values to the normal distribution curve [36]. The interactions between treatments and year for the all variables studied were insignificant; so data were combined over the two growing seasons.

RESULTS AND DISCUSSIONS

A: WEEDS

Weed Flora Composition

The dominant weeds in the experimental field during the two seasons were *Meidicago hispida* Gaertn. which considered the main weed in the field and constituent 69.8% of total weed number in the unweeded check at 50 days after planting (DAP), *Chenopodium album* L. (12.6%), *Emex spinosa* (L.) Campd. (2.1%), *Sisymbrium irio* L. (12.9%) as broad leaved weeds, while *Phalaris minor* Retz. (2.6%) was the only narrow leaf weed (Grass) as shown in Table 1.

Weed density

Different weed control treatments decreased weed density significantly compared to the unweeded check (Fig. 1). Generally weed density at 90 DAP was higher than at 50 DAP, no weeds were observed in all plastic mulch treatments at 50 DAP. The lowest weed density at 90 DAP was recorded in black, blue, biodegradable plastic mulches (3.5-6.9%), while IRT mulch as well as metribuzin and hoeing (9.4-13.4%) came in the second order (Fig. 1). Among all weed control treatments the highest weed density at 90 DAP was noticed in citric acid treatment (58.8%), followed by the mixture of acetic acid and citric acid (38.1), acetic acid (24.9%) and rice straw mulch (21.5%) compared to unweeded check (83.8%).

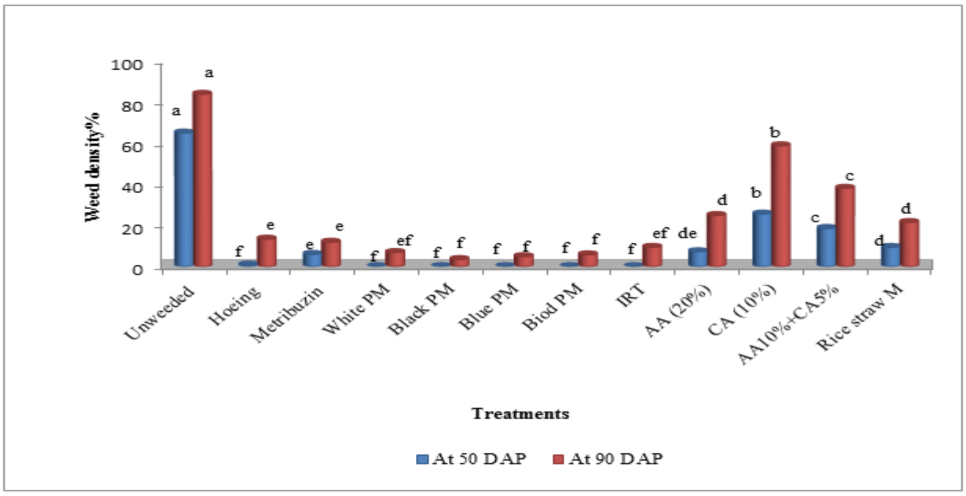

Figure 1. Weed density (%) as affected by different safe weed management methods. Abbreviations: DAP: days after planting; PM: Plastic Mulch. AA: Acetic Acid, CA: Citric Acid. Columns with the same letters are not statistically different at P = 0.05.

Number of Weeds

Number of weed species, total broad leaved weeds and total weeds at 50 and 90 DAP were significantly reduced by the application of weed control treatments (Table 1). At 50 DAP, no weeds were found in synthetic or biodegradable plastic mulches. Insignificant differences were obtained among the previous treatments, hoeing and IRT treatments. Bakht and Khan [37] reported that weed density in black and white plastic mulches was similar to hand weeding. Contrary, [19] reported that number of weeds in white and blue mulches was significantly higher than the control, while in black mulch treatment at 40 days after tomato transplanting was significantly less than the control.

Concerning the number of weeds at 90 DAP; the results in Table 1 show that weed number in unweeded treatment was increased by 6% compared to weeds number at 50 DAP. Acetic acid at 20%, citric acid at 10%, acetic acid at 10% plus citric acid at 5% and rice straw mulch caused a significant reduction in weeds number estimated by 3.5, 22.5, 15.6 and 2.7%, respectively compared to unweeded check, but have a lower efficacy than the other treatments (Table 1).

The results indicated that most safe weed control methods gave more than 90% reduction in weeds number except citric acid 10% and the mixture of acetic acid (10%) and citric acid (5%) which gave 87.7 and 87.1 %. Biodegradable and IRT plastic mulches had the same effect of black plastic mulch and metribuzin herbicide on weeds number (Table 1).

Weed Fresh Weight

The effect of weed control treatments on fresh weight of weed species, broad leaved and total weeds recorded at 50 DAP had a similar trend to number of weeds (Tables 1&2).

Concerning the reduction of weed fresh weight at 90 DAP, the highest reduction (98.2%) was recorded in the black mulch treatment (Table 2). Similar finding was reported [14, 30, 38]. Metribuzin, biodegradable plastic mulch and acetic acid at 20% treatments reduced weed fresh weight by 96.9, 94.1 and 90.7%, respectively (Table 2). The lowest reduction (68.6%) was obtained by citric acid at 10% treatment. All other treatments reduced weeds at the range of 81.2 to 89.4%. Biodegradable blue plastic mulch was capable to reduce weed fresh weight as much as black plastic as found by [28]. IRT plastic mulch produced weed fresh weight significantly similar to the white plastic and higher than black plastic mulch (Table 2). On the contrary, Ngouajio and Ernest [22] found that IRT plastic films achieved weed density and biomass as well as the black polyethylene mulch and less than white film. Weed fresh weight in rice straw mulch treatment wasn't significantly different from all other weed control treatments except for citric acid at 10% which was less effective (Table 2).

Table 1. Effect of weed control treatments on number of weeds at 50 days after planting (DAP) (Combined analysis of two seasons)

Treatments	Broad leaf weeds					*P.*[5] *minor*	Total weeds
	M.[1] *hispida*	*Ch.*[2] *album*	*E.*[3] *spinosa*	*S.*[4] *irio*	Total		
	At 50 DAP						
Unweeded check	130.4 a	23.5 a	3.9 a	24.1 a	181.9 a	4.9 a	186.8 a
Hoeing (twice)	0.0 f	1.3 d	0.0 d	0.0 c	1.3 ef	0.0 d	1.3 fg
Metribuzin herbicide	2.8de	0.0 e	0.5 c	0.0 c	3.4 de	0.0 d	3.4 ef
White plastic mulch	0.0 f	0.0 e	0.0 d	0.0 c	0.0 f	0.0 d	0.0 g
Black plastic mulch	0.0 f	0.0 e	0.0 d	0.0 c	0.0 f	0.0 d	0.0 g
Blue plastic mulch	0.0 f	0.0 e	0.0 d	0.0 c	0.0 f	0.0 d	0.0 g
Biodeg.[6] plastic mulch	0.0 f	0.0 e	0.0 d	0.0 c	0.0 f	0.0 d	0.0 g
Infrared plastic mulch	0.0 f	0.0 e	0.0 d	0.0 c	0.0 f	0.0 d	0.0 g
Acetic acid (AA) 20%	3.8 d	0.6 de	0.5 c	0.5 c	5.4 d	1.3 bc	6.6 d
Citric acid (CA) 10%	31.5 b	5.0 b	1.0 b	3.5 b	41.0 b	1.0 c	42.0 b
AA 10% + CA 5%	22.6 c	3.3 c	0.5 c	1.0 c	27.4 c	1.8 b	29.1 c
Rice straw mulch	1.6 e	0.5 de	0.0 d	1.1 c	3.3 de	1.9 b	5.1 de
	At 90 DAP						
Unweeded check	135.0 a	15.0 a	10.2 a	18.0 a	178.2 a	19.8 a	198.0 a
Hoeing (twice)	9.1 de	1.9 def	1.6 b	0.0 d	12.6 e	0.8 cde	13.4 c
Metribuzin herbicide	4.5 fg	0.8 fg	0.5 de	0.5 cd	6.3 g	0.9 cde	7.1 e
White plastic mulch	5.4 f	1.4 efg	1.3 bc	1.1 cd	9.1 f	1.3 cd	10.4 d
Black plastic mulch	2.4 g	3.0 d	1.0 bcd	0.0 d	6.4 fg	0.0 e	6.4 e
Blue plastic mulch	10.8 cd	0.5 g	1.3 bc	0.5 cd	13.0 e	0.6 de	13.6 c
Biodeg. plastic mulch	5.6 f	2.1 de	0.0 e	1.0 cd	8.8 fg	1.0 cde	9.8 de
Infrared plastic mulch	5.8 f	2.1 de	0.6 cde	0.0 d	8.5 fg	0.5 de	9.0 de
Acetic acid (AA) 20%	7.0 ef	1.5 efg	1.6 b	4.0 b	14.1 e	1.8 c	15.9 c
Citric acid (CA) 10%	14.4 b	4.4 c	1.1 bcd	1.5 c	21.4 c	3.0 b	24.4 b
AA 10% + CA 5%	14.1 b	7.4 b	1.0 bcd	1.5 c	24.0 b	1.5 cd	25.5 b
Rice straw mulch	13.1 bc	1.6 efg	0.0 e	3.5 b	18.3 d	0.0 e	18.3 c

[1]*M.*: *Meidicago*; [2]*Ch. Chenopodium*; [3]*E.Emex*; [4]*S.*: *Sisymbrium*; [5]*P.*: *Phalaris;* [6]Bioodeg.: Biodegradable. Different letters refer to statistically differences following Duncan's multiple range test at P = 0.05.

Citric acid showed a poor effect on weed fresh weight compared to acetic acid and the mixture of acetic acid plus citric acid (Table 2). Acetic acid at 30% had greater control of broadleaf and narrow leaf weeds than citric acid at 10% [32].

It's worthy to mention that most weed control studied had a less effect on *M. hispida* weed at 90 DAP, compared to other weeds, however all treatments significant reduced the number and fresh weight of this weed relative to control (Tables 1&2). This lower efficacy maybe attributed that this weeds continue germinate during the potato growth period as shown in hand hoeing, therefore the contact herbicides AA, CA and their mixture had a lower efficacy on this weed, but metribuzin, black plastic prevented it to germinate.

The adverse effects of natural herbicides (AA, CA and AA +CA) on weeds may be attributed to that these herbicides act as a contact herbicide, destroying cell membranes resulting in tissue desiccation [39]. Rice straw mulch and black plastic mulch prevent the seeds germination and growth of weeds through block the light penetration [16]. In addition the rice straw mulch had allelopathic effects on weeds [30].

Table 2. Effect of weed control methods on fresh weight (g m^{-2}) of weeds at 50 and 90 days after planting (DAP) (Combined analysis of two seasons).

Treatments	Broad leaf weeds					*P.*[5] *minor*	Total weeds
	M.[1] *hispida*	*Ch.*[2] *album*	*E.*[3] *spinosa*	*S.*[4] *irio*	Total		
	At 50 DAP						
Unweeded check	94.5 a	67.8 a	15.0 a	117.9 a	295.1 a	9.7 a	304.8 a
Hoeing (twice)	0.0 e	2.0 d	0.0 e	0.0 d	2.0 ef	0.0 c	2.0 ef
Metribuzin herbicide	0.5 e	0.0 e	1.0 c	0.0 d	1.5 ef	0.0 c	1.5 ef
White plastic mulch	0.0 e	0.0 e	0.0 e	0.0 d	0.0 f	0.0 c	0.0 f
Black plastic mulch	0.0 e	0.0 e	0.0 e	0.0 d	0.0 f	0.0 c	0.0 f
Blue plastic mulch	0.0 e	0.0 e	0.0 e	0.0 d	0.0 f	0.0 c	0.0 f
Biodeg.[6] plastic mulch	0.0 e	0.0 e	0.0 e	0.0 d	0.0 f	0.0 c	0.0 f
Infrared plastic mulch	0.0 e	0.0 e	0.0 e	0.0 d	0.0 f	0.0 c	0.0 f
Acetic acid (AA) 20%	4.7 d	1.5 de	0.0 e	0.9 d	7.5 e	0.9 c	8.4 e
Citric acid (CA) 10%	24.9 b	15.5 b	4.6 b	32.0 b	77.0 b	2.5 b	79.5 b
AA 10% + CA 5%	18.8 c	6.0 c	0.1 d	11.0 c	36.3 c	2.6 b	38.9 c
Rice straw mulch	0.75 e	1.0 de	0.0 e	13.1 c	14.9 d	3.4 b	18.3 d
	At 90 DAP						
Unweeded check	855.6 a	92.8 a	126.0 a	152.5 a	1227.0 a	259.6 a	1487.6 a
Hoeing (twice)	157.6 e	2.1 g	29.9 b	0.0 e	189.6 e	2.4 fg	191.9 c
Metribuzin herbicide	41.9 i	0.7 g	0.6 ef	1.0 e	44.3 h	1.8 fg	46.0 d
White plastic mulch	105.5 f	7.1 f	9.8 d	14.6 d	137.0 f	20.6 d	157.6 cd
Black plastic mulch	14.6 j	10.4 e	1.3 ef	0.0 e	26.2 h	0.0 g	26.2 d
Blue plastic mulch	207.1 d	0.5 g	17.0 c	0.5 e	225.1 d	2.01 fg	227.3 c
Biodeg. plastic mulch	69.1 gh	7.4 f	0.0 f	3.2 e	79.7 g	8.1 ef	87.8 d
Infrared plastic mulch	122.3 f	46.9 b	1.1 ef	0.0 e	170.2 e	0.8 fg	171.0 c
Acetic acid (AA) 20%	48.8 hi	13.9 d	4.4 e	31.3 c	98.3 g	39.6 c	137.9 cd
Citric acid (CA) 10%	289.9 b	5.0 f	4.3 ef	16.7 d	315.8 b	151.6 b	467.5 b
AA 10% + CA 5%	241.3 c	24.9 c	1.0 ef	2.5 e	269.6 c	9.5 e	279.1 c
Rice straw mulch	83.4 g	1.9 g	0.0 f	53.6 b	138.9 f	0.0 g	138.9 cd

1*M.*: *Meidicago*; 2*Ch. Chenopodium*; 3*E. Emex*; 4*S. Sisymbrium*; 5*P.*: *Phalaris;* 6Biodeg.: Biodegradable. Different letters refer to statistically differences following Duncan's multiple range test at *P* = 0.05.

Nutrient removal by weeds

There was a significant reduction in the macro- and micronutrients depletion under all weed control treatments (Table 3). Un-controlling the weeds led to aloss in N, P and K nutrients estimated by 77.3, 5.8 and 66.6 kg/ha, while the removal of micronutrients Mn and Zn were 481.3 and 552.4 g/ha, respectively. Mukherjee e*t al*. [40] reported that weeds removed 35.65 to40.47 kg N, 6.86 to 7.85 kg P and 49.81 to 50.04 kg K/ha from soil in complete weedy situation.

On the other hand controlling the weeds through black plastic mulch treatment saved 76, 5.7, 65.2kg/ha and 473 and542.7 g/fed of N, P, K, Mn and Zn elements, respectively in comparison with the weedy check (Table 3). Black and biodegradable plastic mulches showed a better ability in saving all macro- and micronutrients than the hoeing treatment. There was a direct relation between weed dry matter accumulation under different treatments and nutrient removal by weeds [41].

Table 3. Effect of weed control treatments on removal of macronutrients (N, P and K) (kg/ha) and micronutrient (Mn and Zn) (g/ha) by weeds at 90 days after planting (Combined analysis of two seasons).

Treatment	N	P	K	Mn	Zn
Unweeded check	77.3 a	5.8 a	66.6 a	481.3 a	552.4 a
Hoeing (twice)	10.6 e	0.7 e	8.3 e	60.3 e	72.0 e
Metribuzin herbicide	2.9 h	0.2 h	2.2 fg	16.5 h	19.0 h
White plastic mulch	8.3 f	0.6 ef	6.9 e	50.5 ef	58.1 ef
Black plastic mulch	1.3 h	0.1 h	1.4 g	8.0 h	9.2 h
Blue plastic mulch	13.9 d	0.9 d	10.4 d	77.5 d	91.0 d
Biodegable plastic mulch	5.1 g	0.4 g	4.1 f	29.8 g	34.2 g
Infrared plastic mulch	9.1 ef	0.7 ef	8.2 e	53.3 ef	61.0 ef
Acetic acid (AA) 20%	6.8 fg	0.6 f	6.5 e	46.2 f	51.0 f
Citric acid (CA) 10%	23.9 b	1.7 b	19.9 b	150.5 b	174.9 b
AA 10% + CA 5%	16.5 c	1.1 c	13.0 c	93.5 c	108.1 c
Rice straw mulch	8.0 f	0.6 ef	6.5 e	49.2 ef	52.8 f

Different letters refer to statistically differences following Duncan's multiple range test at *P* = 0.05.

B: POTATOES YIELD

Tuber physical characters

Table 4.Effect of weed control methods on potato total yield, tuber fresh weight, tuber dry weight, tuber diameter, tuber length and specific gravity (Combined analysis of two seasons).

Treatment	Total yield (ton/ha)	Tuber fresh weight (g)	Tuber dry weight (g)	Tuber diameter (cm)	Tuber length (cm)	Specific gravity (g/cm³)
Unweeded check	17.9 g	135.5 f	29.1 d	5.0 d	9.0 c	1.072
Hoeing (twice)	37.6abc	205.1 b	46.1 abc	5.7 bc	10.3 ab	1.092
Metribuzin herbicide	33.8 de	191.2 c	45.1 bc	5.8 bc	11.0 a	1.089
White plastic mulch	36.7bcd	184.7 cd	46.0 abc	5.5 bc	10.0 b	1.090
Black plastic mulch	40.9 a	214.4 ab	53.4 ab	5.9 ab	10.5 ab	1.100
Blue plastic mulch	40.5 a	206.1 ab	47.7 abc	5.6 bc	10.3 ab	1.089
Biodeg. plastic mulch	38.3 ab	192.0 c	47.1 abc	6.2 a	10.7 ab	1.081
Infrared plastic mulch	38.1 ab	215.1 a	55.3 a	5.7 bc	10.6 ab	1.081
Acetic acid (AA) 20%	31.2ef	190.4 c	43.1 c	5.7 bc	10.3 ab	1.089
Citric acid (CA) 10%	29.8 f	170.5 e	41.1 c	5.7 bc	10.3 ab	1.085
AA 10% + CA 5%	31.9ef	167.4 e	40.2 c	5.5 c	10.6 ab	1.081
Rice straw mulch	34.5 cde	179.8 d	43.9 bc	5.7 bc	10.1 b	1.098
						NS

[2]Biodeg.: Biodegradable. Different letters refer to statistically differences following Duncan's multiple range test at *P* = 0.05.

Fresh and dry weight, diameter and length of tuber characters were significantly enhanced by weed control treatments, while the specific gravity of tuber was insignificantly influenced (Table 4). Similar finding on potatoes specific gravity was obtained [42]. IRT achieved the highest tuber fresh but it remains statistically equal to blue and black mulches. Tuber fresh weight in white, biodegradable mulches and acetic acid (20%) treatment was similar to metribuzin treatment (Table 4). Among all treatments the lowest tuber fresh weight was recorded in citric acid (10%) and acetic acid (10%) plus citric acid (5%), however they produced higher values of these criteria than unweeded treatment (Table 4).

Concerning the tuber dry weight, IRT plastic mulch had the highest value of tuber dry weight. However, this value wasn't significantly different from other plastic treatments. The highest value of tuber diameter was recorded in the biodegradable plastic mulch which increased it by 24% compared to unweeded check. Insignificant differences were recorded between biodegradable and black plastic mulches in tuber diameter (Table 4).

Total yield

All weed control methods produced potato yield significantly higher than the weedy check (Table 4).Weed competition with potato plants during the whole growing season reduced total tuber yield by 52.5% compared to hoeing... All plastic and rice mulches treatments produced yield similar to hoeing. Black and blue plastic mulches enhanced the tuber yield by 129.3 and 126.7% over unweeded control, but compared to hoeing the increment in total yield were 8.9 and 7.6% in black and blue plastic mulches respectively (Table4).

According to Ashrafuzzaman [19], black and blue plastic mulches increased chilli pepper yields more than clear mulch and bare soil but this increment wasn't significant between blue and white mulches. White, biodegradable, IRT and rice straw mulches produced yield similar to the hand hoeing treatment (Table 4). Similar findings were recorded [30] in processing tomatoes. Total tuber yield in all natural herbicides treatments weren't significantly differ from the metribuzin herbicide but were lower than the hand hoeing treatment (Table 4). Potato marketable yield achieved in Ecoclear (containing 30% acetic acid) was comparable with the synthetic herbicide [34], while another study revealed that peanut yield wasn't affected by the mixture of citric plus acetic acid [43].

The increment of potato yield and tuber characters in weed control treatments over the unweeded check maybe due to –mainly- reducing the weed number (Table1), fresh weight of the weeds (Table 2) and consequently decreasing the nutrient removal by weeds (Table 3). Different plastic mulches increase the available nutrients for potato plants due to saving nutrient through leaching and removal by weeds (Table4).

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