Fruit quality in strawberry (*Fragaria* sp.) grown on colored plastic mulch

Calidad de fruta en fresa (*Fragaria* sp.) cultivada con acolchados plásticos de colores

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ABSTRACT

Use of mulch has morphogenetic effects on strawberry (*Fragaria* sp.) production. In the present study the effects of red, blue, yellow, green, black, and silver mulches on strawberry growth and fruit quality were evaluated in a trial carried out at 2,500 m a.s.l. in central Colombia. Red mulch gave results similar or better to the black control for most factors. Foliar area, fresh fruit weight, and fruit length were highest with red mulch and lowest for silver. Silver mulch gave the lowest pH and dry fruit weight, and the lowest ratio of total soluble solids/titratable acidity, while black mulch gave the highest value in this ratio. Positive effects of red mulch are possibly due to the increased absorption of red and far-red light by phytochrome, which in turn influences enzymes associated with sweetness and flavor. The superior results of red mulch were not always statistically significant, but the present study indicates the potential value of further tests on the use of red mulch instead of black mulch. If it is definitively shown that red mulch provides for better yield and fruit quality, it will be important to expand and improve its manufacture and stabilize its color, which often fades under high altitude tropical conditions.

Key words: morphogenesis, phytochrome, tropical America, mountain climate.

RESUMEN

El uso de acolchados tiene efectos morfogénicos sobre la producción de fresa (*Fragaria* sp.). En el presente estudio se evaluaron los efectos de acolchados de colores rojo, amarillo, azul, negro, plateado y verde sobre el crecimiento y la calidad del fruto en fresa sembrada a 2.500 msnm en Colombia. El acolchado rojo dio resultados similares o mejores al testigo negro en la mayoría de factores. Área foliar, peso fresco de fruta y longitud de fruto fueron mayores con el acolchado rojo y menores con el plateado. El acolchado plateado presentó el pH y peso seco de fruto más bajos, y menor relación sólidos solubles totales/acidez total titulable, mientras que el acolchado negro mostró el mayor valor de esta relación. El efecto positivo del acolchado rojo pudo deberse a mayor absorción de luz roja y roja lejana por el fitocromo, que influye sobre las enzimas que afectan sabor y dulzor. Los resultados superiores del acolchado rojo no siempre fueron significativos estadísticamente, pero el estudio motiva a indagar más sobre la utilidad del acolchado rojo en comparación con el negro. Si se ve definitivamente que el acolchado rojo induce mejores resultados, será importante expandir y mejorar su fabricación y estabilizar su color, que tiende a desvanecerse bajo las condiciones del trópico alto.

Palabras clave: morfogénesis, fitocromo, América tropical, clima de montaña.

Introduction

The strawberry (*Fragaria* x *ananassa* L. Duch.) is known for its pleasant organoleptic qualities, and its high content of vitamin C, polyphenols, and elagic acid, the latter of which has cancer-fighting properties (Xue *et al.*, 2001). Strawberries are versatile fruits; they can be consumed fresh or used in jams and preserves, juices, and sweets. Other benefits have been ascribed to strawberries, such as high levels of antioxidants that slow aging, properties that prevent urinary tract infection, and the ability to reduce of blood sugar (Villagrán, 2001). The most important components of strawberry quality are appearance, firmness, flavor, maturity, brilliance, and absence of damage to the fruit. Meteorological conditions, crop management, and storage conditions such as temperature and humidity affect fruit quality and shelf life in strawberries (Kader, 1991; Martínez-Soto *et al.*, 2008).

The first use of plastics in farming in the 1940s profoundly transformed production practices for fruit, vegetables, and ornamentals. In the following years came notable technological achievements that improved plastic durability and expanded the material's potential uses (Hallidri, 2001). Plastics technology was introduced to improve crops' input use efficiency in terms of nutrients, irrigation water,

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and agrochemicals, with the ultimate goal of maximizing yield, fruit quality, and harvest precocity (Fan *et al*., 2005). Research has shown that polyethylene mulch improves crop development and increases yield for various species, especially in cooler climates. Such production increases are largely due to improved conservation of soil moisture and better weed control (Al-Assir *et al*., 1992; Albreghts and Chandler, 1993).

Higher plants have developed different types of photoreceptors, which permit them to monitor their environment through the detection of certain wavelengths. On this subject, Meisel *et al*. (2007) describe the photoreceptors for the ranges of blue light (450-500 nm, absorbed by chlorophylls, cryptochromes, and phototropins), green light (500-570 nm, absorbed by carotenes), and yellow light (570-590 nm, also absorbed by carotenes). Due to their reflection of different wavelengths of light, different colors of mulch create specific environments that have a considerable effect on plant growth and development. By the same token, black mulch reflects very little light, so its effects on plant growth are attributed to the changes it causes in soil temperature. In a study with red, black, and organic biodegradable plastic mulches in strawberry, Wang *et al*. (1998) reported that the best results in terms of yield and fruit quality were obtained with black polyethylene. On the other hand, Ghawi y Battikhi (1986) concluded that watermelon produced the highest fresh fruit yield (55.3 t ha^{-1}) with white mulch, which kept evapotranspiration to 44.3 cm in the dry desert climate where the experiment was conducted. Schales (1994) tested black, transparent, green, and white/black coextruded polyethylene mulches in melon, and obtained the highest yields with the coextruded black and white mulch (with the black side in contact with the soil). The shortest time to harvest was obtained with black and white coextruded mulch and with green mulch, which performed better even than the transparent mulch in this aspect.

Polyethylene mulch color is important in plant response, but also important are the time of year and the climate in which the mulch is used, as mulch effect on plants will be positive or negative depending on environmental conditions. Soil temperature affects fruit production and quality in strawberry (Ochmian *et al*., 2007). Furthermore, soil temperature under colored plastic depends on location; Locascio *et al*. (2005) found in a strawberry field that soil temperature under black mulch was significantly higher than under red mulch in Hasting, Florida, while in Gainesville, Florida, the opposite trend was observed. On the other hand, while in Poland Ochmian *et al*. (2007) found that black polyethylene mulch in strawberry increased soil temperature by 4°C as compared to an unmulched control, Kasperbauer (2000) reported that in the area of Florence and Johnstone, South Carolina, soil temperature was only 0,2°C higher under black mulch than under red mulch, a difference that would not appear to account for the 15% reduction in strawberry production under black mulch compared to red mulch. In addition, Kasperbauer (2000) mentions that black and red mulches reflect only 5% of blue-range light.

Building on the results of these prior studies, the present work evaluated the effect of red, green, silver, blue, yellow, and black mulches on physical and chemical properties of strawberry fruit grown in the highland tropics. The strawberry planting system common to the high plains of central Colombia suspends plants in the air such that they grow in all directions, thus increasing light reception and photosynthesis as compared to strawberries planted at ground level. The plastic used to wrap and cover the substrate in this planting system is usually black. The present work thus aimed to evaluate possible alternatives to this black mulch, and thus to modify and improve current practices in strawberry production for high-altitude zones in Colombia.

Methods and materials

The experiment was performed in Tuta, Boyaca (Colombia), located at 5°41'33,47" N and 73°13'47,42" W, at 2,548 m a.s.l. Average relative humidity was 79.8%, average temperature was 13.18°C, and global radiation was 13,419.14 cal cm^{-2} during the course of the experiment. Planting occurred in November, so plants grew during the northern tropical dry season.

Planting material was comprised of 360 strawberry plantlets imported from Chile (*Fragaria* sp. var. Ventana) and vernalized at 4°C for two weeks. The plantlets were conditioned by leaf and root trimming, and planted in horizontal black trough-shaped containers placed one meter above the soil in open fields. These planting containers consisted in black polyethylene plastic draped between two parallel horizontal bars, thus forming a hanging half-cylinder (or "sausage") of 30 cm deep by 40 cm wide. The "sausage" container was filled with substrate, wrapped with more black plastic, and then wrapped with plastic mulch of one of the other colors: red, green, blue, yellow, silver, or black (the latter as a control given its use as the standard mulch color in Boyaca). The planting substrate consisted of a mix of rice husks, fine coal ash, and soil in a 60:10:30 mixture by volume. Plant nutrition was provided by localized fertigation, with three daily pulses, complemented with foliar application of fertilizers.

The first fruits were eliminated at 65 dap (days after planting) to achieve homogeneity, and starting at 75 dap the fruit was harvested for weighing and measuring. Subsequent harvests were carried out every seven days during a month, with the last harvest at 92 dap. Production was highest at 92 dap, at which point total leaf area, fresh and dry weight of fruits, fruit length, juice pH, total soluble solids, and total titratable acidity were measured for each plant. Foliar area was estimated indirectly by measuring length and width of leaflets, using the methodology detailed in Casierra-Posada *et al*. (2007).

The trial had a random block design, with mulch color as the block factor. Each treatment consisted in 60 plants distributed in three replications of 20 plants each, and each plant was taken as one experimental unit. Trial data was subjected to classical variance analysis (with $P \leq 0.05$ denoting significance and $P \leq 0.01$ being extremely significant) and a Tukey range test through the PASW (Predictive Analytics Software) program, version 18.0.0; IBM Corporation, Somers, USA).

Results and discussion

Leaf area showed extremely significant differences ($P \leq 0.01$) in plants grown using different mulch colors. Silver, blue, and yellow mulches gave leaf areas respectively 37.07, 26.41, and 19.96% lower than the black mulch traditionally used for strawberry production in the Boyaca region. Silver mulch strongly induced lower leaf area, perhaps due to the UV radiation reflected by this aluminized material (following Summers *et al*., 2004). In fact, plants grown with this mulch showed burns on their leaf margins. The result obtained with red mulch is notable, though not statistically significant by Tukey's test; leaf area increased 9.04% as compared to the black mulch (Fig. 1).

Regarding the apparently higher leaf area presented in plants exposed to red mulch, Nishiyama y Kanahama (2009) have found that leaf production in strawberry plants is promoted by light in the red range. In the present study, red mulch would reflect red light toward the strawberry plants. On the other hand, plant response to different mulch colors is highly dependent on the species, on experimental conditions, and on the moment of leaf area sampling; in tomato plants exposed to black or white mulches, leaf area was unaffected (Decoteau, 2007), while fresh and dry weight of tomato leaves, as well as leaf area measured in pre-flowering phase, were affected by mulch color.

In the present experiment, fresh fruit weight was significantly affected by mulch color ($P \leq 0.05$). In comparison with black mulch, strawberry plants exposed to silver mulch showed 12.38% lower fresh fruit weight, while red mulch increased fresh weight by 2.31%. Other mulch colors did not show statistically significant differences in this parameter as compared to the black mulch (Tab. 1).

Extremely significant differences ($P \leq 0.01$) were found in fruit length. Compared to fruits from plants grown on black mulch, red mulch increased fruit length by 3.48%. Green, silver, blue, and yellow mulches reduced fruit length

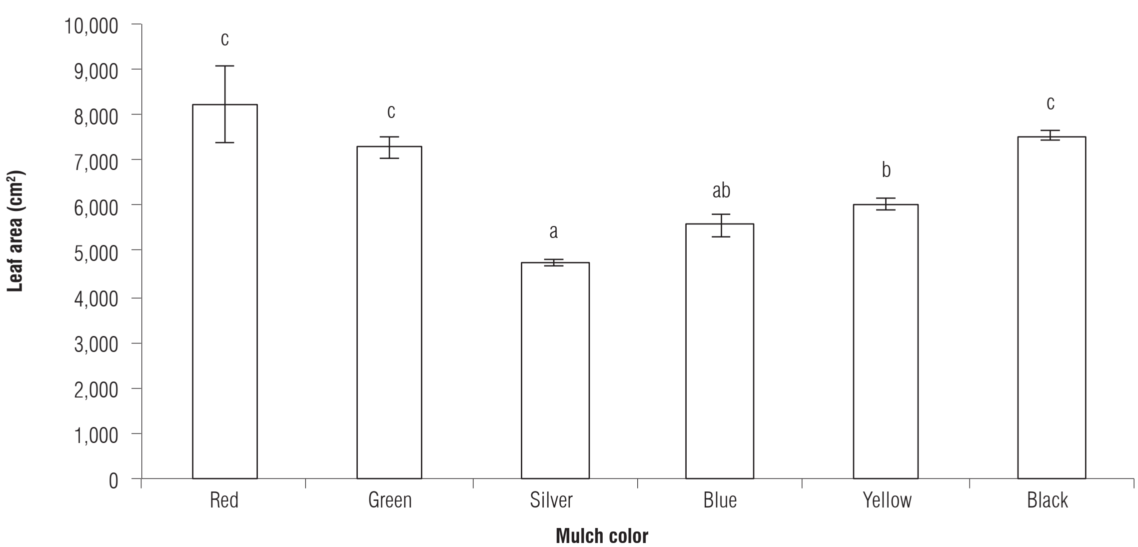

FIGURE 1. Leaf area in strawberry plants grown using different colors of mulch.

TABLE 1. Physico-chemical quality properties in strawberry grown on different colors of mulch.

Mulch color	Fresh fruit weight (g)	Fruit length (cm)	pH	Fruit dry weight (g)	TSS/TA
Red	12.81 c	3.56 c	3.36 ab	1.31 b	7.73 c
Green	12.02 b	3.29 ab	3.32 ab	1.27 b	7.09 b
Silver	10.97 a	3.20 a	3.24 a	1.04 a	6.14 a
Blue	12.23 b	3.25 ab	3.29 ab	1.27 b	7.99 d
Yellow	12.40 b	3.27 ab	3.33 ab	1.28 b	7.17 b
Black	12.52 b	3.44 bc	3.48 b	1.30 b	8.18 e

by between 4.36 and 6.79%, with silver mulch causing the largest reduction (Tab. 1).

The low fresh fruit weight exhibited in plants grown on silver mulch could be a consequence of their lower leaf area. On the other hand, the length and fresh weight results from plants grown on red mulch may be due to the red light reflected onto plants by the mulch, given that red and far-red light cause a morphogenic effect that modifies strawberry plants in terms of fruit quality (Black *et al*., 2005; Kasperbauer *et al*., 2001), leaf area, and flower number (Nishiyama and Kanahama, 2009). Nevertheless, climate conditions must also be kept in mind in strawberry experiments, given that Ochmian *et al.* (2007) found that black mulch induced a negative effect on strawberry fruit size in the north of Poland.

Regarding juice pH and dry fruit weight, the present study found that silver mulch gave the lowest values. Other mulch colors did not exhibit significant differences compared to black mulch. Plants grown on silver mulch produced 20% less fruit dry matter than in the black mulch treatment. This could be due to the reduction of leaf area, and the leaf margin burns caused by the silver mulch.

As with the other variables, the relation of total soluble solids to titratable acidity, also referred to as harvest index, was affected by mulch color. Compared to the black mulch, all other colors caused a reduction in this value. The largest reduction was seen with silver mulch, whose harvest index was 24.93% lower than the black mulch treatment (Tab. 1). The reduction of harvest index on red-mulch-grown strawberries in the present study contradicts Kasperbauer *et al.* (2001), who found that strawberries produced under sunny conditions gave higher harvest index values in red-mulch-grown plants than in those grown on black mulch. Light conditions in the present study were relatively cloudy, which is typical of the highland equatorial region in which the experiment was carried out. This may explain the discrepancy with Kasperbauer *et al.* (2001).

Total soluble solids measured in the juice of the different fruits showed highly significant differences ($P \leq 0.01$) between different mulch colors. Silver, blue, and yellow mulches showed no difference among themselves, and respectively showed values of 12.94, 11.66, and 11.37% lower total soluble solids than the level measured in black mulch. No statistically significant difference was found between black, green, and red mulch treatments (Fig. 2).

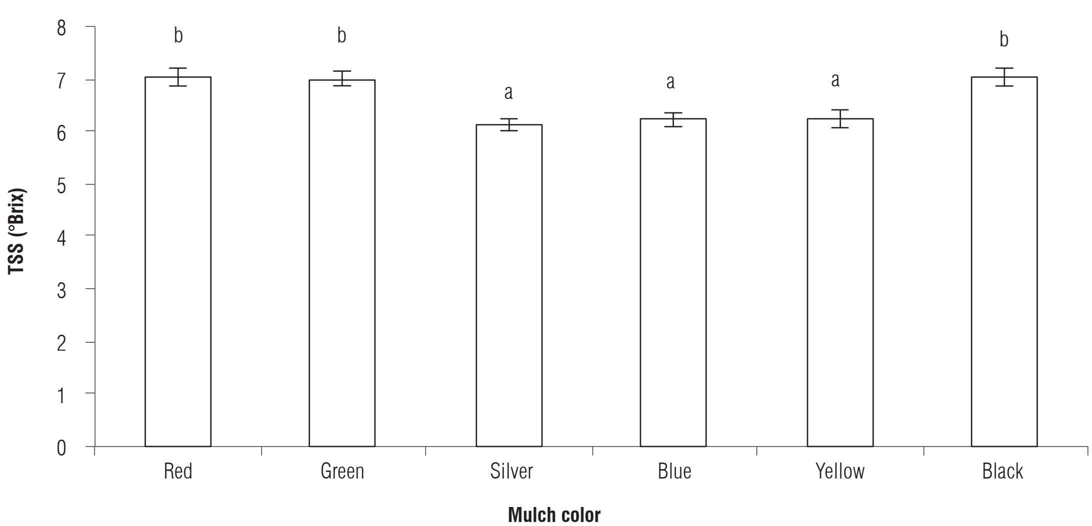

FIGURE 2. Total soluble solids in juice from strawberries grown using different mulch colors.

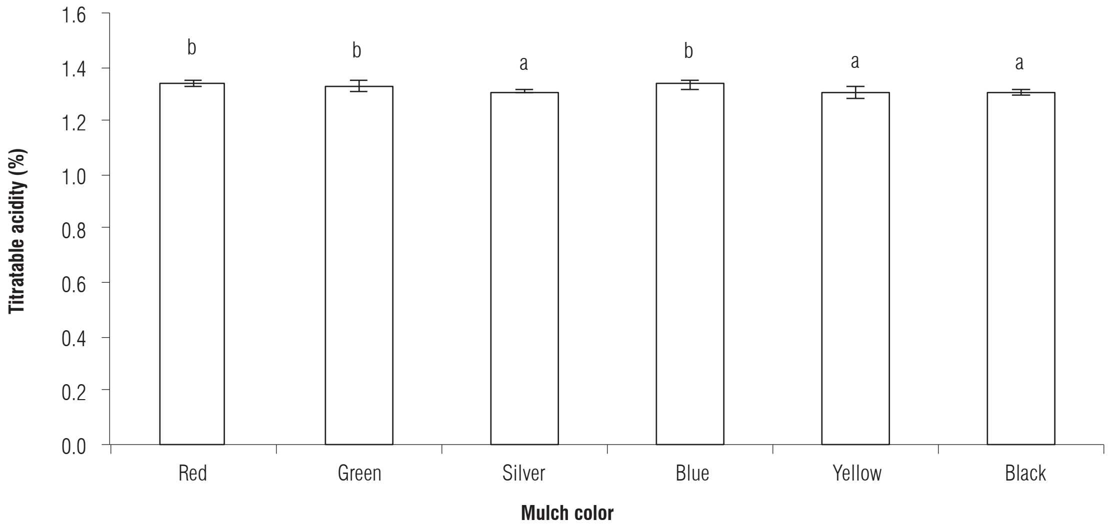

FIGURE 3. Titratable acidity in strawberry juice produced from fruits grown with different colors of mulch.

The response of strawberry plants in terms of fruit total titratable acidity was different than the response in total soluble solids, though it also showed statistically significant differences ($P \leq 0.05$). The lowest values were found with the use of silver, yellow, and black mulches, which showed no significant difference between them. The highest values of total titratable acidity were found on red, green, and blue mulches, with respective values of 1.33, 1.32 and 1.33% titratable acidity (Fig. 3).

Sugar accumulation in many fruit species, including strawberry, is controlled in part by the enzyme saccharose phosphate synthase (Hubbard *et al*., 1991). Nevertheless, in strawberry varieties Festival and Ventana (the variety used in the current experiment), it is reported that activity of this enzyme is very low, while other enzymes such as invertase, pyrophosphate-dependent phosphofructokinase (PFP), and fructose-1,6-bisphosphatase (FBPase) show different patterns of activity during strawberry development, and can affect the composition and accumulation of acids and sugars in strawberry fruit (Basson *et al*., 2010).

Kasperbauer *et al*. (2001) mention that red and far-red light is captured by phytochrome, which triggers a series of chemical modifications in fruits that alter sugar and organic acid contents. This contributes to improved sweetness and flavor of fruit from plants grown on red mulch. They posited that the proportion of red and far-red radiation reflected by red mulch onto strawberry plants is the cause of improved fruit quality, due to an increase in the activity of saccharose phosphate synthase. However, the activity of this enzyme is not determined by phytochrome in all plants; Vassey (1988) found that phytochrome is involved in saccharose phosphate synthase in maize (*Zea mays*), but not in soy (*Glycine max*) or sugar beet (*Beta vulgaris*). Phytochrome-mediated activity in other enzymes has been reported in different plant species, such as tobacco (*Nicotiana* sp.). In tobacco it has been found that genes in charge of fructose-1,6-bisphosphatase activity are regulated by phytochrome (Lee and Hahn, 2002). The enzyme fructose-1,6-bisphosphatase is also related to the flavor of strawberry fruits (Basson *et al*., 2010), so this enzyme is another candidate for explaining the improved chemical characteristics encountered in strawberries grown on red mulch in the present study.

Hence the differences in physicochemical properties found in strawberry fruits in Kasperbauer (2000), as well as in the present study, can likely be attributed to differences in the proportion of red to far red light reflected by the mulches, which contributes to differences in the light spectrum surrounding developing strawberries. These results are supported by Decoteau *et al*. (1988), who affirm that plants grown on colored plastic mulch respond to the small changes in ambient light induced by mulch color.

Conclusions

In the present study, strawberry plants seemed to respond to the radiation reflected by different mulches, which is detected by plant photoreceptors that provoke photomorphogenic responses affecting the physicochemical quality of fruits and in the development of leaf area.

The positive response of strawberry plants to mulch color, manifested in the physico-chemical characteristics of the fruit, was most evident with the use of red mulch, which gives evidence of the action of phytochrome pigment in strawberry plants. The exposure of plants to silver mulch caused a negative effect in all the variables measured, probably as a consequence of an excess of UV light reflection towards the plants, which caused leaf burns and had negative effects on fruit characteristics. The use of green, blue, and yellow mulches did not improve physico-chemical properties appreciably, possibly because the photoreceptors that capture this range of wavelengths are less effective than phytochromes in inducing photomorphogenic responses.

Kasperbauer *et al*. (2001) report that black polyethylene reflects less than 5% of incident radiation. Thus we may assume that the response to black mulch found in the present experiment (the improvement of fruit quality with black mulch) is due to changes in substrate temperature, more than to reflected light.

The present experiment found indications that red mulch may give improved yield and quality in strawberry fruit. Red mulch gave similar or better results to the black mulch control for most of the factors evaluated. For foliar area, red mulch gave the highest value, though Tukey's test showed no significant difference from the leaf area obtained with green and black mulches. Silver gave the lowest leaf area by far, even causing burns on leaf margins, presumably due to the reflection of intense UV radiation. In fruit fresh weight, red mulch gave the highest value, with silver again performing most poorly. Red mulch gave the longest fruits, and silver the shortest, though there was much statistical overlap between treatments. Silver mulch gave the lowest pH and dry fruit weight as well as the lowest ratio between total soluble solids and titratable acidity, while black mulch gave the highest value in this ratio. Green, blue, and yellow mulches rated consistently in the middle for all measured factors.

While for certain factors results were inconclusive using Tukey's range test, red mulch shows potential for improved strawberry quality and yield with respect to the black mulch commonly used in the high plains of Colombia. It is important to evaluate this trend further, as it could represent an improvement in production techniques for local farmers. However, in this and other trials carried out by the authors, it has been observed that red mulch fades over the growing season, becoming a lighter, pinkish color by season's end. If the increased use of red mulch proves to be advantageous to strawberry growers, it will be important to find ways to increase and improve production of red polyethylene, in particular addressing this issue of color fading.

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