

Effect of bunch protection material and bagging time on the yield of 'Nanica' banana and chilling control

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Abstract

The bagging of banana bunch can control chilling injury (CI) in the field, which causes browning of banana peel. The purpose of this study was to evaluate the effect of changing the bunch protection material and bagging time on the yield of 'Nanica' banana (AAA) and the occurrence of CI. The experiment was conducted in Jacupiranga, SP, Brazil. The experimental design was completely randomized design arranged in a 2 x 2 x 6 factorial scheme with eight replicates, two bunch formation periods (autumn-winter and winter-spring), two bagging times (early, before the opening of bracts, and late, after complete opening) and six treatments. Treatments were polyethylene bags with different thickness (blue bags of 3 μ in thickness and black bags of 6, 8 and 10 μ in thickness combined with white non-woven fabric, black bag of 10 μ in thickness combined with blue polyethylene bag 5 μ in thickness impregnated with insecticide) and non-bagged banana. The change of sunlight transmission with black polyethylene bags of different thickness promoted a small increase in fruit peel temperature (0.14 to 0.57°C) on colder days (8.72°C), reduced CI index and improved peel brightness (L*) and h^o (hue angle), although it did not affect bunch mass. However, in late winter, sunburn increased fruit losses. Sunlight transmission in fruit peel was correlated with CI index (r=0.92*), L* (r=-0.77*) and phenols (r=0.85*). Despite not controlling CI, early bagging is recommended for increasing peel L*.

Keywords: *Musa* spp., cold protection, black polyethylene, thickness, sunlight transmission, peel browning, phenols.

Abbreviations: CI_chilling injury; T_temperature; Tmin_minimum temperature; ST_sunlight transmission; Tmax_maximum; NB_non-bagged; Pol blue 3+WFN_blue transparent polyethylene 3 μ + white non-woven fabric 3 μ ; Pol black 6+WFN_black polyethylene 6 μ + white non-woven fabric 3 μ ; Pol black 8+WFN_black polyethylene 8 μ + white non-woven fabric 3 μ ; Pol black 10+WFN_black polyethylene 10 μ + white non-woven fabric 3 μ ; Pol black 10+Pol B_black polyethylene 10 μ + blue transparent polyethylene 5 μ impregnated with insecticide; CI_index_chilling injury index; BM_bunch mass; PHF_period between flowering and harvest; CL_a_chlorophyll a; CL_b_chlorophyll b; CAR_carotenoids; PHE_total phenols; a*_coordinated a*; b*_coordinated b*; L*_brightness; C*_chromaticity; h^o_hue angle.

Introduction

Banana is a plant of tropical origin (Robinson and Saúco, 2012) that is grown commercially from the equator to the subtropics and its fruits are widely consumed all around the world (Fortescue et al., 2011).

Under sufficient water supplies, banana growth and yield are mainly determined by temperature (Robinson and Saúco, 2012). Moderate temperature (20–30 °C) is an essential requirement for appropriate vegetative growth, fruit development and maximum yield (Simmonds, 1962). Chilling (temperatures lower than 20 °C) is one of the factors that limits the establishment of banana plantations at certain latitudes, and has an impact on the growth and development of plants, yield and fruit quality (Zapata et al., 2015).

Banana fruit are highly susceptible to chilling injury (CI), whose symptoms can occur at approximately 12°C (Chen et al., 2008) and causes losses of up to 50% in the yield (Zapata et al., 2015). Mild symptoms, commonly caused by field CI

include only peel browning of sub-epidermal peel tissue (Chen et al., 2008), but strongly affect the visual quality and marketability (Hashim et al., 2012)

Banana bunch bagging is a physical protection method, which improves the peel coloration of fruit and reducing blemishes, the incidence of disease and insect pest, mechanical damage, sunburn, agrochemical residues, bird damage (Santosh et al., 2017)

Bunch bagging had been also reported to increase temperature of fruit microenvironment and the visual quality (Jullien et al., 2008; Sarkar, 2014; Kutinyu et al., 2014; Pathak et al., 2017b; Santosh et al., 2017) and can prevent CI in field (Harvey, 2006).

Blue polyethylene is the material mostly used for this purpose (Robinson and Saúco, 2012). However, other materials may be used, such as non-woven fabric, paper, canvas, drill cloth, sisal, hessian, polylactic acid (Mustaffa and Kumar, 2012, Pathak et al., 2017, Santosh et al., 2017).

Optical and thermal characteristics of bagging material vary in function of their chemical and physical properties, as well as radiative heat transfer process, which is different in each material (Al-Mahdouri et al., 2013). The color, thickness and layering can affect the thermal properties and the sunlight transmission.

The use of double-layer bagging material with a different color than the usual and thicker material has reduce field CI and produced larger banana fruits in Tule, Australia (Harvey, 2006). Differences in temperature inside the bag due to color of polyethylene and presence or absence of perforation were able to reduce CI in Mozambique, Africa (Kutinyu et al., 2014). However, in that region the minimum temperature did not exceed 11.8°C. The use of black polyethylene in winter is a usual practice in China (Xu et al., 2011), promoting both absorb and re-emit radiation as thermal energy or long wavelength infrared (Lamont, 2017). The early bunch bagging (immediately after emergence of the inflorescence) was recommended by Mustaffa and Kumar (2012) to increase fruit length and reduce the time between flowering and harvest. However, there are no reports about its effect on fruit color and CI prevention.

The bagging technology should be exploited for trapping heat inside solar energy and devices and/or suppressing the outside ambient convection. The purpose of this study was to evaluate the effect of changing the bunch protection material and bagging time on the yield of 'Nanica' banana (AAA) and the occurrence of CI.

Results and Discussion

Effect of protection material on temperature of fruit peel/surface

On the coldest day, T_{min} was very close for both bunch formation periods, averaging 8.72°C (Table 1). Under this condition, the treatments increased T between 1.19 and 1.96°C. The non-bagged treatments (NB) were incapable to maintain the peel T higher than 12°C, which is the limit for the occurrence of CI in Cavendish banana (Chen et al., 2008, Hashim et al., 2012). The T value detected on the peel surface reflected the combinations of materials (Table 2). In two-film-layers treatments, heat must first be transferred from the inner (WFN or Biflex®) to the outer layer (polyethylene) of the bag before it is transferred to the atmosphere. Since it is very porous (Mangaraj et al. 2009), polypropylene (WFN) tends to have lower heat transfer compared to polyethylene (Biflex®). Pol blue 3 + WFN have been used by farmers, exhibiting the lowest thermal effect.

Black polyethylene bags used in treatments were transparent, allowing sunlight transmission (ST) depending on thickness (Table 1). At the same time, bags created a "greenhouse" effect to capture the long wave radiation under the film surface. The increase in thickness also probably contributed to the reduction of heat loss by convection. This explains its greater impact on peel T_{min} and T_{max}.

The use of double layer polyethylene bags extended the ability to increase T (Harvey, 2006), which confirmed with Pol black 10 + Pol B (Table 1), which was designed to combine early thermal protection with the control of thrips. One hypothesis to explain the greater thermal effect of this treatment is the higher water condensation due to existence

of small droplets on the inner surface of the black bag, which reduces transmission of long wave radiation and increases emission, while transmissivity to short wave radiation is almost unaffected (Lamont et al, 2017). Loss of energy by convection was prevented with the use of non-perforated black polyethylene bag.

On warm days, black polyethylene bag with greater thickness (low LT) excessively increases the air T in both periods (Table 1) and caused sunburn. About 81.25% of bunches, pol black10 + Pol B caused sunburn on fruits of hand 1 and hand 2, against about 31.25% in Pol black 10 + WFN and 12.5% in Pol black 8 + WFN and only on fruits of hand 1 (p <0.05). The occurrence of sunburn may be directly associated with greater water condensation on the inner surface of the film.

The difference in the occurrence of sunburn between Pol black 10+WFN and Pol black10+Pol B (p <0.05) can be related to the movement of water vapor generated by the fruit transpiration to the inner surface of the polyethylene bag. Biflex® has perforation that favors diffusion (Table 2), while WFN is continuous and has higher barrier to water vapor, compared to polyethylene (Mangaraj et al. 2009).

Alterations promoted a small increase in the fruit surface T_{min}, which occurred at dawn, when there is no sunlight. In other studies with polyethylene, similar results were observed, with significant increases in air T_{max} compared to the external environment, and slight increases T_{min} (Rebouças et al., 2015), an effect attributed to the low capacity of polyethylene to retain long wavelength radiation. There was a difference of 20h in stress T (<12 ° C) between bunch growth periods, whereas none of which showed temperature below 5°C. This caused severe symptoms in fruits, less frequent in the region.

Effect of protection material and bagging times on fruit yield

There was no triple interaction for any of variables studied (p <0.05). Bunches harvested in winter-spring showed higher BM, CL *a* and CAR content and lower PHF and CI index, when compared to those harvested in autumn-winter (Table 3) due to higher T and lower cold stress hours (Table 1).

Bagging times did not affect any of the agronomic characteristics (BM and PHF), CI index, content of pigments, and PHE of fruit peel (Table 3). However, Jullien et al. (2008) observed fruits of large diameter with early bagging compared with NB. This is a response attributed to the elevated T of about 2°C in the bag, which may have increased the cell division and fruit filling rates.

Protection materials did not influence BM, only PHF, which was extended in 9 days between Pol black 10 Pol B and NB (Table 3). This indicates that the photosynthetic activity of fruits might be influenced when fruit grows with low ST through of bag and that this effect overlapped the increase in T (Table 1). Other treatments were not different. In north Queensland in Australia, bags with high LT increased bunch photosynthesis and improved fruit size (Harvey, 2006). However, in Costa Rica, polyethylene bags of different thicknesses did not influence BM and fruit size (Vargas-Calvo and Valle-Ruiz, 2011). Bagging materials affected CI index, CL *a* and CAR content (Table 3). NB and Pol blue 3+WFN exhibited higher CI index (severe injury) when compared

Table 1. Temperature (°C) of the air in canopy and in the surface fruits/peel in function of protection material during colder and warmer day of the two periods of bunch formation.

	Autumn-Winter			
	Tmin	Tmin bag-Tmin NB	Tmin	Tmin bag-Tmin NB
Canopy	8.70	-	31.37	-
NB	9.19	-	28.86	-
Pol blue 3+WFN	10.38	1.19	29.06	0.20
Pol black 6+WFN	10.52	1.33	33.03	4.17
Pol black 8+WFN	10.60	1.41	34.65	5.79
Pol black10+WFN	10.65	1.46	35.04	6.18
Pol black10+Pol B	10.76	1.57	40.46	11.60

	Winter-Spring			
	Tmax	Tmax bag-Tmax NB	Tmax	Tmax bag-Tmax NB
Canopy	8.74	-	39.08	-
NB	9.52	-	43.08	-
Pol blue 3+WFN	10.91	1.39	43.25	0.17
Pol black 6+WFN	11.09	1.57	43.62	0.54
Pol black 8+WFN	11.27	1.75	44.75	1.67
Pol black10+WFN	11.39	1.87	52.71	9.63
Pol black10+Pol B	11.48	1.96	67.71	24.63

*Mean values obtained from two replicates of thermocouples. NB, non-bagged; Pol blue 3+WFN, blue transparent polyethylene 3 μ +white non-woven fabric 3 μ ; Pol black 6+WFN, black polyethylene 6 μ +white non-woven fabric 3 μ ; Pol black 8+WFN, black polyethylene 8 μ +white non-woven fabric 3 μ ; Pol black 10+WFN, black polyethylene 10 μ +white non-woven fabric 3 μ ; Pol black 10+Pol B, black polyethylene 10 μ +blue transparent polyethylene 5 μ impregnated with insecticide. Autumn-Winter: 28.52 h with T <12°C e 0 T <5 °C. Winter-Spring: 8.74 h with T <12°C e 0 T <5 °C.

Table 2. Characteristics of bunch bags (protective materials).

Bags	Protection material	Thickness μ	Dimension length x width (m)	Diameter perforation and spacing (m)	Additional characteristics	ST %
Pol blue 3+WFN	blue transparent polyethylene	3	1.50 x 0.75	0.008 diameter every 0.18 x 0.14	low density	68.3
	white non-woven fabric	3	1.50 x 0.80	absent	with long filaments of polypropylene thermally bonded with hydrophilic treatment	
Pol black 6+WFN	black translucent polyethylene	6	1.50 x 0.75	0.008 diameter every 0.18 x 0.14	low density	7.1
	white non-woven fabric	3	1.50 x 0.80	absent	with long filaments of polypropylene thermally bonded with hydrophilic treatment	
Pol black 8+WFN	black translucent polyethylene	8	1.50 x 0.75	0.008 diameter every 0.18 x 0.14	low density	4.7
	white non-woven fabric	3	1.50 x 0.80	absent	with long filaments of polypropylene thermally bonded with hydrophilic treatment	
Pol black 10+WFN	black translucent polyethylene	10	1.50 x 0.75	0.008 diameter every 0.18 x 0.14	low density	0
	white non-woven fabric	3	1.50 x 0.80	absent	with long filaments of polypropylene thermally bonded with hydrophilic treatment	
Pol black10+Pol B	black translucent polyethylene	10	1.50 x 0.75	0.008 diameter every 0.18 x 0.14	low density	0
	blue translucent polyethylene (Biflex®)	5	1.57 x 0.82	0.008 diameter every 0.18 x 0.14	low density, anti-UV additive, impregnated with bifenthrin insecticide	

* μ =0.001mm. **ST, sunlight transmission through bag was measured on the controlled conditions of the laboratory using a portable light meter under illuminance light of 840 klx.

Table 3. Agronomic characteristics, chilling injury index, content of photosynthetic pigments and total phenols in the peel of green fruits of banana 'Nanica', in function to the period of formation of the bunch, bagging time and protection material.

	BM kg	PHF day	CI index	CL <i>a</i>	CL <i>b</i> µg g ⁻¹	CAR	PHE mg g ⁻¹
Autumn-Winter	27.93 B	142.88 A	3.38 A	7.40 B	6.65	8.47 B	1.40
Winter-Spring	30.96 A	113.42 B	2.13 B	11.50 A	6.98	11.39A	1.37
vc (%)	19.52	128.15	7.75	12.22	24.44	17.14	9.63
F	13.39**	282.08**	8.15**	73.71**	1.13 ^{ns}	83.65**	2.25 ^{ns}
Late	29.85	127.26	2.63	9.80	6.65	9.95	1.37
Early	29.87	129.05	2.88	9.08	6.98	9.91	1.39
vc (%)	19.09	5.69	6.49	12.22	24.44	17.14	17.72
F	0.03 ^{ns}	2.51 ^{ns}	2.14 ^{ns}	2.97 ^{ns}	1.13 ^{ns}	0.02 ^{ns}	1.69 ^{ns}
NB	27.28	121.89 B	4.00 A	10.71 A	6.97	11.72 A	2.02 A
Pol blue 3+WFN	28.52	129.45 AB	3.67 A	10.52 AB	6.85	10.76 AB	1.92 A
Pol black 6+WFN	30.96	129.06 AB	2.67 AB	10.12 ABC	7.03	10.08 BC	1.45 B
Pol black 8+WFN	30.40	127.65 AB	2.33 AB	8.61 ABC	6.87	9.74 BC	1.38 B
Pol black 10+WFN	30.39	130.21 AB	2.00 B	8.05 CD	7.20	8.78 C	0.79 C
Pol black10+Pol B	31.59	130.78 A	2.00 B	8.74 D	5.86	8.54 C	0.72 C
vc (%)	19.09	7.31	8.30	12.22	11.94	17.14	16.27
F	1.51 ^{ns}	3.25*	9.78**	4.60**	1.13**	9.07**	10.14**

BM, bunch mass; PHF, period between flowering and harvest; CI index, chilling injury index; CL *a*, chlorophyll *a*; CL *b*, chlorophyll *b*; CAR, carotenoids; PHE, total phenols. NB, non-bagged; Pol blue 3+WFN, blue transparent polyethylene 3µ+white non-woven fabric 3µ; Pol black 6+WFN, black polyethylene 6µ+white non-woven fabric 3µ; Pol black 8+WFN, black polyethylene 8µ+white non-woven fabric 3µ; Pol black 10+WFN, black polyethylene 10µ+white non-woven fabric 3µ; Pol black 10+Pol B, black polyethylene 10µ+blue transparent polyethylene 5µ impregnated with insecticide. Means followed by the same letters in the column did not differ from each other by the Tukey test (p<0.05). *, p <0.05; **, p <0.01; ^{ns}, not significant to F test (p<0.05).

Table 4. Peel color components of fruits of banana 'Nanica' in function to the period of formation of the bunch, bagging time and protection material.

	L*	a*	b*	C*	h°
Green fruit					
Autumn-Winter	57.90 B	-17.64	35.39	39.61 B	116.47 B
Winter-Spring	59.69 A	-17.52	37.54	40.71 A	117.61 A
vc (%)	6.21	10.80	21.70	2.89	1.58
F	6.77*	0.01 ^{ns}	2.11 ^{ns}	40.16**	37.07**
Ripe fruit					
Autumn-Winter	66.76 B	0.31	39.79 B	39.83 B	90.32
Winter-Spring	71.15 A	0.33	43.07 A	43.14 A	88.90
vc (%)	6.13	10.80	9.27	10.02	5.76
F	30.69*	2.46 ^{ns}	20.79**	18.06**	2.16 ^{ns}
Green fruit					
Late	58.35 B	-18.56	35.65	40.22	117.50 A
Early	60.28 A	-16.54	37.34	40.09	116.55 B
vc (%)	6.21	10.80	21.70	2.89	1.58
F	6.86**	3.42 ^{ns}	1.29 ^{ns}	0.35 ^{ns}	7.42**
Ripe fruit					
Late	67.73 B	0.32	40.83	40.98	89.47
Early	70.27 A	0.31	42.07	42.02	89.76
vc (%)	6.13	10.80	9.27	10.02	5.76
F	10.28**	0.04 ^{ns}	3.01 ^{ns}	1.80 ^{ns}	0.09 ^{ns}
Green fruit					
NB	54.25 B	-19.07 A	34.94	39.84	118.60 AB
Pol blue 3+WFN	55.46 B	-19.42 A	34.94	39.99	119.14 A
Pol black 6+WFN	57.32 B	-18.13 AB	39.69	39.95	117.34 BC
Pol black 8+WFN	60.88 A	-16.90 B	36.19	40.53	116.51 C
Pol black 10+WFN	61.52 A	-15.38 B	36.33	40.49	116.00 CD
Pol black10+Pol B	63.36 A	-16.73 B	36.43	40.48	114.63 E
vc (%)	6.21	12.11	19.70	2.89	1.58
F	18.41**	1.35 ^{ns}	0.94 ^{ns}	1.21 ^{ns}	15.20**
Ripe fruit					
NB	66.70 B	2.58 A	44.74 A	44.35 A	86.40 B
Pol blue 3+WFN	66.65 B	1.62 AB	43.16 AB	43.28 AB	87.53 AB
Pol black 6+WFN	69.93 A	-0.41 AB	41.22 ABC	41.96 ABC	90.74 AB
Pol black 8+WFN	69.81 A	-0.31 AB	40.13 BC	39.92 BC	90.51 AB
Pol black 10+WFN	70.30 A	-1.12 B	41.21 ABC	41.50 ABC	91.76 A
Pol black10+Pol B	69.16 A	-0.69 AB	38.22 C	38.43 C	90.50 AB
vc (%)	6.13	10.80	9.27	10.02	5.76
F	4.15*	3.11*	6.45**	4.92**	3.08*

Means followed by the same letters in the column did not differ from each other by the Tukey test, (p<0.05). *, p <0.05; **, p <0.01; ^{ns}, not significant to F test (p<0.05). L*, brightness; a*, coordinated a*; b*, coordinated b*; C*, chromaticity; h°, hue angle.

with Pol black 10+WFN and Pol black 10+Pol B (mild injury), while other treatments did not differ.

The reduction in LT with bagging affected the content of photosynthetic pigments and consequently fruit peel color (Tables 2 and 3). NB and Pol blue 3+WFN exhibited higher CI index (severe injury) when compared with Pol black 10+WFN and Pol black 10+Pol B, not differing from each other (Table 3). However, there was no interference of LT on CL *b*. Hasan et al. (2000) observed that fruits protected with black polyethylene bags exhibited lower CL *a* content and higher CL *b* content compared to NB.

Bunches harvested in winter-spring showed higher L*, C* and h° when green, and higher L*, b* (yellow) and C* when ripe (Table 4). Therefore, they exhibited higher visual quality than fruits harvested in autumn-winter. L* (brightness). This is a color component that most decreases after the occurrence of CI. These results agree with the lower number of hours capable of causing stress (Table 1) and CI index (2.13), which indicated mild damage, as compared estimates in autumn-winter (3.38), which indicated moderate damage (Table 3). The standard (desirable) color of fruits formed in the same experimental area in 2013 and 2014, in the absence of cold (summer), had mean L* value of 73.92%, indicating larger deviations for fruits formed in autumn-winter ($\Delta L^* = -7.96$) than in winter-spring ($\Delta L^* = -2.77$). Early bagging promoted the harvest of fruits with higher L* and lower h° (light green) (Table 4). The ripe bagged fruits showed peels with higher L*. Green fruits bagged with Pol black 10 + Pol B, Pol black 10+WFN and Pol black 8+WFN showed peel with higher L* and a*, but with lower h°, light green peel, compared to the other treatments (Table 4). After maturation, L* remained higher in fruits of these treatments. However, they also showed lower b* and C* and higher h° values, denoting light yellow. Due to CI, h° decreases and shifted towards the reddish region (Hashim et al. (2012), due to the discoloration of vascular strands (Chen et al., 2008). This is associated with the accumulation of oxidized polyphenols (Hashim et al., 2014). Harvey (2006) observed that reducing ST caused paler fruits before and after ripening. However, the increment of 7.6 μ in the bag thickness did not result in increased yield or improved fruit color (Vargas-Calvo and Valle-Ruiz, 2011). The PHE content was higher in NB and Pol blue 3+WFN, which exhibited higher CI index, followed by Pol black 8+WFN, Pol black 6+WFN, and Pol black 10+ WFN and Pol black 10+Pol B (Table 3). The PHE was associated with cold tolerance in two banana genotypes (El-Mahdy et al., 2018). During storage of banana at chilling T, Chen et al. (2008) detected increase in mRNA transcripts, phenylalanine ammonia-lyase (PAL) and protein levels, which is a key enzyme in the biosynthesis of various phenolic compounds. Although fruit bagging prevents PAL from being induced by sunlight, PHE synthesis is inhibited in the peel of various fruits (Sharma et al., 2014), which justifies its lower values in the peel of fruits of Pol black 10+WFN and Pol black10+Pol B treatments (Table 3). Bagging treatment with sunlight-impermeable, double-layer paper bags decreased the PHE content in peels of different apple cultivars (Chen et al., 2012).

In this study, we could not dissociate the effect of low T and ST through the bag on the PHE content and color of green or ripe fruits. In addition, free phenolic compounds are consumed in oxidation reactions and subsequent polymerization (Nguyen et al., 2003) in banana subjected to

post-harvest cold stress. Dissimilarly, fruits exposed to more cold stress, NB and Pol blue 3 + WFN presented the highest levels (Table 3).

Regardless of bunch formation period and bagging time, significant and strong correlation between Tmin on the peel surface and CI index ($r=-0.94^*$) and L* in green fruits ($r=0.78^*$) was observed, indicating the effect of stress T on the reduction of peel L*, as well as PHE ($r=-0.92^*$) and CAR contents ($r=-0.64^*$).

Through the bagging material, ST was correlated with CI index ($r=0.92^*$), L* ($r=-0.77^*$) and PHE ($r=0.85^*$) in the peel of green fruits, confirming that fruits that received less sunlight showed higher L*, and lower CI index and PHE content. There was positive correlation between ST and CL *a* ($r=0.59^*$) and CAR contents ($r=0.67^*$) on the peel of green fruits, showing that the synthesis of these pigments is related to sunlight availability. The correlation between PHE and h° in green ($r=0.60^*$) and ripe fruits ($r=-0.46^*$) indicates that higher the PHE content causes higher h° (more green), as opposed to the response observed in ripe fruits (less yellow). However, higher PHE content was correlated with lower L* ($r=-0.81^*$) in the peel of green fruits.

New experiments should be carried out to verify if: (1) the reduction of PHE in fruit peel with the use of material with low ST is an efficient measure to prevent cold damage on fruit peel; (2) the bag that prevents the transmission of long wavelength infrared during cold nights creates an insulating effect.

Materials and methods

Experimental area

The research was conducted at Univale farm, located at Jacupiranga, state of São Paulo, Brazil (24° 24' 00" S latitude, 48° 0' 00" W longitude and 80 m above sea level). The climate of the region is classified as Af; tropical rainy without dry season (Alvares et al., 2013).

The soil is classified as Haplic Cambisol (Embrapa Solos, 2013), with 420, 110 and 470 g kg⁻¹ of clay, silt and sand, respectively. The 0-20 cm layer of the soil had the following characteristics: organic matter (OM) = 29 g dm⁻³; pH in water = 5.4; P resin = 20 mg dm⁻³; K, Ca, Mg, potential acidity (H+Al), exchangeable acidity (Al) and cation exchange capacity (CEC) (mmolc dm⁻³) = 1, 30, 10, 40, 0.1 and 81.1, respectively; and base saturation (V%) = 50.68%; S, B, Fe, Mn, Cu and Zn (mg dm⁻³) = 10, 0.3, 207, 17.5, 1.5 and 3.5.

Plant material

Planting was performed in 2013 in a density of 1600 plants ha⁻¹ using pest-free banana tissue-cultured plants (*Musa* spp. AAA group, Cavendish subgroup, cv. Nanica). In this research, we used inflorescences from 3rd cycle of fruit production. All the cultural treatments necessary for good production were carried out.

Experimental design

The experimental design was a completely randomized design with eight replicates arranged in a 2 x 2 x 6 factorial scheme, with two periods of bunch formation, two bagging times and six bag materials.

The periods of bunch formation were autumn-winter (20/04/2015 to 14/08/2015) and winter-spring (31/07/2015 to 10/12/2015), coinciding, respectively, with the decrease of the T in autumn and the elevation of the T in spring. The bagging time was before of opening of the bracts (early) and after the complete opening, when all female hands were identified (late). The treatments were polyethylene bags with different thickness: blue transparent polyethylene 3 μ + white non-woven fabric 3 μ (Pol blue 3+WFN), black polyethylene 6 μ + white non-woven fabric 3 μ (Pol black 6+WFN), black polyethylene 8 μ + white non-woven fabric 3 μ (Pol black 8+WFN), black polyethylene 10 μ + white non-woven fabric 3 μ (Pol black 10+WFN) and black polyethylene 10 μ + blue transparent polyethylene 5 μ impregnated with bifenthrin insecticide (Biflex®) (Pol black 10+Pol B) (Table 1). Non-bagged (NB) were used as the control.

In all plants, the flower, bracts and hands were removed and 8 hands bunch⁻¹ were kept. 80g ha⁻¹ of Imidacloprid was sprayed to control the tripes, except in the Pol black 10+Pol B. The bags were attached at the top of the bunch, on the stalk, and left open at the bottom.

General assessments

The temperature of the air in canopy and of the surface of fruits inside the bags were measured with copper-constantan thermocouples digitized in a data logger (Campbell Scientific, Logan, Utah, USA, Model CR 1000). T sensors were attached with adhesive tape to fruits of the median portion of bunch (4th hand). Mean daily T and cumulative rainfall were recorded at a meteorological station (Campbell Scientific, Logan, Utah, USA).

The fruit bunches were harvested when fruits from the last hand reached 3 cm in diameter. The BM and PFH were recorded. The 4th hand was stored at 25°C and 85-95% relative humidity up to stage 6 of the Von Loeseck scale (1950).

Assessed variables

CI index

The CI was scored visually based on the intensity of surface browning according to the methodology of Nguyen et al. (2003) as follows: 1= no CI; 2= mild injury; 3= moderate injury; 4= severe injury; 5= very severe injury.

Color of fruit peel

It was measured at four locations around equatorial region on each fruit using a colorimeter (CR-400, Minolta, Tokyo, Japan). The illuminant was D65 and color was measured using the CIE L*a*b* system. L* denotes brightness (0 = black and 100 = white) and chromatic co-ordinates a* (+a* = green and -a* = red) and b* (+b* = yellow and -b* = blue). The hue angle ($h^{\circ} = \tan^{-1} [b^*/a^*]$) and chromaticity ($C^* = [a^{*2} + b^{*2}]^{1/2}$) were calculated.

Photosynthetic pigments

Three peel discs were removed from one side of banana fruit and incubated with dimethyl sulfoxide for 24 h in the dark (Hiscox and Israelstam, 1979). The supernatant was used to

determine the chlorophyll and carotenoid content according to Wellburn (1994), in a spectrophotometer Shimadzu UV-1601.

Total phenols content

Frozen peel tissue were homogenized in ethanol and extraction was carried by 24 h in the dark. Then the homogenate was centrifuged at 12.000 \times g for 20 min at 4°C. The Folin-Ciocalteu method determined total phenols as described by Singleton et al. (1999). The quantification was conducted in a spectrophotometer Shimadzu UV-1601 and the results expressed as gallic acid equivalents in mg g⁻¹ FM⁻¹.

Statistical analysis

Data of analyses were expressed as means of three replicate determinations. Statistical analysis was conducted with the SISVAR software (Ferreira, 2011). Mean comparisons were performed using the Tukey's test ($p < 0.05$). Correlation between variables was determinate by Pearson's coefficient. Plots in this paper were made by Origin 8.0.

Conclusions

The change of sunlight transmission with black polyethylene bags of different thickness did not promote significant increase in temperature and bunch mass, but reduced chilling injury and increased the peel brightness. On the other hand, late winter can increase fruit losses by sunburn. Although not controlling CI, early bagging is recommended to increase peel L*.

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