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RESEARCH ARTICLE

Application of naphthalene acetic acid and gibberellic acid favours fruit induction and development in oil palm hybrid (*Elaeis oleifera* x *Elaeis guineensis*)

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Summary
The OxG hybrid bunches contain more parthenocarpic fruits (PF) than normal fruits (NF) and present problems of development and ripening due to either an asynchronous opening of flowers or insufficient pollination. The objective of this study was to compare the effect of α-naphthaleneacetic acid (NAA) and gibberellic acid (GA_3) in the induction and development of PF and NF, the fatty acid profile (FAP), and the oil potential in the 'Coari x La Mé' oil palm hybrid. NAA and GA_3 induced parthenocarpy in the fruits and did not alter the FAP of the mesocarp oil. The commercial dose of pollen (0.9 g talc + 0.1 g pollen) resulted in increased bunch weight (BW) (20.8 kg) and lower percentage of PF in the bunch (65.4%). The most effective hormonal doses to induce the formation of PF in the bunch were NAA 300 and 600 mg L^{-1}. GA_3 alone or in mixture with NAA increased the percentage of PF but did not increase the BW, indicating that GA_3 had no synergistic effect on BW. The NAA applications represent alternatives to complement assisted pollination of OxG hybrids to increase bunch production and oil yield.

Keywords: Plant growth regulators; Pollination; Parthenocarpy; Fatty acid profile

Introduction

OxG hybrids result from the cross between the American palm (*Elaeis oleifera*) and the African palm (*Elaeis guineensis*). These interspecific hybrids are a valued alternative to produce oil due to their characteristics: resistance to pest and diseases, acceptable bunch production, oil extraction performance in beneficiation plants (Zambrano, 2004), high-quality unsaturated oil (oleic 55% – linoleic 11%), and significant contents of vitamin E (Mondragon and Pinilla, 2015; Mozzon *et al.*, 2013) along with carotenes (Choo and Nesaretnam, 2014; Rivera *et al.*, 2013).

OxG hybrids present some peculiarities that affect their natural pollination, such as low production of male inflorescences, low viability of pollen and lack of attractive odours and colours towards pollinating insects (Alvarado *et al.*, 2000), the presence of morphological barriers, such as the peduncular bracts or spathes of the female inflorescence (Corley and Tinker, 2016), and a prolonged and irregular anthesis phase that extends pollination times in the same inflorescence. This low pollination rate produces few normal fruits (NF) per bunch and a greater number of aborted flowers. These are variables of utmost importance in oil yield per ha. For these reasons, it is necessary to carry out the practice of assisted pollination. The aim is to ensure that female flowers in anthesis receive sufficient pollen to stimulate the development of most of the fruits and to obtain high oil/bunch and extraction rates (Barcelos *et al.*, 2015; Rosero *et al.*, 2017).

OxG hybrids are characterised by parthenocarpy, a process by which seedless fruits are developed in the presence or absence of pollination and fertilisation (Mesejo, 2012; Vardi *et al.*, 2008). Mature bunches had redder and whiter parthenocarpic fruits (PF) compared to the NF. The oil content in the red PF is similar to that of the NF, while the white or aborted PF contain no oil (González *et al.*, 2013; Yáñez *et al.*, 2006). The advantage of red PF from the OxG hybrid is that they develop and ripe like the NF, but due to their higher proportion of mesocarp (up to 98%) they contain more oil (Bastidas *et al.*, 2007; Preciado *et al.*, 2011a). Furthermore, the contribution of red PF to the total percentage of oil in the bunch is greater (20–50%) than of NF (Preciado *et al.*, 2011b).

Parthenocarpy and increased fruit growth can be induced in many species through the application of auxins and gibberellins; the latter can induce an increase in the content of endogenous auxins in the ovary of a non-pollinated flower and cause the growth of fruits in the absence of fertilisation (Azcón-Bieto and Talón, 2013).

Studies on the effect of the application of hormones for fruit formation in oil palm are scarce. The first works on the subject indicated that auxin 2,4,5-TP (2,4,5-trichlorophenoxyacetic acid) was effective for inducing parthenocarpy in the inflorescences of *pisifera* palms, usually sterile (Sparnaaij, 1960). Subsequently, Thomas *et al.* (1973) reported parthenocarpy induction with exogenous applications of α-naphthaleneacetic acid (NAA) and gibberellic acid (GA_3). Furthermore, Corley and Breure (1992) observed that NAA favoured the emission of female inflorescences in *tenera* palms, even though this effect only appeared 24 months after treatment. In more recent research on hybrids of different origin, Prieto *et al.* (2015) observed that spraying of NAA and GA_3 to inflorescences during anthesis induced parthenocarpy and increased fruit size. Treatments with GA_3 (100 mg L^{-1}) and hormone application with pollen (GA_3 + assisted pollination) were more effective. Prieto *et al.* (2015) also pointed out that hormonal treatments increased their effectiveness in older palms.

Hormone spraying during flowering or post-flowering, mainly GA_3 and NAA, could be an option to increase the number and quality of PF in the OxG hybrid. This will reduce costs and frequency of assisted pollination making plantations more profitable and sustainable. On that basis, the objective of this study was to compare the effect of controlled sprays of GA_3 and NAA in the induction, growth, and development of bunch PF and NF, the fatty acid profile (FAP), and the oil potential (OP) in the high oleic OxG hybrid.

Materials and Methods

Location and plant material

The experiment was carried out from December 2016 to June 2017 in the Guaicaramo commercial plantation located in Barranca de Upía, Meta, Colombia (7°14'52.40" N, 73°48'15.56" W). Climatic conditions during the experiment were 2,713 mm/year (208 mm/month), 78% relative air humidity, 27.2 °C average temperature, 32.9 maximum temperature and 22.4 °C minimum temperature, and average annual solar brightness of 1,700 h. Six-year-old interspecific OxG hybrid product of the cross between American palm Coari (Brazil) and African palm La Mé (Ivory Coast) was used. The palms were planted at a density of 116 trees per ha in an experimental field with sandy clay loam soil, characterised with pH 4.7, CEC 12.3 cmol kg^{-1} and 2.6% organic matter.

Experiment design and treatments

The experiment design was completely randomised (CRD) with eight treatments: (1) NAA 300 mg L^{-1}; (2) NAA 600 mg L^{-1}; (3) GA_3 150 mg L^{-1}; (4) NAA + GA_3 300 + 150 mg L^{-1}; (5) NAA + GA_3 600 + 100 mg L^{-1}; (6) commercial pollen: 0.9 g talc + 0.1 g pollen; (7) pure pollen: 3 g/inflorescence; and (8) natural pollination; all treatment with four replicates, four palms per

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replicate and four inflorescences per palm. As hormonal sources, the products Hormonagro® (NAA 17.2 g L^{-1}) and Progibb® (GA_3 10%) were used. A single experiment was performed as this research searched to elucidate whether this new methodology of the hormone application would be effective on oil palm.

Isolation of inflorescences and treatment applications

The female inflorescences were previously isolated in the phenological stage 601 or pre-anthesis 1 (Rosero *et al.*, 2017) and cautiously enfolded to avoid the entry of external pollen and guarantee that the later development of the fruits was an exclusive consequence of the application of each hormonal treatment. For the enfolding process, the peduncular bracts that surround bunches were removed. White polyester isolation Green Putumayo® bags were placed and firmly tied to the floral peduncle, ensuring that they were hermetic to avoid contamination from surrounding natural pollen or the entry of pollinating insects. The commercial pollen used in this experiment was collected from selected African Tenera palms, in which the male inflorescences were cut in anthesis stage 607. The finger-like spines were separated and dried in a forced convection oven for 12 h at 39 °C until 6% humidity; then they were shaken carefully to release the pollen from the anthers, and its germination quality was determined with the germination test described by Turner and Gilbanks (1974); only pollen with at least 76% germination was used.

The treatments were applied when the inflorescences reached the phenological stage 607 of anthesis stage, this is when 80% of the flowers had beige receptive stigmas (Hormaza *et al.*, 2012). The application was made through a spray inserted in the window of the bag, spraying uniformly each inflorescence with a 60-ml solution of the corresponding dose. The hole was sealed afterwards using electrical tape. The isolation bags were removed 10 days after spraying the treatments.

Harvest and bunch analysis

Bunches were harvested following the criteria of harvesting when the first fruits were detached or showed cracking signs (González *et al.*, 2013). Bunch analyses (García and Yáñez, 2000) were performed to determine bunch weight (BW), rachis weight (RW), fruit/bunch (NF, PF and aborted fruits (AF)), contribution of the NF and PF to bunch oil, and OP.

Fatty acid profile (FAP)

The FAP of the NF and PF mesocarp oil was performed using the analytical procedure of the AOCS (1994). The fatty acid methyl esters were determined by gas chromatography (GC) with flame ionisation detector (FID). The oil sample was saponified using KOH/MeOH. The fatty acids were derived into esters, using a solution of BF3-methanol. The esters were removed, and 1 μL was injected into the chromatographic system. The equipment used was a 7890 A gas chromatograph (Agilent Technologies, Wilmington, USA) along with a DB-23 (JandW Scientific, Cat. 122-2362) 60m x 0.25 mm ID x 0.25 μm, for example, column for the analysis. The injection was performed at the split mode (50:1). Hydrogen was used as stripping gas at a constant flow of 33 cm s^{-1}. A mixture of SupelcoTM 37 component and FAME (Supelco, Bellefonte, PA, Cat No. 47 885-U) was employed as the reference standard for retention times. The fatty acid methyl esters were identified by comparison with the retention times of the standard mixture analysed under the same chromatographic conditions. The quantification was performed using the area normalisation method. The results were expressed in percentage mass to mass (m/m) in accordance with the AOCS standard official method Ce 1-62 (AOCS, 1997).

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Table 1. Effect of hormone doses on the components of the bunch

Treatment	Dose (mg L^{-1})	BW (kg)	RW		Fruits (%)		
			(kg)	(%)	NF	PF	AF
NAA	300	10.8^{b}	$5.8^{b,c}$	54.4^{b}	0.0^{b}	81.6^{a}	18.4^{b}
NAA	600	10.7^{b}	5.2^{c}	49.5^{b}	0.0^{b}	74.7^{a}	25.3^{b}
GA_3	150	$6.2^{b,c}$	4.4^{c}	70.5^{a}	0.0^{b}	78.7^{a}	21.3^{b}
NAA + GA_3	300 + 150	10.6^{b}	$5.4^{b,c}$	53.7^{b}	0.0^{b}	79.7^{a}	20.3^{b}
NAA + GA_3	600 + 100	$9.6^{b,c}$	4.8^{c}	52.7^{b}	0.0^{b}	80.8^{a}	19.2^{b}
Commercial pollen*	0.9 + 0.1	20.8^{a}	$7.4^{a,b}$	35.6^{c}	31.9^{a}	65.4^{b}	2.7^{c}
Pure pollen†	3.0†	21.1^{a}	7.6^{a}	35.6^{c}	30.8^{a}	66.0^{b}	3.2^{c}
Natural pollination	–	4.7^{c}	3.6^{c}	78.7^{a}	2.7^{b}	27.0^{c}	70.3^{a}
Mean		15.0	6.2		14.9	70.5	14.6
CV (%)		21.3	25.5		47.4	22.6	98.8
Significance		**	**		**	**	**

Note: BW – bunch weight, RW – rachis weight, NF – normal fruits, PF – parthenocarpic fruits, AF – aborted fruits.*g talc + g pollen; †g/inflorescence; **Significant F-test ($p < 0.01$).

Statistical analysis

The generated data that did not present homogeneity of variance were transformed by means of $\sqrt{x + 0,5}$, and an analysis of variance was performed. Duncan´s test ($p \leq 0.05$) was used to analyse differences between treatments. The statistical program SAS® 9.0 was employed.

Results

Bunch components

The BW was defined as the sum of the weights of spikelets with fruits and rachis (peduncle) of the bunch. Table 1 shows that, among the doses of hormones applied, the BW was higher for the NAA doses (300 and 600 mg L^{-1}) and the NAA + GA_3 mixtures than for the GA_3 dose (150 mg L^{-1}), which was also reflected in the general conformation of the bunches (Figure 1a–e). The BW was significantly higher in the pollen treatments (commercial pollination and pure pollen) compared with the hormone treatments (NAA and GA_3) and natural pollination, which was reflected in better development and size of these bunches (Figure 1f–g). This is explained by the exogenous spraying of pollen that increased the number of pollen grains reaching the stigma of the female flowers. Subsequent germination favoured the formation of most of NF of the bunch. Conversely, this did not occur in the hormone treatments where pollen did not enter the inflorescences during anthesis as these were completely isolated by the bags. In natural pollen treatment, the lowest BW was, probably, due to insufficient amount of viable pollen and/or low activity of pollinating insects, which did not allow for the normal formation of the fruits (Figure 1h). The lowest BW was obtained in the natural pollen treatment. In fact, natural pollination is fluctuating and uncertain because it depends on the availability, viability, and germination of pollen, climatic variations of rainfall, dry seasons, temperature, and relative humidity.

The RW was significantly higher for the pollen treatments than for the NAA and GA_3 applications. This, probably, indicates that, while the pollen favoured the flow of the assimilates towards the rachis increasing the RW, the hormones might have reduced it favouring the filling of the PF of the bunch.

The percentage of NF/bunch was significantly higher for the treatments with commercial pollen (31.9%) and pure pollen (30.8%), low for natural pollination (2.7%); and there was no formation of NF in hormone treatments. The non-formation of NF in the treatments with NAA and GA_3 was due to the previous isolation of the inflorescences that prevented the entry of any external pollen. On the contrary, in the pollen treatments (natural, commercial and pure), the NF and PF were indeed formed simultaneously.

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Figure 1. Effect of hormone doses on bunch development. (a) NAA 300 mg L^{-1}, (b) NAA 600 mg L^{-1}, (c) GA_3 150 mg L^{-1}, (d) NAA 300 mg L^{-1} + GA_3 150 mg L^{-1}, (e) NAA 600 mg L^{-1} + GA_3 100 mg L^{-1}, (f) commercial pollen (0.9 g talc + 0.1 g pollen), (g) pure pollen (3 g/inflorescence) and (h) natural pollination.

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Table 2. Effect of hormone doses on the bunch oil potential (OP), and contribution of normal fruits (NFBO) and parthenocarpic fruits (PFBO) to bunch oil

Treatment	Dose (mg L^{-1})	Oil/bunch (%)		
		NFBO	PFBO	OP
NAA	300	0.0^{b}	20.0^{a}	20.0^{a}
NAA	600	0.0^{b}	22.6^{a}	22.6^{a}
GA_3	150	0.0^{b}	$13.8^{a,b}$	13.8^{b}
NAA + GA_3	300 + 150	0.0^{b}	22.6^{a}	22.6^{a}
NAA + GA_3	600 + 100	0.0^{b}	23.7^{a}	23.7^{a}
Commercial pollen†	0.9 + 0.1	11.6^{a}	11.5^{b}	23.1^{a}
Pure pollen	3‡	10.6^{a}	11.6^{b}	22.2^{a}
Natural pollination	–	2.0^{b}	6.1^{c}	8.1^{c}
Mean		5.3	16.1	21.4
CV (%)		55.6	29.8	22.2
Significance		**	**	*

Note: OP = NFBO + PFBO.
†g talc + g pollen.
‡g/inflorescence.
*Significant F-test ($p < 0.05$).
**Significant F-test ($p < 0.01$).

In all hormone treatments, the percentage of PF/bunch was higher than in the other treatments and there was no formation of NF. Although there were no significant statistical differences between the doses of hormones, the percentages of PF were higher with the doses of NAA (300 and 600 mg L^{-1}) and NAA 600 mg L^{-1} + GA_3. A combined effect of NAA and GA_3 was evident in the induction and development of bunch PF. In the enfolded treatments that only received pollen (commercial pollen and pure pollen) and in the free pollination treatment (natural pollen), the percentage of PF was significantly lower, but NF were formed because of the pollen-induced parthenocarpy. However, the percentages of PF and NF were the lowest in the control treatment (natural pollination), indicating little availability and circulation of pollen in the experimental field, which did not guarantee the formation of the fruits (Figure 1).

All AF determined in this study include those that were not formed due to lack or shortage of pollen and adverse environmental conditions during its initial development. Fruit abortion/bunch (AF) was low for commercial pollination (2.7%) and for pure pollen (3.2%), intermediate in hormone treatments (18.4 to 25.3%) and high (70.3%) in natural pollination. Although these percentages of abortion were relatively high, the fact that the inflorescences remained isolated for 15 days might have generated atypically high temperatures inside the bags. Since natural pollination depends on the availability of pollen in the environment and the activity of pollinating insects, it is strongly influenced by the environmental conditions of temperature and relative humidity (Syed, 1979; Tandon *et al.*, 2001).

Bunch oil content

The total oil/bunch content was the sum of the mesocarp oil of NF and PF. The contribution of the NF to the bunch oil (NFBO) was 11.6% for the commercial pollen treatment and 10.6% for the pure pollen treatment, but it was low (2.0%) in the natural pollination treatment. In hormonal treatments, this contribution was 0.0% as a reasonable consequence of the non-formation of NF in those inflorescences that did not receive pollen (Table 2). In contrast, the PF contributed more than NF to the oil of the bunch because its formation and development was induced by NAA and GA_3.

The OP is a theoretical value of the oil content in the harvested bunches that reach the extraction plant. The oil extraction rate (OER) is the estimated quantity of oil extraction/bunch at the extraction plant (OER = OP × 0.85). The OP and OER were significantly lower in natural

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pollination and in GA_3 (150 mg L^{-1}) treatments, as compared to pollen treatments (commercial pollination and pure pollen) and other doses of NAA and GA_3.

Fatty acid profile (FAP)

The main fatty acids found in the mesocarp of mature fruit (Table 3) were the oleic (C18:1), linoleic (C18:2), and vaccenic (C18:1) unsaturated fatty acids (UFA), and the palmitic (C16:0) and stearic (C18:0) saturated fatty acids (SFA). Other UFA and SFA were found in negligible amounts (<1%). No significant differences were found among the treatments for the FAP ($p < 0.05$), but these were found between the NF and PF.

The effect of NAA and GA_3 treatments on the composition of fatty acids (SFA and UFA) shows that UFA of the PF were significantly higher than SFA. In the pollen treatments (natural pollination, commercial pollen and pure pollen), the UFA of NF and PF were similar, but significantly higher than their SFA. Likewise, the UFA of the PF formed in hormone-treated plants were similar to the NF of the pollen treatments. It is important to mention that no NF was formed with hormones because, as it was explained earlier, no pollen entered the enfolded inflorescence of those treatments. The NAA and GA_3 doses (single or mixed) did not alter the FAP of the fruit (NF and PF) mesocarp oil.

Discussion

Bunch components

The BW was the sum of the weights of spikelets with fruits and peduncle or rachis of the bunch. The low BW obtained in the natural pollen treatment was, probably, due to the shortage of viable pollen in the experimental field. In addition, natural pollination of hybrids is scarce due to the reduced emission of male inflorescences that produce little amount of low viability pollen (Hormaza *et al.*, 2012). The significant increase of BW in hormonal treatments that included NAA when compared with GA_3 was, probably, due to the known effect of NAA and GA_3 on the induction of fruit parthenocarpy (Bishop *et al.*, 2015; Engels *et al.*, 2012) and on their effects on cell division and elongation (Bennett and Leyser, 2014), considering that the OxG hybrids have a higher percentage of PF per bunch. In date palms, El-Kosary (2009) and Awad and Al-Qurashi (2012) also found significant increases in bunch and fruit weight when using GA_3.

In oil palm, the RW, which includes the peduncle and the fruitless spikelets (Breure and Menendez, 1990), represents 22 to 25% of the BW (Redshaw, 2012) and increases simultaneously and proportionally to the increase in BW (Corley and Breure, 1992). In this study, the RW (kg) was lower in the hormonal treatments, but the RW (%) in the hormonal treatments was higher than that in the assisted pollination treatments (Table 1). This is a promising result, since the oil losses increase with an increased percentage of RW during sterilisation when the rachis become impregnated with oil that normally is lost in the rachis discharge (Redshaw 2012); this would, probably, happen in bunches obtained from the hormonal treatments.

The highest percentage of NF/bunch in pollen treatments and the absence of NF in the NAA and GA_3 treatments can be explained on account of pollen application for enfolded inflorescences. The increase in the amount of pollen grains that contact and germinated in the receptive stigma of female flowers favoured the development of most of bunch NF; this did not occur in the NAA and GA_3 treatments since no pollen entered because the inflorescences remained completely isolated by bags.

Since the percentage of PF/bunch was higher in the hormone treatments than in the other treatments, it was evident that NAA and GA_3 stimulated parthenocarpy for most bunch fruits and favoured their development. Pollen-induced parthenocarpy explains the simultaneous formation of NF and PF in pollen treatments (natural, commercial and pure pollen), because the NF

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Table 3. Effect of NAA and GA_3 on the fatty acids profile (% m/m) of normal fruits (NF) and parthenocarpic fruits (PF)

Treatments	NAA (300 mg L^{-1})	NAA (600 mg L^{-1})	GA_3 (150 mg L^{-1})	NAA + GA_3 (300 + 150)	NAA + GA_3 (600 + 150)	Commercial pollen		Pure pollen		Natural pollination		CV (%)	F (Treat)
Fruit	PF	PF	PF	PF	PF	NF	PF	NF	PF	NF	PF		
Palmitic (C16:0)	29.1	29.4	24.0	29.4	28.0	32.5	31.5	29.0	27.8	28.3	32.0	42.5	ns
Stearic (C18:0)	3.2	2.7	3.0	2.6	3.6	2.5	2.2	2.3	2.1	3.9	4.1	29.6	ns
Oleic (C18:1)	56.4	55.6	58.9	55.2	57.3	51.9	53.7	54.7	58.1	56.7	54.9	46.2	ns
Vaccenic (C18:1)	1.0	1.1	0.9	1.3	1.0	1.4	1.5	1.4	1.6	0.9	0.9	16.9	ns
Linoleic (C18:2)	8.6	9.8	11.9	9.8	8.9	9.9	9.5	10.7	9.0	8.6	5.8	43.2	ns
Myristic (C14:0)	0.3	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.2	0.2	0.3	0.3	ns
Margaric (C17:0)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	ns
Palmitoleic (C16:1)	0.2	0.2	0.2	0.4	0.2	0.4	0.4	0.4	0.3	0.2	0.2	0.2	ns
α-Linolenic (C18:3)	0.3	0.3	0.4	0.3	0.3	0.4	0.3	0.4	0.3	0.3	0.2	0.2	ns
SFA	33.2	32.8	27.5	32.9	32.3	36.0	34.5	32.2	30.5	33.0	37.6	43.2	ns
UFA	66.8	67.2	72.5	67.1	67.7	64.0	65.5	67.8	69.5	67.0	62.5	47.5	ns

Note: SFA – saturated fatty acids; UFA – unsaturated fatty acids.
ns – Non-significant F-test ($p < 0.05$).

formation required pollen grains to contact the flower receptive stigma during anthesis; this did not happen in the hormone treatments due to the previous isolation of the inflorescences.

In some species, parthenocarpy and fruit growth can be induced by NAA and GA_3, since GA_3 increases the content of endogenous auxins in the ovary of non-pollinated flowers and generates fruit growth without fertilisation (Mesejo, 2012). Endogenous auxins and GA_3 reach their highest concentrations in fruits when the dry mass build-up rate is the highest, that is, when the fruit sink activity and phloem discharge are the highest (Engels *et al.*, 2012). Also, Prieto *et al.* (2015) observed increased growth rates in fruits from OxG inflorescences sprayed with NAA and GA_3. A recent study indicated that 600 and 1200 mg L^{-1} NAA produced bunch formation comparable to that obtained with assisted pollination (Romero *et al.*, 2021). Corley and Tinker (2016) affirmed that the OxG quality of having more PF per bunch is inherited from the mother *E. oleifera*, which can be 49 or 56% PF per bunch depending on its genetic origin (Rosero *et al.*, 2017; Zambrano, 2004).

The high percentage of fruit abortions (FA) (between 18.4 and 25.3%) in the NAA and GA_3 treatments apparently results from the lack of pollen and high temperatures within the isolation bags, whereas, in natural pollination treatment, FA (70.3%) could be due to a shortage of pollen and high air temperature during the fruit formation, which indeed occurred during the experimental period. In relation to this, Lagos *et al.* (2015) stated that temperature is one of the climatic factors that influences the most in physiological processes of plants, whereas Hedhly (2011) indicated that its effect is more harmful during the formation of floral primordia. Other authors stated that premature FA might be a consequence of incorrect pollination, lack of assimilates, water stress, or extreme temperatures during the fruit development (Combres *et al.*, 2013; Corley and Breure, 1992; Corley and Tinker, 2016). According to Binder and Patterson (2009), increased fruit abscission during periods of high temperature is a consequence of the increased internal concentrations of abscisic acid and ethylene in the fruit tissues. The doses of hormones (Daza *et al.*, 2021) and the number of hormone applications (Romero *et al.*, 2021) were also considered as causes for FA in oil palm.

Inflorescence abortions tend to appear 2 to 5 months prior to anthesis (Sparnaaij, 1960) or 10 months before harvest (Corley and Tinker, 2016); the harvest usually occurs 5 months after anthesis. Female inflorescences are more likely to abort than male ones (Breure and Menendez, 1990; Corley and Breure, 1992). Unexpected flower and FA that occur during dry seasons, even in pollination-assisted palms, are a direct physiological consequence of high temperatures that reduce carbohydrate reserves in pollen grains and stigma cells; this alters the distribution of assimilates by changing the balance between the phloem simplastic and apoplastic load (Taiz and Zeiger, 2006). Also, Sakata *et al.* (2010) suggested that pollen infertility is related to an alteration of the auxin biosynthesis during the anther development, and this reduces the possibilities for the female flowers to be fertilised and increases the fruit premature abortion.

Bunch oil

In the OxG plants, the PF contribute the most to the bunch oil because they are greater in number, and their mesocarp, of up to 98% of the fruit, contributes more oil than the one from the NF (Bastidas *et al.*, 2007; Preciado *et al.*, 2011a, 2011b). The NAA and GA_3 doses (single or mixed) provoked parthenocarpy induction in most bunch fruits, causing oil potential (OP and OER) to be higher in those treatments. The OP indicates the amount of oil that is possible to extract per unit of fresh fruit bunch (Moreno *et al.*, 2017). The plants differed in OP and OER because OER was calculated from OP (OER = OP × 0.85), and these two variables depended on the contribution of oil from normal (NFBO) and parthenocarpic fruits (PFBO). Corley and Tinker (2016) stated that the variations in OP and OER depend on the proportion of NF and PF in the bunch which are the ones that contain oil.

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Fatty acid profile (FAP)

The UFA are chemical molecules with double bonds in their chain, while SFA do not possess them (Cassiday, 2016). The UFA are essential in human nutrition and have cardioprotective properties due to their ability to reduce low-density lipoprotein (LDL) cholesterol, commonly known as 'bad cholesterol', and to increase high-density lipoprotein (HDL) cholesterol, considered as 'good cholesterol' (Khosla, 2014). For many years, *E. guineensis* palm's raw oil was discredited because its content of SFA represented a risk for heart disease (Cassiday, 2016) but today this oil is considered to be balanced since it contains approximately 50% of SFA (mainly palmitic) and 50% of UFA (mainly oleic) (Basri *et al.*, 2005). The hybrid palm oil contains 33% of SFA –mainly palmitic – and 66% of UFA – mainly oleic and linoleic (Mozzon *et al.*, 2013), where oleic acid has cardioprotective properties due to its ability to reduce LDL cholesterol and increase HDL cholesterol (Khosla, 2014). The FAP of the hybrid palm oil in this study coincides with that reported in the literature for the OxG hybrids (Montoya *et al.*, 2013; Tan *et al.*, 1985).

Conclusion

The NAA (300 and 600 mg L^{-1}) doses are effective and promising to increase BW and oil yield in the oil palms without altering the FAP of mesocarp oil and can be considered as complementary alternatives in the assisted pollination of the OxG hybrids.

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References

Alvarado A., Bulgarelli J. and Moya B. (2000). Germinación del polen en poblaciones derivadas de un hibrido entre Elaeis guineensis Jacq. y E. oleífera HBK, Cortes. *ASD Oil Palm Papers* **20**, 35–36.

AOCS. (1994). *Official and Recommended Methods of the American Oil Chemists' Society*. Champaign, IL: American Oil Chemists' Society.

AOCS Ce 1-62. (1997). *Official Methods and Recommended Practices of American Oil Chemist' Society Method Ce 1-62. Fatty Acid Composition by Gas Chromatography*. Champaign, IL: AOCS Press.

Awad M.A. and Al–Qurashi A.D. (2012). Gibberellic acid spray and bunch bagging increase bunch weight and improve fruit quality of 'Barhee' date palm cultivar under hot arid conditions. *Scientia Horticulturae* **138**, 96–100.

Azcón–Bieto J. and Talón M. (2013). *Fundamentos de Fisiología Vegetal*. Barcelona: Graw Hill, Ediciones Mc.

Barcelos E., Rios S.A., Cunha R.N.V., Lopes R., Motoike S.Y., Babiychuk E., Skirycz A. and Kushnir S. (2015). Oil palm natural diversity and the potential for yield improvement. *Frontiers Plant Science* **6**, 190.

Basri M.W., Siti Nor Akmar A. and Henson I.E. (2005). Oil palm – achievements and potential. *Plant Production Science* **8**, 288–297.

Bastidas S., Peña E., Reyes R., Pérez J. and Tolosa W. (2007). Comportamiento agronómico del cultivar híbrido RC1 de palma de aceite (*Elaeis oleifera x Elaeis guineensis*) *x Elaeis guineensis*. *Corpoica Ciencia y Tecnología Agropecuaria* **8**, 5–11.

Bennett T. and Leyser O. (2014). The auxin question, a philosophical overview. In Zazímalová E., Petrásek E. and Benková E. (eds), *Auxin and its Role in Plant Development*. Vienna: Springer, pp. 3–19.

Binder B. and Patterson S. (2009). Ethylene–dependent and –independent regulation of abscission. *Stewart Postharvest Review* **5**, 1–10.

Bishop G., Sakakibara H., Seo M. and Yamaguchi S. (2015). Biosynthesis of hormones. In Buchanan B.B., Gruissem W. and Jones R.L. (eds), *Biochemistry and Molecular Biology of Plants*. Chichester: Wiley, pp. 769–833.

Breure C.J. and Menendez T. (1990). Determination of bunch yield components in the development of inflorescences in oil palm (*Elaeis guineensis* Jacq.). *Experimental Agriculture* **26**, 99–115.

Cassiday P. (2016). Una controversia de peso, cambiando paradigmas sobre las grasas saturadas. *Palmas* **37**, 41–53.

https://doi.org/10.1017/S001447972200031X Published online by Cambridge University Press

Choo Y. and Nesaretnam K. (2014). Research advancements in palm oil nutrition. *European Journal of Lipid Science and Technology* **116**, 1301–1315.

Combres J., Pallas B., Rouan L., Mialet–Serra I., Caliman J., Braconnier S., Soulie J. and Dingkuhn M. (2013). Simulation of inflorescence dynamics in oilpalm and estimation of environment–sensitive phenological phases, a modelbased analysis. *Functional Plant Biology* **40**, 263–279.

Corley R.H.V and Breure C.J. (1992). Fruiting activity, growth and yield of oil palm. I. Effects of fruit removal. *Experimental Agriculture* **28**, 99–109.

Corley R.H.V. and Tinker P.B. (2016). *The Oil Palm*, 5th Edn. Oxford: John Wiley and Sons, Ltd., Wiley Blackwell.

Daza E., Ayala-Díaz I., Ruiz-Romero R. and Romero H.M. (2021). Effect of the application of plant hormones on the formation of parthenocarpic fruits and oil production in oil palm interspecific hybrids (*Elaeis oleifera* Cortes x *Elaeis guineensis* Jacq.). *Plant Production Science* **24**, 354–362.

El–Kosary O. (2009). Effect of GA_3, NAA and cytophex spraying on Samany and Zaghloul date palm yield, fruit retained and characteristics. *Journal Horticultural Sciences Ornamental Plants* **1**, 49–59.

Engels C., Kirkby E. and White P. (2012). Mineral nutrition, yield and source–sink relationships. In Marschner P. (ed), *Mineral Nutrition of Higher Plants*. San Diego, CA: Elsevier, pp. 85–131.

García J. and Yáñez E. (2000). Aplicación de la metodología alterna para análisis de racimos y muestreo de racimos en tolva. *Revista Palmas* **21**, 303–311.

González D., Cayón G., López J. and Alarcón W. (2013). Development and maturation of fruits of two Indupalma OxG hybrids (*Elaeis oleifera* x *Elaeis guineensis*). *Agronomía Colombiana* **31**, 343–351.

Hardon J. and Turner P. (1967). Observations on natural pollination in commercial plantings of oil palm (*Elaeis guineensis*). *Experimental Agriculture* **3**, 105–116.

Hedhly A. (2011). Sensitivity of flowering plant gametophytes to temperature fluctuations. *Environmental Experimental Botany* **74**, 9–16.

Hormaza P., Fuquen E. and Romero H. (2012). Phenology of the oil palm interspecific hybrid *Elaeis oleifera* × *Elaeis guineensis*. *Scientia Agricola* **69**, 275–280.

Khosla P. (2014). Efectos del aceite de palma en la salud humana. Más allá del perfil de ácidos grasos. *Palmas* **35**, 59–72.

Lagos B., Bacca T., Herrera P. and Delgado T. (2015). Biología reproductiva y polinización artificial del tomate de árbol (Cyphomandra betacea (Cav.) Sendt). *Bolletin Cientifico Museo Historia Natural Universidad de Caldas* **19**, 60–73.

Mesejo C. (2012). *Citricultura. El cuajado del fruto. Polinización y partenocarpia. Las giberelinas.* Available at http://riunet.upv.es/bitstream/handle/10251/16898/Elcuajadodelfruto–polinizaciónypartenocarpia–lasgiberelinas.pdf?sequence=3 (accessed 19 June 2021).

Mondragón A. and Pinilla C. (2015). Aceite de palma alto oleico, propriedades fisicoquímicas y beneficios para la salud humana. *Revista Palmas* **36**, 57–66.

Montoya C., Lopes R., Flori A., Cros D., Cuéllar T., Summo M., Speout S., Rivallan R., Risterucci A.–M., Bittencourt D., Zambrano J.R., Alarcón W.H., Villeneuve P., Pina M., Nouy B., Amblard P., Ritter E., Leroy T. and Billotte N. (2013). Quantitative trait loci (QTLs) analysis of palm oil fatty acid composition in an interspecific pseudo–backcross from Elaeis oleifera (H.B.K.) cortés and oil palm (Elaeis guineensis Jacq.). *Tree Genetics and Genomes* **9**, 1207–1225.

Moreno E., García J.M., Díaz C.A. and Ramírez N.E. (2017). Optimización de la medición del potencial industrial de aceite. *Palmas* **38**, 98–107.

Mozzon M., Pacetti D., Lucci P., Balzano M. and Giuseppe Frega N. (2013). Crude palm oil from interspecific hybrid *Elaeis oleifera* × *Elaeis guineensis*, fatty acid regiodistribution and molecular species of glycerides. *Food Chemistry* **141**, 245–252.

Preciado C., Bastidas S., Betancourth C., Peña E. and Reyes R. (2011a). Predicción y control de la cosecha en el híbrido interespecífico Elaeis oleifera x Elaeis guineensis en la zona palmera occidental de Colombia. I. Determinación del período de madurez para obtener racimos de alto contenido de aceite. *Corpoica Ciencia y Tecnología Agropecuaria* **12**, 5–12.

Preciado C., Bastidas S., Betancourth C., Peña E. and Reyes R. (2011b). Predicción y control de la cosecha en el híbrido interespecífico Elaeis oleifera x Elaeis guineensis en la zona palmera occidental de Colombia. II. Determinación del ciclo de cosecha para obtener racimos de alto contenido de aceite. *Corpoica Ciencia y Tecnología Agropecuaria* **12**, 13–19.

Prieto A., Ochoa I. and Cayón G. (2015). Efecto de la aplicación de Auxinas y Giberelinas en la Formación de Frutos Partenocárpicos en los Híbridos *Elaeis oleífera* H.B.K. Cortés *x Elaeis guineensis* Jacq. en Unipalma de los Llanos S.A. XVIII International Oil Palm Conference, September 22–25, 2015. Colombia: Cartagena de Indias.

Redshaw M. (2012). Utilización de los residuos del campo y de los subproductos de la planta extractora. In Fairhurst T.H. and Härdter R. (eds), *Palma de Aceite, Manejo para Rendimientos Altos y Sostenibles*. Singapore: International Plant Nutrition Institute and International Potash Institute, pp. 337–350.

Rivera Y., Cayón G. and López J. (2013). Physiological and morphological characterization of American oil palms (*Elaeis oleifera* HBK cortes) and their hybrids (*Elaeis* oleifera x *Elaeis* guineensis) on the Indupalma plantation. *Agronomía Colombiana* **31**, 314–323.

Romero H., Daza E., Ayala–Díaz I. and Ruiz–Romero R. (2021). High–oleic palm oil (HOPO) production from parthenocarpic fruits in oil palm interspecific hybrids using naphthalene acetic acid. *Agronomy* **11**, 290.

https://doi.org/10.1017/S001447972200031X Published online by Cambridge University Press

Rosero G., Santacruz L., Rios A. and Carvajal S. (2017). Influencia del destape de la inflorescencia en la polinización asistida del híbrido OxG. *Revista Palmas* **38**, 49–62.

Sakata T., Oshino T., Miura S., Tomabechi M., Tsunaga Y. and Higashitani N. (2010). Auxins reverse plant male sterility caused by high temperatures. *Proceeding of the National Academy of Sciences of the United States of America* **107**, 8569–8574.

Sparnaaij L. (1960). The analysis of bunch production in the oil palm. *Journal of West African Institute for Oil Palm Research* **3**, 109–180.

Syed R. (1979). Studies on oil palm pollination by insects. *Bulletin of Entomological Research* **69**, 213–224.

Taiz L. and Zeiger E. (2006). Stress physiology. In Taiz L. and Zeiger E. (eds), *Plant Physiology*. Sunderland, MA: Sinauer Associates, Inc., pp. 671–681.

Tan B., Ong S., Rajanaidu N. and Rao V. (1985). Biological modification of oil composition. *Journal of the American Oil Chemists' Society* **62**, 230–236.

Tandon R., Manohara T., Nijalingappa B. and Shivanna K. (2001). Pollination and pollen–pistil interaction in oil palm, *Elaeis guineensis*. *Annals of Botany* **87**, 831–838.

Thomas R., Seth A., Chan K. and Ooi S. (1973). Induced parthenocarpy in the oil palm. *Annals of Botany* **37**, 447–452.

Vardi A., Levin I. and Carmi N. (2008). Induction of seedlessness in *Citrus*, from classical techniques to emerging biotechnological approaches. *Journal of the American Society for the Horticultural Science* **133**, 117–126.

Yáñez E., García J., Fernández C. and Rueda C. (2006). *Guía de Análisis de Racimo*. Bogotá: Cenipalma.

Zambrano J. (2004). Los híbridos ínterespecíficos Elaeis oleifera H.B.K x Elaeis guineensis Jacq. Una alternativa de renovación para la Zona Oriental de Colombia. *Palmas* **25**, 339–349.

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