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How to Improve the Production and Quality of Chirimoya (*Annona cherimola* Mill.) in the Tropical Andes

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***Abstract*— The production of chirimoya (*Annona cherimola* Mill) is seasonal; therefore, the fruit's prices and availability are compromised. This research aimed to develop technologies to improve the production and competitiveness of off-season chirimoya fruit production. This research was conducted in the subtropical valley of Tumbaco, Pichincha province, Ecuador. Chemical defoliants (zinc sulfate, hydrogenated cyanamide, and copper chelate) and a sprouting inducer (hydrogenated cyanamide) were evaluated to standardize and increase defoliation improve sprouting, and consequently bring the harvest season forward. The study was conducted on eight-year-old trees of San José de Minas and MAG-Tumbaco genotypes. The assessed variables were defoliation, sprouting, elapsed flowering time, and harvest period. The fruit harvest was shortened by 18.4 days by applying the defoliants and sprout inducer. For the San José de Minas genotype, the best response for defoliation (99%) was copper chelate at 1%, compared to the control with 58.9% defoliation at 35 days after its application. In the MAG-Tumbaco genotype, the best defoliation results were also obtained with cooper chelate at 1% (99.7% defoliation), while the control achieved 95.5% for 35 days after its application. In the latter genotype, defoliants significantly outperformed the control in terms of sprouting at 21 and 28 days after application; as a result, harvest was advanced by 22.6 days. These treatments should be tested in other climate zones to establish them as cultural practices to increase off-season fruit production, benefiting farmers and industry.**

***Keywords*— Chemical defoliation; off-season harvesting; production; sprouting induction.**

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I. INTRODUCTION

Chirimoya (*Annona cherimola* Mill) has been called the "pearl of the Andes" and "queen of the subtropical fruits". It is considered the finest of the Annona, due to its creamy pulp and volatile compounds [1]. It is commercially cultivated in Ecuador, Peru, Bolivia, Chile, Mexico, and Spain. Until recently, its origin was believed to be southern Ecuador or northern Peru [2]; however, current studies into the distribution of the species in the Neotropics, which combined repeated simple sequence markers (SSRs) and geographic information systems (GIS), showed the highest diversity was present in Central America. This represents the center of primary origin, while South America would be a secondary center of diversity [3]. Several studies into the diversity of chirimoya in Ecuador [4] pointed out that this fruit has a great future in national and international markets since it is among the top 10 species that already have an open market in developed countries.

Chirimoya has continuous phenological phases of growth (sprouting, flowering, and fruiting), maturity (harvest), and rest (ecodormancy and paradormancy), followed by a new growth cycle which is similar to deciduous trees. Floral buds in adult trees undergo three stages: induction, initiation and floral differentiation [5]. In the subtropical valleys, the resting period of the buds is controlled by genetic and environmental factors. When temperatures are not cold enough, buds do not have a deep dormancy (endodormancy), and leaves do not fall, which inhibits bud sprouting.

In the valleys of Ecuador (1200 to 2400 m.a.s.l.), the chirimoya's natural resting period occurs after harvest (May to August). Water stress and high temperatures reduce the plant's vegetative growth, promoting maturation of tissues and buds. These conditions causes senescence and partial leaf fall, sprouting, and low non-uniform flowering. Floral buds go through a series of developmental stages and are completely

differentiated when the bud is swollen, which occurs shortly before sprouting. The leaf petiole is hollow, which hides and protects the buds that will sprout and later flower. Hence the leaves must fall or be removed completely [5].

In the valleys of the Ecuadorian Andes, it has been possible to shorten the resting time of deciduous fruit tree buds that require low temperatures to be induced. This was possible by incorporating several agronomic practices, such as the use of defoliants and sprout inducers, which accelerate leaf fall and bud sprouting. Studies of defoliation and sprouting inducers have been carried out in atemoya. Various researchers [6]–[8] concluded that manual or chemical tree defoliation advances flowering and fruit harvest. In some cases, this could be improved with supplemental early pruning [9] or the use of sprouting inducers [10], [11] in an addressed way. In terms of defoliation, it is important to know when new flower buds are induced with subsequent flower formation, consequently, early defoliation causes the inhibition of immature buds.

In addition, it is important to know when new buds are differentiated and flowers formed because floral induction is inhibited by early defoliation. To start the new production cycle, trees need to accumulate reserves such as carbohydrates and sugars [12], [13]. Electron microscopy studies into chirimoya cv. Fino de Jete achieved in shoots of different ages showed the high flowering capacity of young bud shoots [14]. Early bud differentiation on branches formed in the previous cycle [15] is favored by defoliant application immediately after harvest, which reduces the dormancy period, thereby advancing fruit production cycles.

This research aimed to develop technologies to improve the production and competitiveness of off-season chirimoya fruit production.

II. Materials and Methods

The study was carried out at INIAP's Experimental Farm, located at latitude 00º13'00''S, longitude 78º24'00''O, and 2348 m.a.s.l. in the province of Pichincha, Ecuador. The annual temperature, rainfall, and relative humidity averages are 15.7 °C, 867.3 mm, and 73% respectively. The study was conducted on sandy loam, with 4% organic matter and a pH of 7.4.

The study was carried out on 8-year-old chirimoya trees of genotypes San José de Minas (Fig. 1) and MAG-Tumbaco (Fig. 2). Three defoliants (p) were evaluated in two doses: p1 = zinc sulphate (Zn 22%, S 18%) in doses of 8 and 6%; p2 = copper chelate (Cu EDTA 9%) in doses of 2 % and 1% and p3 = hydrogenated cyanamide (HC, 49% active ingredient) at doses of 1% and 1.5%. To potentiate sprouting, hydrogenated cyanamide was assessed in two doses (0 % and 0.5%) 15 days after defoliants (DADA) application.

Treatments were applied to five branches (25-30 cm) located in the middle third of each tree. Manual pollination, cultural work, sheathing of fruits, sanitary controls, and harvesting were carried out according to recommended cultivation methods. A randomized complete block design with a factorial treatment arrangement of 3 x 2 x 2 + 1 was used and replicated 4 times.

Fig. 1 Fruit from genotype the San José de Minas.

Fig. 2 Fruit from the genotype MAG-Tumbaco.

The factors were defoliants (p), dose (d), complementary inductor (c), and the control -non-application (Table I). The analysis of variance and further functional analysis were realized by means of Tukey's test (alpha 5%,). The variables evaluated were defoliation (%), sprouting (%), and flowering at 7, 14, 21, 28, and 35 days after defoliant application (DADA) and harvest period. The variables expressed in percentage were transformed by arcsine. The statistical analysis was carried out using the statistical package InfoStat, version 2016.

TABLE I
DEFOLIANTS AND SPROUTING INDUCER EVALUATED IN TWO CHIRIMOYA GENOTYPES

Treatments	Code	Description
t0	p0d0c0	Control
t1	p1d1c1	Zinc Sulfate 8% + HC 0%
t2	p1d1c2	Zinc Sulfate 8% + HC 0.5%
t3	p1d2c1	Zinc Sulfate 6% + HC 0%
t4	p1d2c2	Zinc Sulfate 6% + HC 0.5%
t5	p2d1c1	Cooper Chelate 2% + HC 0%
t6	p2d1c2	Cooper Chelate 2% + HC 0.5%
t7	p2d2c1	Cooper Chelate 1% + HC 0%
t8	p2d2c1	Cooper Chelate 1% + HC 0.5%
t9	p3d1c1	HC 1.5% + HC 0%
t10	p3d1c2	HC 1.5% + HC 0.5%
t11	p3d2c1	HC 1% + HC 0%
t12	p3d2c2	HC 1% + HC 0.5%

p: product; d: defoliant doses; c: Cyanamide doses, HC: Hydrogenated Cyanamide.

III. Results and Discussion

A. Defoliation

Upon analyzing the San José de Minas genotype, copper chelate was the most effective at 7 days as it doubled the

percentage of defoliation (Fig. 3) compared to the other two defoliants. At 14 DADA, both copper chelate and hydrogenated cyanamide shared the first range with averages above 64% defoliation. At 21 DADA, copper chelate showed the highest defoliation at 96.4%. After 28 and 35 DADA, the defoliants did not differ, despite defoliation being higher than 91% (Table II).

Fig. 3 Defoliation of the chirimoya tree.

TABLE II
DEFOLIATION PERCENTAGE AT DIFFERENT DADA IN THE SAN JOSÉ DE MINAS GENOTYPE

Defoliant	Defoliation (%)				
	7d*	14d*	21d*	28d*	35d*
Zinc Sulfate	9.0 b	39.4 b	87.3 b	91.6 ns	93.7 ns
Cooper Chelate	28.0 a	68.1 a	96.4 a	97.5 ns	98.2 ns
Hydrogenated Cyanamide	12.3 b	64.1 a	91.5 ab	95.3 ns	97.0 ns

Means followed by the same letter are statistically equal (Tukey 5%); ns: no statistical differences. d*= days.

The rapid effect of copper chelate in defoliation may be because the plant easily assimilates the molecule, and if applied at a high dosage, it produces more auxins, ethylene, and abscisic acid overacting as an enzyme activator in the falling of leaves [16]. Regarding the complementary application of HC (0.5% after 15 d), statistical differences were observed from 21 to 35 DADA, reaching 100% after 21 days (Table III).

TABLE III
DEFOLIATION (%) OF THE COMPLEMENTARY APPLICATION OF HYDROGENATED CYANAMIDE IN THE SAN JOSÉ DE MINAS GENOTYPE

Doses	Description	Defoliant (%)		
		21d*	28d*	35d*
c1	Hydrogenated Cyanamide 0%	83.46 b	89.59 b	92.57 b
c2	Hydrogenated Cyanamide 0.5%	100.00 a	100.00 a	100.00 a
Factorial	Description			
p1d1c1	Zinc Sulfate 8% - Hydrogenated Cyanamide 0%	72.72 ns	78.69 ns	83.37 ns
p1d1c2	Zinc Sulfate 8% - Hydrogenated Cyanamide 0.5%	100.00 ns	100.00 ns	100.00 ns
p1d2c1	Zinc Sulfate 6% - Hydrogenated Cyanamide 0%	76.49 ns	87.49 ns	91.27 ns
p1d2c2	Zinc Sulfate 6% - Hydrogenated Cyanamide 0.5%	100.00 ns	100.00 ns	100.00 ns
p2d1c1	Cooper Chelate 2% - Hydrogenated Cyanamide 0%	88.73 ns	92.03 ns	93.33 ns
p2d1c2	Cooper Chelate 2% - Hydrogenated Cyanamide 0.5%	100.00 ns	100.00 ns	100.00 ns
p2d2c1	Cooper Chelate 1% - Hydrogenated Cyanamide 0%	96.71 ns	98.13 ns	99.38 ns
p2d2c2	Cooper Chelate 1% - Hydrogenated Cyanamide 0.5%	100.00 ns	100.00 ns	100.00 ns
p3d1c1	Hydrogenated Cyanamide 1.5%-Hydrogenated Cyanamide 0%	93.26 ns	95.16 ns	95.68 ns
p3d1c2	Hydrogenated Cyanamide 1.5%-Hydrogenated Cyanamide 0.5%	100.00 ns	100.00 ns	100.00 ns
p3d2c1	Hydrogenated Cyanamide 1%-Hydrogenated Cyanamide 0%	72.84 ns	86.05 ns	92.42 ns
p3d2c2	Hydrogenated Cyanamide 1%-Hydrogenated Cyanamide 0.5%	100.00 ns	100.00 ns	100.00 ns
Comparison	Description	7d*	14d*	21d*	28d*	35d*
Factorial	Defoliant x Doses x Hydrogenated Cyanamide	16.43 a	57.20 a	91.73 a	94.80 a	96.29 a
p0d0c0	Control	2.61 b	6.13 b	41.14 b	51.71 b	58.92 b

p: product; d: defoliant doses; c: Cyanamide doses. d*= days. Means followed by the same letter are statistically equal (Tukey 5%).

This result shows that it is possible to increase defoliation of the San José de Minas genotype, improving sprouting and facilitating manual pollination [17]. No statistical differences were observed for the interaction of p x d x c from 21 to 35 days, but it is worth noting the high percentage of defoliation, which exceeds 70% after 21 days, important for accelerating subsequent physiological events (Table III).

Statistical differences were obtained in all the readings compared to the factorial and the control. Initiating defoliation at 7 DADA (16.4%) and reaching high values at 35 DADA (96.3%), as compared to the control, which reached only 59% at 35 days (Table III).

Results suggested that these chirimoya genotypes need the application of defoliants to increase leaf fall because naturally, it reaches <60% at 35 DADA, causing lower bud sprouting and flowering [15].

The defoliant effect of the products in short periods of application (21 DADA) can be up to 91.7 %, in contrast to the control. Upon analyzing the MAG-Tumbaco genotype regarding the defoliant effect, there were only statistical differences at 7 and 14 DADA. Copper chelate had the greatest effect showing 73.4% defoliation at 14 DADA, while the value reached by HC was 60.8% and Zn Sulphate 47.4% (Table IV).

TABLE IV
DEFOLIATION PERCENTAGE AT DIFFERENT DADA IN THE MAG-TUMBACO GENOTYPE

Defoliant	Defoliation (%)				
	7d*	14d*	21d*	28d*	35d*
Zinc sulfate	7.32 b	47.45 b	92.43 ns	96.77 ns	98.01 ns
Cooper chelate	26.40 a	73.35 a	99.25 ns	99.70 ns	99.92 ns
Hydrogenated cyanamide (HC)	12.33 b	60.76 ab	95.95 ns	97.71 ns	98.57 ns

Means followed by the same letter are statistically equal (Tukey 5%). d*= days.

The complementary application of HC (0.5%) positively affected defoliation at 21, 28, and 35 DADA, reaching 100% defoliation (Table V), indicating that the additional application of the inducer also improved defoliation in this genotype. Statistical differences were observed between the factorial and the control at 21, 28, and 35 DADA. The interaction showed 95.9% defoliation at 21 days and 98.8% at 35 days, whereas the control reached 95.5% at 35 days (Table V). This effect may be due to the increased abscission metabolism of the leaves. It is important to note that the MAG-Tumbaco control had a high percentage of defoliation (95%) at 35 DADA, a value greater than the San José de Minas genotype (56% at 35 DADA). No statistical differences were observed for the interaction of p x d x c from 21 to 35 days, but it is important to mention that defoliation in the MAG-Tumbaco genotype at 21 days exceeded 85%. This allows one to accelerate sprouting, flowering, and the harvest period. It is important to mention that the MAG-Tumbaco tends to defoliate more easily than the San-Jose de Minas genotype (Table V).

TABLE V
DEFOLIATION (%) OF THE COMPLEMENTARY APPLICATION OF HC IN THE MAG-TUMBACO GENOTYPE

Doses	**Description**	Defoliation (%)				
				21d*	28d*	35d*
c1	Hydrogenated Cyanamide 0%			91.75 b	96.12 b	97.67 b
c2	Hydrogenated Cyanamide 0.5%			100.00 a	100.00 a	100.00 a
Factorial	**Description**					
p1d1c1	Zinc Sulfate 8% - Hydrogenated Cyanamide 0%			85.50 ns	96.33 ns	97.92 ns
p1d1c2	Zinc Sulfate 8% - Hydrogenated Cyanamide 0.5%			100.00 ns	100.00 ns	100.00 ns
p1d2c1	Zinc Sulfate 6% - Hydrogenated Cyanamide 0%			84.24 ns	90.75 ns	94.13 ns
p1d2c2	Zinc Sulfate 6% - Hydrogenated Cyanamide 0.5%			100.00 ns	100.00 ns	100.00 ns
p2d1c1	Cooper Chelate 2% - Hydrogenated Cyanamide 0%			99.01 ns	99.54 ns	100.00 ns
p2d1c2	Cooper Chelate 2% - Hydrogenated Cyanamide 0.5%			100.00 ns	100.00 ns	100.00 ns
p2d2c1	Cooper Chelate 1% - Hydrogenated Cyanamide 0%			97.98 ns	99.25 ns	99.67 ns
p2d2c2	Cooper Chelate 1% - Hydrogenated Cyanamide 0.5%			100.00 ns	100.00 ns	100.00 ns
p3d1c1	Hydrogenated Cyanamide 1.5%-Hydrogenated Cyanamide 0%			86.71 ns	92.15 ns	94.30 ns
p3d1c2	Hydrogenated Cyanamide 1.5%-Hydrogenated Cyanamide 0.5%			100.00 ns	100.00 ns	100.00 ns
p3d2c1	Hydrogenated Cyaamide 1%-Hydrogenated Cyanamide 0%			97.09 ns	98.71 ns	100.00 ns
p3d2c2	Hydrogenated Cyanamide 1%-Hydrogenated Cyanamide 0.5%			100.00 ns	100.00 ns	100.00 ns
Comparison	**Description**	7d*	14d*	21d*	28d*	35d*
Factorial	Defoliant x Doses x Hydrogenated Cyanamide	15.35 ns	60.52ns	95.88 a	98.06 a	98.83 a
p0d0c0	Control	16.58 ns	44.10 ns	70.70 b	90.01 b	95.51 b

p: product; d: defoliant doses; c: Cyanamide doses. d*= days. Means followed by the same letter are statistically equal (Tukey 5%).

These results infer varietal differences in defoliation response, as indicated in a previous study [18].

B. Sprouting

In the San José de Minas, 79% sprouting was obtained when HC (0.5%) was applied complementarily at 42 DADA (Fig. 4).

Fig. 4 Sprouting on the chirimoya branch.

According to previous researchers [14], this genotype had 47.9, 67.4, 72.8, and 75.4% sprouting at 21, 28, 35, and 42 DADA, respectively. Our study showed statistical differences from 21 to 35 DADA (Table VI). These results agree with a previous report [10] that found a 95% sprouting in the Cumbe cultivar after applying HC at 1%, following manual defoliation, thus exposing the buds to the sprouting inducer. Without the application of this product, there is little sprouting, possibly due to apical dominance [19]. Therefore, aggressive pruning to activate the buds has been recommended [9].

It was evidenced that the application of defoliants improved sprouting, showing 50.6 and 77.1% at 21 and 42 DADA respectively, while control reached only 16.6% and 54.8% of sprouting over the same time period (Table VI). It was also found that the San José de Minas genotype had a higher natural sprouting of buds than the Cumbe genotype. Sprouting was enhanced by 22% when hydrogenated cyanamide (HC) was applied.

TABLE VI
EFFECT OF THE COMPLEMENTARY APPLICATION OF HC ON SPROUTING (%) IN THE SAN JOSÉ DE MINAS GENOTYPE.

Doses	Description	Sprouting (%)			
		21d*	28d*	35d*	42d*
c1	Hydrogenated Cyanamide 0%	44.18 b	64.22 b	71.39 b	74.93 ns
c2	Hydrogenated Cyanamide 0.5%	56.99 a	75.65 a	78.51 a	79.35 ns
Factorial	Defoliant x Doses x Hydrogenated Cyanamide	50.59 a	69.93 a	74.95 a	77.14 a
p0d0c0	Control	16.58 b	36.96 b	46.29 b	54.78 b

d*= days.

Statistical differences were found when comparing the factorial and the control only at 21 and 28 days. The factorial had 51.6 and 67.5% of sprouting, whereas the control amounted to 28.1 and 51.6% respectively (Table VII).

TABLE VII
EFFECT OF THE COMPLEMENTARY APPLICATION OF HC ON SPROUTING (%) IN THE MAG-TUMBACO GENOTYPE

Doses	Description	Sprouting (%)			
		21d*	28d*	35d*	42d*
Factorial	Defoliant x Doses x Hydrogenated Cyanamide	51.56 a	67.52 a	75.25 ns	79.13 ns
p0d0c0	Control	28.12 b	51.56 b	73.04 ns	79.47 ns

Means followed by the same letter are statistically equal (Tukey 5%). d*= days.

For the MAG-Tumbaco genotype, statistical differences were not detected after 35 or 42 days (Table VII). A prior study [9] indicated that defoliation, whether accompanied by late pruning or not, had little effect on sprouting, especially in the basal buds of the branch, producing fewer flowers.

Under these circumstances, it is convenient to cut the tips of the branches to promote sprouting. Chirimoya needs to accumulate between 50 and 100 cold hours to accelerate defoliation and sprouting. However, this is debatable because the elimination of the leaves in summer results in immediate sprouting, thereby inducing the production of spring fruit in temperate zone countries [20].

Nevertheless, this is difficult to achieve in subtropical valleys, where environmental temperatures are high most of the year. Limited sprouting of the basal buds on the branches of chirimoya, atemoya, and other deciduous fruit trees is related to apical dominance. Consequently, using sprouting inducers (HC) applied after defoliation at appropriate doses reduces this physiological effect, favoring basal sprouting [20].

C. *Flowering*

In chirimoya, the flowering period is long [21]. When defoliants and a sprouting inducer were applied to the San José de Minas genotype, flowering took place at 96.2 DADA, while the control required 116.5 days. Meanwhile, the plants in the MAG-Tumbaco genotype flowered at 104.7 DADA and 110.0 DADA for the control (Table VIII).

TABLE VIII
EFFECT OF DEFOLIANTS, DOSES, AND HC ON FLOWERING (D) OUTCOME IN SAN JOSÉ DE MINAS AND MAG-TUMBACO GENOTYPES.

Comparison	Description	Flowering (d*)	
		San José Minas	MAG-Tumbaco
Factorial	Defoliant x Doses x Hydrogenated Cyanamide	96.17 a	104.69 ns
p0d0c0	Control	116.50 b	110.00 ns

Means followed by the same letter are statistically equal (Tukey 5%). d*= days.

These results agree with a previous report [9], which mentioned that defoliation favors sprouting and flowering. In addition, it stated that by increasing the leaf fall in chirimoya, flowering accelerated, and the fruit set improved. Another study [22] determined the effect of manual leaf removal and early pruning in the cv. Campas, accelerated flowering by 26 days.

The MAG-Tumbaco genotype flowered later (104.7 days) than San José de Minas (96.2 days). Results obtained for the MAG-Tumbaco were in concordance with another study [22] for the Campas variety, where manual defoliation advanced flowering. It is important to note that flowering may vary among buds depending on its location on the branch [6].

D. *Harvest PERIOD*

Fruit from the San José de Minas (defoliant + inductor) was harvested earlier than the MAG-Tumbaco (Table IX). Data analysis showed that the application of defoliants and a sprouting inducer accelerated the fruit harvest by 18.4 days in comparison with the control, whereas the fruit harvest was advanced by 22.6 days in the MAG Tumbaco. Previous researchers [6] point out that the acceleration of flowering and harvest is a function of the tree's chemical defoliation and sprouting induction.

TABLE IX
EFFECT OF DEFOLIANTS, DOSES, AND HC ON DAYS TO HARVEST IN SAN JOSÉ DE MINAS AND MAG-TUMBACO GENOTYPES.

Comparison	Description	Harvest (d*)	
		San José Minas	MAG-Tumbaco
Factorial	Defoliant x Doses x Hydrogenated Cyanamide	335.06 a	303.94 a
p0d0c0	Control	353.50 b	326.50 b

Means followed by the same letter are statistically equal (Tukey 5%). d*= days.

Ecuador has different deciduous fruit trees [23], [24], and defoliation has become an obligatory practice for forced production. This action is needed in tropical countries such as Ecuador where there are not enough environmentally cold hours, and this fruit crop also has different plant densities [25].

When comparing the results of the two genotypes, it was determined that the MAG-Tumbaco genotype had an earlier harvesting time than the San José de Minas by about 31 days. According to prior researchers [20], the rapid and uniform sprouting of chirimoya buds is due to defoliation. To summarize, the practices mentioned above allow growers to program fruit production based on manipulating the fruit trees [26] by using defoliant agents [27] and choosing an appropriate genotype.

IV. CONCLUSION

The defoliant treatments and the sprout inducer positively affected flowering in the chirimoya genotypes. Copper chelate at 1% was the best defoliant and the complementary application of hydrogenated cyanamide at 0.5% enhanced defoliation and sprouting.

The MAG-Tumbaco genotype had high natural defoliation, while the San José de Minas genotype had a greater dependence on chemical products for defoliation. In addition, the MAG-Tumbaco a shorter time to harvest than the San José de Minas. These results should be useful to chirimoya producers who would like to improve production by defining the optimum management of the trees to obtain off-season harvest when the market supply is reduced.

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