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Heat Wave Impacts on Incidence of Deformed Banana (*Musa* AAA) Bunches in Ecuador, Possible Causes and Mitigation Options: A Case Study

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Abstract: During the beginning of 2023 in banana (*Musa* AAA) producing areas of Ecuador, the presence of deformed bunches was detected in the farms. Many of the fruits due to their small size (length and diameter), did not meet the specifications required for export, despite having reached the physiological age. This was an isolated event, which is reported with such intensity for the first time. An attempt was made to identify what management or climatic variable could have promoted this phenomenon. After analyzing and reviewing the condition of the plants from which the bunches came, it was concluded that the problem was not management. Among climatic variables, precipitation was discarded because at the time the phenomenon occurred was within the rainy season and otherwise water requirements were supplied by the irrigation system. During the development of the bunches, maximum temperatures higher than 34 ºC were registered, which suggests, based on what has been reported in the literature, that the phenomenon was caused by a heat wave. Some palliatives are mentioned that could reduce the magnitude of damage from future phenomena.

Keywords: *average temperature, deformed bunches, farm management, heat stress, maximum temperature, solar radiation.*

BACKGROUND

During the beginning of 2023 in banana (*Musa* AAA) producing areas of Ecuador, the presence of deformed bunches (also called altered or pachucos) was detected on farms. The Quality Makes Difference (2023) has been gathering valuable observations of the number of bunches rejected by default or damage in different farms in the provinces of Guayas, Los Ríos, and El Oro. In the report of Quality Makes Difference (2023), it was compared the last four years (2020 to 2023) in the same farms where it was reported an unexpected increase in the number of deformed bunches rejected (higher than 8%) between week 15 to 19, 2023 mainly in El Oro province (Figure 1A-C). Early 2023, other farms also in El Oro totaling 1300 hectares reported the discarding of approximately 57000 deformed bunches. In another two farms where this production anomaly was first reported, which was the motivation for this study, 6697 bunches (6697 * ratio 1.42 = 9509 boxes of 18.14 kg) and 7001 bunches (7001 * 1.66 ratio = 11621 boxes of 18.14 kg) were left unprocessed within a period of 10 consecutive weeks from January to March 2023. In addition, from week 13 to 22, 2023, the presence of ripen fruits was reported in the destination markets. One of the exporters reported the rejection of 110 containers due to ripening problems at destination.

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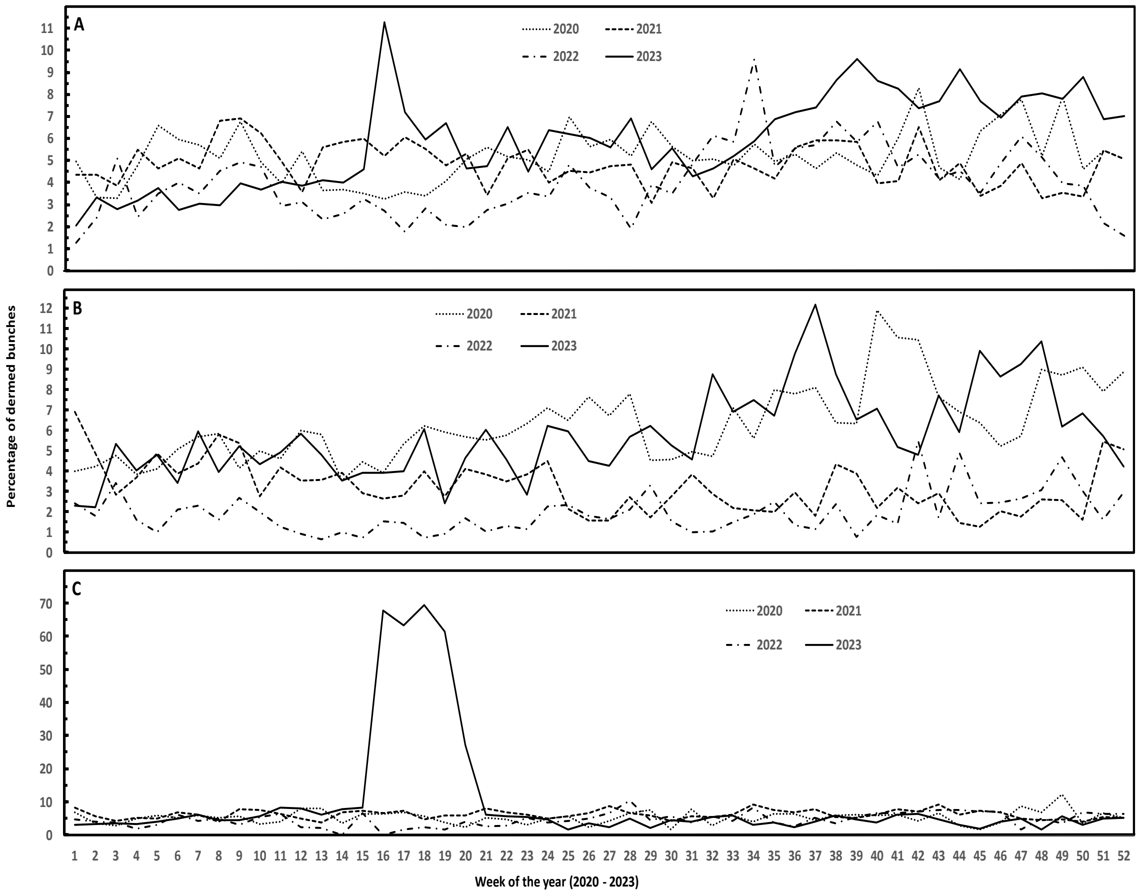

Figure 1A-C. Percentage of deformed bunches by week of the year during 2020 to 2023 in farms of the province of Guayas (A), Los Ríos (B) and El Oro (C), Ecuador. For the farms of Guayas, the number of bunches processed varied between 57074 and 104082, for Los Ríos between 37166 and 123743, and for El Oro between 4482 and 51926 by week during 2023. Similar number of bunches were processed on those farms for the other years.

Many of the fruits, due to their small size (length and diameter), did not meet the specifications required for export, despite having reached the physiological age. The problem was not found in all bunches and in those that did occur, the pattern was uneven. The presence of fruits with reduced size was in one or more intermediate hands, or in apical hands. This inconsistency in the distribution of fruits with reduced size in the bunch confused the worker who evaluates the bunches in the yard of the packinghouse. Therefore, the presence of reduced size fruit in the packinghouse of many farms and the presence of ripe ones in the destination markets led to large losses in Ecuadorian production.

Weather-Related Relationships

Figure 2 shows the evolution of average temperature and precipitation for the beginning of 2023 in the Machala region. Therein, a period of relatively persistent warmer temperatures coinciding with relatively low precipitation occurred during days 25 to 35. In the study region, most farms are equipped with irrigation systems aiming to supply precipitation deficits. Hence, it is likely that water availability directly was unrelated to the production anomaly. The national weather service issued a heatwave warning during this period (Diario el Universo dated January 27, 2023). This heatwave event coincided with the warm outbreak in Figure 3 where it shows the spatial patterns of the weather anomalies in the outline period, highlighting a broad area of warm anomalous temperatures impacting southern Colombia, Ecuador and northern Perú. Central and northern banana regions in coastal Ecuador, however, were kept relatively cooler during the heatwave owing to the co-located wet precipitation anomalies, leaving most of the heatwave impacts over the southern banana areas. Of note is that the impact region also shows low dew point temperature and below average cloud cover.

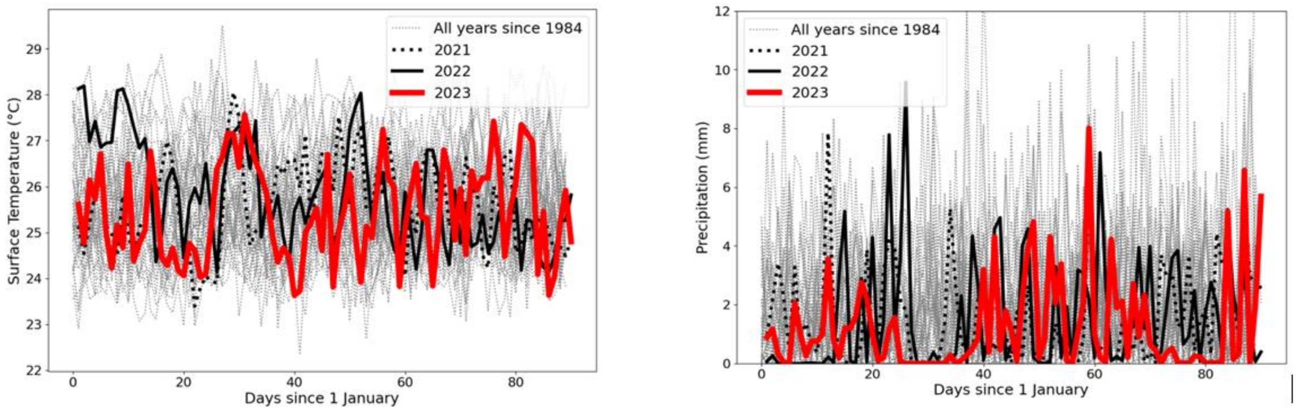

Figure 2. ERA5 area daily mean of A) surface temperature and B) precipitation averaged over the Machala region.

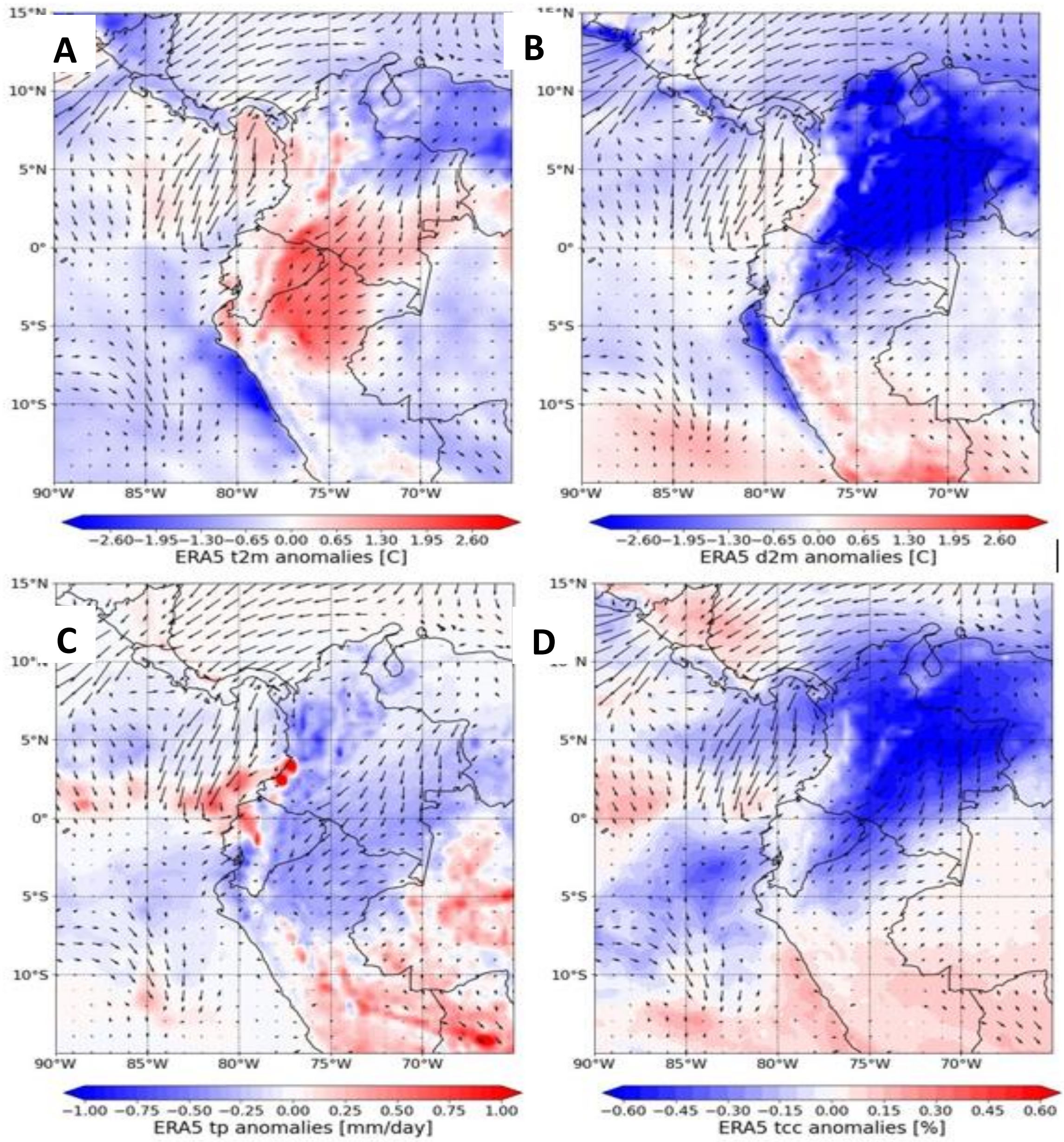

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Figure 3. ERA5 regional patterns of A) surface temperature, B) dew point, C) precipitation and D) cloud cover anomalies during Jan 25-Feb 5, 2023, relative to the January-March, 2023 means. Wind vectors in each panel shows the surface wind anomalies.

To our knowledge, this is the first time that an episode with such intensity has been reported in the region. This study aims to diagnose the potential drivers of these losses; finding observable and predictable drivers of such systematic and widespread production anomaly that can lead to developing early warning system that help mitigate future events. Of the climatic variables, precipitation (water deficit) was discarded, since in the period where the phenomenon occurred was within the rainy season. Given the alerts about the heatwave it was decided to analyze whether the daily highest average temperature, the maximum temperature, the photoperiod (thermal amplitude), or the maximum accumulated radiation affected the development of the deformed bunches.

MATERIALS AND METHODS

Detailed survey of deformed bunches was carried out in two commercial banana farms (*Musa* AAA cv Valery) located in the El Guabo county, El Oro province, in the Machala region in Ecuador. The farms are managed similarly, and we refer to them as Farms I and II. The soils are alluvial, taxonomically classified as Inceptisol with a variable texture: Sandy Clay Loam, Sandy Loam, Clay Loam and Loam with a pH in water between 5.8 and 6.7 and between 1.2 and 1.58% organic matter. The following concentrations of extractable bases were found, using Modified Olsen as extractant: Ca between 10.1 and 20.4, Mg between 5.2 and 7.2 and K between 0.45 and 1.3 cmol L^{-1}, and P between 28 and 57, Zn between 12.0 and 57.2, Cu between 4.5 and 11.8, Fe between 56 and 117, and Mn between 12.3 and 80.9 µg ml^{-1}. The planting density was close to 1450 plants per hectare in conventional areas and 1750 plants in renovated areas. Both farms are provided with primary, secondary, and tertiary drainage networks for the evacuation of excess water during intense rainfall. From May to December each year, sub-foliar sprinkling irrigation is applied, according to the requirements indicated by the weather station located on each farm.

De-suckering was carried out every 6-8 weeks, leaving each production unit with a bearing mother plant, a large daughter sucker (follower) and a small grand daughter (peeper) when possible. Bunched plants were tied up with doble polypropylene twine to the bottom of two well developed adjacent plants. The follower sucker of each production unit was fertilized every 28 days at a rate of 87 kg ha^{-1} with a formula adapted to the soil and crop requirements, consisting of urea (46% N) and muriate of potassium (60% K_2O).

Leaf fungi, especially black Sigatoka (*Pseudocercospora fijiensis*), was managed by deleafing weekly to reduce the pressure of black Sigatoka inoculum and by aerial spraying of fungicides which resulted in 34 sprayings, alternating systemic and protective fungicides (Epoxiconazole, Mancozeb, Calimorph, Chlorothalonil and Copper pentahydrate) mixed with water or agricultural oil. Foliar fertilizers (Zn, B, Ca) were included with the application of protective fungicides. Weed control was carried out with glyphosate and gluphosinate every 6 to 8 weeks. Nematode control was done based on the economic threshold, which resulted in two nematicide cycles per year where the products available on the market were rotated.

When deformed bunches began to appear in a proportion greater than 5% of the total bunches harvested, instructions were given to the workers to leave them in the field and carry out their phytosanitary and nutritional assessment and the number of deformed bunches and their color ribbon were recorded per week. At the harvest of those bunches, one or two weeks after their identification, the number of leaves at harvest, degree of black Sigatoka infection, the presence of nutritional symptoms was recorded, and the bunches were transported to the packing shed where the number of apparently healthy hands and the maturation condition of the bunches was observed (Figure 1A-E). The technicians from Agrocalidad were contacted to carried out pathological isolation from fruits and the rachis of the deformed bunches.

Here we analyzed whether the daily temperature high, the photoperiod (thermal amplitude) or the maximum accumulated radiation could have affected the development of the deformed bunches. To determine the effect of temperature, when deformed bunches were found in the yard of the packing shed, the number of bunches deformed with their ribbon color was recorded. The number of deformed bunches of each ribbon color was correlated with the mean, and maximum temperature recorded in their flower emergence week and then with the weekly maximum and mean temperatures observed throughout the growing development (weeks 1-12). The number of deformed bunches of each ribbon was also correlated with the thermal amplitude of the day when the maximum temperature was recorded and with the maximum accumulated radiation in the day of the week (0:00 – 23:59) of its floral emergence and then with the thermal amplitude and maximum accumulated radiation of the day for weeks 1-12 of fruit development. Weather observations include the estimated from the ERA5 reanalysis data (Copernicus Climate Change Service C3S 2017; Hersbach *et al.*, 2020) whereas in-situ observations for the two commercial banana farms were retreived from two quality assured/quality-controlled data from two Campbell surface station at subhourly time increments.

RESULTS

The deformed bunches identified (Figure 4B-D,F) came from apparently normal plants, without symptoms of nutrient deficiencies (Figure 4F), with an acceptable black Sigatoka control and a number of leaves at harvest between 7 and 10. These bunches came from plants in different soil textures, from conventional and renovated areas, with follower suckers with normal growth and development that did not present any physical damage perceptible to the naked eye. These observations led to discard that the problem was due to management. The Agrocalidad technicians of the province of El Oro, after carrying out isolations, discarder that the problem was due to a pathogen, since they could not establish that there was any fungal or bacterial infection in the fruits and rachis of the deformed bunches. The deformed bunches had a maximum of 4 basal hands with normal development. The fruits ripened unevenly, where the oldest hand (basal) did not necessarily ripen first (Figure 1C-D). In some bunches, it was found fruits of the fourth hand with ripening color grade 4 while in the second hand the fruits had a ripening color grade 2. Fruit maturation was not normal and as would be expected, gradual from the basal to the apical hands.

On Farm I, the average temperature ranged between 25.7 and 27.6 ºC, the maximum between 33.7 and 35.5 ºC (Table 1), the thermal amplitude between 11.38 and 13.13 ºC (data no shown) and the maximum accumulated radiation in the day of the week fluctuated between 631 and 1081 W m^2 (data no shown). In the correlation analyzes carried out between the number of deformed bunches according to ribbon color with the average and maximum temperature, thermal amplitude, and maximum accumulated radiation in the day of the week of each week during its development, positive and negative correlations were found, which could cause confusion in interpretation. The highest correlation was found with the average temperature in week 9 after bunch bagging (r= -0.79; P= 0.0058), with the maximum temperature at 5 weeks after bagging (r= -0.66; P= 0.0383), with the thermal amplitude at week 4 after bagging (r= -0.63; P= 0.0496), and with the maximum accumulated radiation in a day at week 6 after bagging (r= 0.68; P= 0.0302). It is worth noticing that these excessive heat and enhanced radiation corresponds to the period of the heatwave described above.

On Farm II, the average temperature during bunch growth and development ranged between 26.1 and 27.8 ºC (data not shown), the maximum between 33.2 and 35.8 ºC (Table 2), the thermal amplitude between 10.21 and 13.5 ºC (data no shown), and the maximum accumulated radiation in a day of the week fluctuated between 211 and 725 W m^2 (data no shown). In the correlation analyzes carried out between the number of deformed bunches according to ribbon color with the average and maximum temperature (Table 2), thermal amplitude, and the maximum accumulated radiation in a day of the week of each week during its development, low and positive correlations were obtained, and none of which were significant. The highest correlation was found with the average temperature in week 12 after bunch bagging (r= 0.57; P= 0.0818), with the maximum temperature at 11 weeks after bagging (r= 0.47; P= 0.1662; Table 2), with the thermal amplitude at week 12 after bagging (r= 0.52; P= 0.1232), and with the maximum accumulated radiation in the day of the week 5 after bagging (r= 0.57; P= 0.0834).

Figure 4A-F. A) Well-formed bunches with cylindrical shape with a degree of gradual development of the fruits from the basal to the apical hands, **B)** deformed bunch due to poor growth and development of the fruits in the apical hands, **C-D)** deformed bunch due to the presence of ripen fruits in the middle hand of the bunch, **E)** evaluation of ripening in the second basal hand of the bunch and **F)** plant with deformed bunch where the number of leaves at harvest, with slight black Sigatoka infection and absence of symptoms of nutritional deficiencies.

Table 1. Correlation and associated probability of the number of deformed bunches according to ribbon color in the week of 2023 with the average (TP) and maximum (TM) ºC temperature in the week of bagging (TP0 or TM0) and at 1 (TP1 or TM1), 2 (TP2 or TM2), 3 (TP3 or TM3), 4 (TP4 or TM4), 5 (TP5 or TM5), 6 (TP6 or TM6), 7 (TP7 or TM7), 8 (TP8 or TM8), 9 (TP9 or TM9), 10 (TP10 or TM10), 11 (TP11 or TM11) and 12 (TP12 or TM12) weeks of bunch development on Farm 1.

Week	No bunches	Incidence	TP0	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	T12
2	70	1.4	25.7	25.9	26.8	26.8	26.5	26.7	26.4	26.9	25.9	27.2	26.9	26.1	26.8
3	619	9.7	25.9	26.8	26.8	26.5	26.6	26.4	26.9	25.9	27.2	26.9	26.1	26.8	26.7
4	1595	23.8	26.8	26.8	26.5	26.6	26.4	26.9	25.9	27.2	26.9	26.1	26.8	26.7	26.5
5	1607	28.6	26.8	26.5	26.7	26.4	26.9	25.9	27.2	26.9	26.1	26.8	26.7	26.5	26.5
6	1272	29.5	26.5	26.6	26.4	27.0	25.9	27.2	26.9	26.1	26.8	26.7	26.5	26.5	27.3
7	943	16.2	26.7	26.4	26.9	25.9	27.2	26.8	26.1	26.8	26.7	26.5	26.5	27.3	27.5
8	610	11.9	26.4	27.0	25.9	27.2	26.9	26.1	26.8	26.7	26.5	26.5	27.3	27.5	27.6
9	121	1.7	27.0	25.9	27.2	26.9	26.1	26.8	26.7	26.5	26.5	27.3	27.5	27.6	26.4
10	62	1.3	25.9	27.2	26.9	26.1	26.8	26.7	26.5	26.5	27.3	27.5	27.6	26.4	26.7
11	102	2.8	27.2	26.9	26.1	26.8	26.7	26.5	26.5	27.3	27.5	27.6	26.4	26.7	26.3
	Correlation		0.29	0.14	-0.15	-0.10	-0.01	0.01	0.06	0.03	-0.20	-0.79	-0.38	-0.08	0.13
	Probability		0.4050	0.6891	0.6653	0.7701	0.9975	0.9757	0.8682	0.9321	0.5605	0.0058	0.2710	0.8073	0.7104

			TM0	TM1	TM2	TM3	TM4	TM5	TM6	TM7	TM8	TM9	TM10	TM11	TM12
2	70	1.4	33.7	34.0	34.4	34.5	34.6	35.2	34.5	34.3	33.7	35.0	34.8	34.4	35.2
3	619	9.7	34.0	34.4	34.8	34.6	35.2	34.5	34.3	33.7	35.0	34.8	34.4	35.2	34.8
4	1595	23.8	34.4	34.8	34.5	35.2	34.5	34.3	33.7	35.0	34.8	34.4	35.2	34.8	34.8
5	1607	28.6	34.8	34.6	35.2	34.5	34.3	33.7	35.0	34.8	34.4	35.2	34.8	34.8	34.8
6	1272	29.5	34.6	35.2	34.5	34.3	33.7	35.0	34.8	34.4	35.2	34.8	34.8	34.8	34.9
7	943	16.2	35.2	34.5	34.3	33.7	35.0	34.8	34.4	35.2	34.8	34.8	34.8	34.9	35.5
8	610	11.9	34.5	34.3	33.7	35.0	34.8	34.4	35.2	34.8	34.8	34.8	34.9	35.5	35.3
9	121	1.7	34.3	33.7	35.0	34.8	34.4	35.2	34.8	34.8	34.8	34.9	35.5	35.3	34.0
10	62	1.3	33.7	35.0	34.8	34.4	35.2	34.8	34.8	34.8	34.9	35.5	35.3	34.0	34.7
11	102	2.8	35.0	34.8	34.4	35.2	34.8	34.8	34.8	34.9	35.5	35.3	34.0	34.7	34.0
	Correlation		0.44	0.40	0.15	-0.16	-0.45	-0.66	-0.29	0.16	0.04	-0.51	0.05	0.17	0.30
	Probability		0.2015	0.2456	0.6697	0.6519	0.1885	0.0383	0.4147	0.6504	0.9133	0.1324	0.8900	0.6310	0.3885

Table 2. Correlation and associated probability of the number of deformed bunches according to ribbon color in the week of 2023 with the maximum ºC temperature (TM) in the bagging week (TM0) and at 1 (TM1), 2 (TM2), 3 (TM3), 4 (TM4), 5 (TM5), 6 (TM6), 7 (TM7), 8 (TM8), 9 (TM9), 10 (TM10), 11 (TM11) and 12 (TM12) weeks of development and growth of the bunch on Farm II.

Week	No bunches	Incidence	TM0	TM1	TM2	TM3	TM4	TM5	TM6	TM7	TM8	TM9	TM10	TM11	TM12
2	316	9	34.3	35.3	35.8	35.4	35.7	35.0	35.2	34.7	34.5	34.7	35.0	34.4	35.0
3	38	1	35.4	35.8	35.4	35.7	35.0	35.2	34.7	34.5	34.7	35.0	34.4	35.0	34.6
4	0	0	35.6	35.4	35.7	35.0	35.2	34.7	34.5	34.7	35.0	34.4	35.0	34.6	34.9
5	1371	35	35.4	35.7	35.0	35.2	34.7	34.5	34.7	35.0	34.4	35.0	34.6	34.9	34.9
6	2371	61	35.7	35.0	35.2	34.7	34.5	34.7	35.0	34.4	35.0	34.6	34.9	34.9	34.8
7	1287	38	35.0	35.2	34.7	34.5	34.7	35.0	34.4	35.0	34.6	34.9	34.9	34.8	35.0
8	716	22	35.2	34.7	34.5	34.7	35.0	34.4	35.0	34.6	34.9	34.9	34.8	35.0	34.8
9	424	13	34.7	34.5	34.7	35.0	34.4	35.0	34.6	34.9	34.9	34.8	35.0	34.8	33.7
10	105	4	34.5	34.7	35.0	34.4	35.0	34.6	34.9	34.9	34.8	35.0	34.8	33.7	34.0
11	69	2	34.7	35.0	34.4	35.0	34.6	34.9	34.9	34.8	35.0	34.8	33.7	33.9	33.2
	Correlation		0.4	0.00	-0.14	-0.32	-0.43	-0.29	0.03	-0.16	-0.12	-0.06	0.26	0.47	0.42
	Probability		0.2030	0.9968	0.6859	0.3616	0.2072	0.4061	0.9301	0.6591	0.7274	0.8526	0.4569	0.1662	0.2254

DISCUSSION

The absence of nutrient deficiency symptoms, the presence of a controlled black Sigatoka infection, the failure to isolate a causal pathogen from the fruits or rachis and given the symptoms described, it is assumed that the problem was physiological. According to INTAGRI (2015), when fruiting plants are under stress, they may decide to eliminate part of their organs, with the fruits being the first to be removed, as they are a source of storage and not of synthesis of photo assimilates. This agrees with Lahav *et al*. (2000) and Turner *et at.* (2007), who indicated that any adverse effect of environmental conditions in the banana fruiting stage is reflected in the shape and anatomy of the fruits.

During the 10 weeks in which the event occurred, the average temperature fluctuated between 25.7 and 27.6 ºC on Farm I and between 26.1 and 27.8 ºC on Farm II and the maximum fluctuated between 33.7 and 35.5 ºC on Farm I and between 33.2 and 35.8 ºC on Farm II, in all the ribbon colors where the effect of the phenomenon was reported. In 2022, in those same weeks, no deformed bunches were detected, and bunch discarding was less than 2% on both farms. In this period, the average temperatures varied on Farm I, between 23.5 and 26.7 ºC and the maximum temperatures between 30.2 and 34.4 ºC and on Farm II, the average temperatures fluctuated between 24.5 and 27.0 ºC and the maximum temperatures between 30.3 and 34.6 ºC. In those same weeks of 2021, no deformed bunches were recorded, and the rejection of bunches was again less than 2% in these farms and the average temperatures varied on Farm I, between 23.1 and 26.6 ºC and the maximum temperatures between 27.7 and 35.0 ºC and on Farm II the average temperatures fluctuated between 23.7 and 26.9 ºC and the maximum temperatures between 28.2 and 34.7 ºC. The global average of maximum temperatures in the 10 weeks of 2023 in which deformed bunches were observed on Farm I exceeded the average maximum of those same weeks of 2022 by 1.1 ºC and that of 2021 by 0.9 ºC. On the Farm II, the increases in maximum temperatures were 1.1 ºC compared to 2022 and 1.0 ºC compared to 2021.

With respect to the thermal amplitude, banana is currently regarded as day-neutral for floral induction because it does not depend on photoperiod for flowering (Turner *et al.*, 2007). However, photoperiods of less than 12h are associated with a slowing in the rate of bunch initiation that is independent of temperature expressed as growing degree days. This may contribute to seasonal variations in banana flowering, even in more tropical environments with moderate temperatures.

The day of maximum radiation in the weeks of bunch development fluctuated between 631 and 1081 W m^{-2} on Farm 1 and between 211 and 725 W m^{-2} on Farm 2. In those same weeks of 2022, the maximum accumulated radiation in a day varied between 396 and 671 W m^{-2} on Farm I, and between 463 and 679 W m^{-2} on Farm II and in the same period of 2021, it varied between 442 and 719 W m^{-2} on Farm I and between 493 and 701 W m^{-2} on Farm II. Even though a higher solar radiation was recorded in 2023, those values agreed with that cited by Zelaya (2020) that during a clear day in the tropics, a banana plant can receive a solar radiation of 250 W m^{-2} at 7:00 am, while at noon it receives close to 1200 W m^{-2}. Although it is known that when there is an excess of light energy (Campillo *et al*., 2012; Tyystjärvi, 2013), photoinhibition occurs, which refers to a reduction in the plant's capacity to carry out photosynthesis, it seems that this was not the case since the maximum value recorded was below the referred normal value and not visible leaf symptoms as yellowing and burn damage were observed (Robinson, 1996; Robinson and Galán, 2010; Gurjar *et al*., 2017). According to INTAGRI (2017) the optimum daily average accumulated solar radiation varies between 15 and 21 MJ m^2 day^{-1} and greater than 24 MJ m^2 day^{-1} is considered high.

The banana plant, due to its origin and its C_3 photosynthetic metabolism, is highly sensitive to temperature acclimation (Yamori *et al*., 2014). Evaluations of net carbon assimilation indicate that above 34°C its CO_2 fixation capacity is reduced considerably, due to a reduction in stomatal conductivity that results in less gas exchange (Israeli and Lahav, 2019). Robinson (1996) indicated that an average temperature of 27 ºC is optimal for crop production, 14 ºC is the minimum for growth and an average temperature of 31 ºC is optimal for foliar emission, but at this temperature the net assimilation rate is reduced. Furthermore, the author mentioned that extreme temperature conditions are common in the subtropics where bananas are grown, but that they could also occur in the dry and humid tropics where the crop occurs. Paull and Duarte (2011) cited an optimal temperature of 27 ºC and a maximum of 38 ºC at which growth is paralyzed and there may be necrosis in leaves.

According to Robinson (1996) and Robinson and Galán (2010), when plants are exposed to high temperatures, low relative humidity and in the absence of precipitation or good soil humidity, their leaves can quickly reach 5 or more degrees Celsius above the ambient temperature, due to a lack of transpiration, which leads to very rapid wilting of the leaves. More recently, Israeli and Lahav (2019) found that a leaf in a horizontal position exposed to direct sunlight may reach 12°C above ambient temperature. In this condition, some leaves may show symptoms of radiation damage that correspond to yellowing and may end in necrosis. The maximum temperatures in both farms exceeded 33-34 ºC, especially between weeks 4 and 6.

The precipitation during the months (January to March 2023) of the event was 831 on Farm I and 324 mm on Farm II. With such precipitation good soil moisture would be expected, but due to the symmetrical distribution of the plants, the distribution of the harvested plant crop residues, and soil compaction, not all plants are at the same humidity in the soil profile. Then, it is possible that some plants were found in soil with water deficit (less than field capacity) where when adding the 5 ºC cited by Robinson (1996) and Robinson and Galán (2010) in those plants, given the drop in their transpiration, its leaves could have reached more than 39 ºC. So, although the correlation of the deformed bunches with the average and maximum temperature or with the thermal amplitude and the accumulated radiation could not be statistically supported, they were the product of a temporary heatwave that occurred in the fruiting stage, when the bunch was developing, hanging on the plant. Maximum temperatures above 34 ºC occurred in time periods of up to 2 hours (3/15/2023: 13:53 to 15:53 varied between 34.02 and 34.56 ºC). Given that the maximum authorized harvest is 12 weeks, the presence of deformed bunches began in harvests from week 13 onwards. Likewise, problems in the destination markets began to be reported in weeks 14 to 22 of 2023, consistent with the dates on which the bunches were developed.

The presence of ripe fruits at destination was expected since Robinson (1996) reported that one of the main factors of mixed-ripe fruit is heat stress on fruit before and after harvest. Also, it is known that, under storage conditions, ethylene production increases as temperature increases (Ahmad *et al*. 2001). This probably happened with fruit in land transit from the farms to the port, where the majority goes without refrigeration. Even if it is fresh fruit from the same day, is subjected to additional stress, since the days and nights are too warm, and the fruit already comes with heat stress from cultivation. So, as the temperature increased, transpiration and respiration increased, which led to greater release of ethylene. It is also reported that at higher temperatures the hydrolysis of starches is greater, so that the fruits lose their consistency-firmness more quickly and become soft (Ahmad *et al*. 2001).

Fruit development and growth depends on hormonal action (Nitsch 1952, Simmonds, 1953) and it is known that the physiological processes of plants in optimal and suboptimal conditions are mainly governed by hormones (Bürger and Chory, 2020) which show a close relationship with temperature and other environmental factors (Castroverde and Dina 2021). When plants are exposed to high or low temperatures, physiological mechanisms can be compromised, since stress can alter certain molecular components of hormonal pathways and eventually the overall performance of the plant (Chaves and Gutiérrez 2017, Lippmann *et al*., 2019; Ding *et al*., 2020; Kim *et al*., 2021).

The presence of deformed bunches was not in all the bunches harvested of each ribbon color. Although all plants were at the same maximum environmental temperature, heat stress occurred in plants that were also exposed to water deficit. It is possible that in some plantations, self-shading occurs between plants due to the symmetrical or equidistant distribution of the plants, and it is known that the interception of radiation differs between leaves (Campillo *et al*., 2012). So, it could be that in a fruiting plant only one or two leaves were directly exposed to that temperature and perhaps to be affected by the phenomenon, most of the photosynthetically active foliage had to be equally exposed.

Maximum temperatures above 34 ºC were also recorded in weeks 12 and 13 and later in weeks 17 to 20 of 2023. During these weeks there have been heat waves in the area that have caused momentary thermal stress. Climate variability and change mean that agricultural crops are exposed to more intense extreme heat events outside the range of extreme values observed. In Ecuador, the exposure of banana cultivation to extreme heat waves appears to be more critical during El Niño events, and under global warming climate change scenarios. Hence, it is likely that heatwaves will be more recurrent in the future and although there is relatively high confidence about the direction of these extreme changes, growers and decision makers require information to take adaptation and mitigation measures that help them be more resilient in the management of their agricultural resources.

To mitigate the effects of this phenomenon, soil humidity must always be maintained at field capacity, through a good drainage channel network during the rainy season and by the irrigation systems when water is scarce, to prevent the leaves from reaching a higher temperature than the environment because of the drop in transpiration. The application of a phyto-sunscreen should be implemented in the cultivation phase, pre-entry and during the warmer season (January to May), as has been suggested by Vargas *et at*. (2017). Studies (Castillo 2021, Castillo *et al.*, 2024) with the Photon-sunscreen (Zn 3%, SiO_2 1.5%) in banana crops showed a reduction between 0.6 and 2.4 ºC compared to plants without application and reduced the negative effects of ultraviolet radiation. Furthermore, these studies showed that the incorporation of Photon is compatible and stable in the solutions of systemic and protective fungicides used to control black Sigatoka, it did not affect the biological effectiveness of the fungicides and the tenacity of the solutions was maintained on the surface of the leaves. The application of salicylic acid, which has induced or improve thermotolerance in crops, should also be considered in this period (Chaves and Gutiérrez 2017, Chen *et al*., 2023).

The ripening evaluation is carried out in the packinghouse in the second basal hand (Figure 4E) of 100% of the bunches. However, during those weeks, some farms applied what is known as skimming, which is the practice of saving and introducing into the process, the hands whose fruits meet the specifications requested for the types of boxes. Sometimes normal development of the first 3 or 4 basal hands was observed, one or two altered hands intermediate in the bunch, which could be the fourth and fifth, and then return to normal development. So, if the evaluator of a packinghouse yard is not well instructed and attentive, some bunches may go through processing, but they are already physiologically altered. The skimming surely happened and explains why boxes with ripe fruits were reported at destination, especially from week 13, 14 of 2023, onwards. Therefore, the practice of skimming should be suppressed, and clear and precise instructions should be given to evaluators for the discarding of malformed bunches. When the incidence of deformed bunches is greater than 5%, it is advisable to leave those bunches in the field on harvest day and organize a harvest cycle separately, without a process, to remove those bunches from the field without generating pressure in the harvesting process, evaluation, and packing. Generally, packinghouse personnel are required to meet the volume for which they were quoted, and their remuneration is per box processed. Harvesting deformed bunches separately allows for more precise documentation to estimate and value the economic impact on production.

To the marketing companies are suggested to restore the number of ribbon colors used for bagging to 12 colors. This prevents harvest personnel from confusing fruit age of deformed bunches when using differentiated calibration in the last apical hand, where bunches with 12 weeks of physiological age, with a repeated ribbon color, may present a fruit size with an appearance of 8 to 9 weeks and that the staff leaves them without harvesting.

Given the instability in climatic conditions, the application of gibberellin (750 to 1000 ppm) post-harvest during fruit packing should be required for greater safety against adverse climatic conditions (Vargas and López, 2011). Given the current climatic conditions, it is most convenient for the fruit to enter the cold chain as soon as possible after the process. When the trucks that transport fruit from the farms to the ports do not have cold chains, the use of tents with white color that cover them, as well as in the packing cartons, could help the fruit remain fresher given that said color reflects light.

CONCLUSION:

A well-categorized outbreak of deformed bunches was related to an observable and predictable heat wave event. This extreme temperature event co-occurred during a dry spell in the rainy season exacerbating the heat wave impact and favoring hotter and shiny days. Distinct pathological factors help isolate the fruit symptom to excessive heat exposure. Similar deformed bunches identified in the region highlights that the deformed bunches are unrelated to individual management of the crop and pointed towards environmental forcings affecting the area. This study becomes more relevant as heat waves are likely to impact with more intensity and higher frequency due to climate change (IPCC, 2022). To mitigate the impact of similar or more intense heat wave events in the future, some palliatives are mentioned that could reduce the magnitude of damage during future events. The application of a phyto-sunscreen and salicylic acid, which has induced or improve thermotolerance in crops, should be implemented in the cultivation phase, pre-entry and during the warmer season (January to May) to mitigate the impact.

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