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'Hass' Avocado Internal Disorders under Simulated Export Conditions and Its Relationship with Flesh Mineral Content and Preharvest Variables

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Abstract: The most important issues that affect consumer fruit acceptance in the 'Hass' avocado international market are flesh disorders. These defects can be influenced by both pre- and postharvest factors. The aim of this work was to evaluate the effect of the harvest season, storage time, mineral content, and preharvest variables on internal fruit disorders. Here, fruit was sampled from four farms in Antioquia (Colombia) at 22%, 26%, and 30% dry matter (DM) content. Samples were stored and ripened under simulated export conditions. Then, flesh bruising, flesh discoloration, body rots, vascular browning, stem end rot, and mineral content were assessed. The results showed that flesh disorders differ among farms and by harvest index and storage time. The most frequent defects found were vascular browning and stem end rot. Boron, calcium, nitrogen, manganese, magnesium, and potassium have a strong relationship with flesh disorders. Therefore, high boron and calcium contents, as well as a harvest at 26% DM, can substantially reduce avocado flesh disorders and improve internal fruit quality. Farmers that had a high flesh and soil mineral content and low rainfall and temperature produced fruits with fewer internal disorders.

Keywords: harvest season; flesh quality; Hass avocado; minerals; storage

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1. Introduction

The global Hass avocado market is projected to register a compound annual growth rate of 5.9% every year during the forecast period of 2018−2026 [1]. Therefore, there is an opportunity for producer countries such as Mexico, Peru, Chile, and Colombia, among others, to enter different markets. Fruit that makes it to market shows internal quality issues such as anthracnose, flesh browning, and stem end rot that are only seen when the fruit is "ready to eat". Those problems can affect consumers' future purchase decisions, according to Gamble et al. [2] and Bosio, [3], who found that maturity, appearance, and price are the most relevant factors for the consumer when making a decision whether to buy an avocado fruit.

According to Burdon et al. [4] and Ferreyra et al. [5], flesh defects (stem end rot, flesh bruising, flesh discoloration, vascular browning, and body rot) have been associated with physiological or pathological causes [6]. The effects promoted by growing conditions, maturity, and storage time under cold chain conditions can generate internal disorders that affect fruit quality [7]. Furthermore, mineral flesh composition could influence 'Hass' avocado fruit to have superior quality in terms of the decrease in mesocarp defects [8–10]. Calcium, for example, is the mineral that has the closest relationship with the avocado fruit's postharvest quality, as it provides cellular resistance and membrane functionality [8]. Other minerals have also been associated with postharvest quality (nitrogen, magnesium,

and potassium), although they have also shown antagonistic effects that lead to a reduction in the product's shelf life [10].

In the 'Hass' avocado international market, Colombia is a new exporter. Compared to other avocado origin countries, Colombia is a country that produces avocado at higher altitudes (1900−2500 m.a.s.l meters above the sea level), and its soil and weather conditions allow the fruit to be grown year-round. Currently, Colombia has open markets in Europe, the U.S., Canada, Asia (UAE), Japan, Latin America (Costa Rica, Argentina, Panama), and China [11]. Therefore, it is necessary to know what the main issues of quality at different storage durations are because each market requires a different time of shipment from Colombian harbors (US 6 d, Europe ≥15 d, and Asia ≥32 d). For those reasons, the aim of this work was to evaluate internal fruit quality, focused on flesh mineral composition vs. internal disorders of fruit harvested at 23% (early season), 26% (middle season), and 30% (late season) DM and storage at different storage times.

2. Materials and Methods

2.1. Sampling

Samples were taken from four exporting farms certified (Good Agricultural Practices, Global GAP) from the department of Antioquia (Colombia). Farms were located in Antioquia as follows: two in the northern region (CS: Cantabria de La Sierra, EB: El Banco), one in the eastern region (LE: La Escondida), and one in the southwestern region (BV: Bella Vista) (Table 1). On each farm, 30 trees from 7 to 10 years of age were previously identified, and from these trees, 400 fruits per farm were labeled before their harvest period (placing a tape on each fruit peduncle).

Table 1. Location and geographical information for the farms where avocado cv. 'Hass' fruits were sampled.

Region Farm Code	Southwest	East	North	
	BV	LE	EB	CS
Tree age (years)	10	8−9	8	8−9
Latitude	05°35′50.2″ N	6°05′57.0″ N	6°29′39.6″ N	6°29′23.8″ N
Longitude	075°48′19.8″ W	75°26′14.9″ W	75°31′42.0″ W	75°31′29.1″ W
m.a.s.l.	2025	2167	2464	2411
Soil orders	Andisols	Entisols	Inceptisols	Oxisols
Average maximum temperature (°C)	29.51	30.16	23.93	28.10
Average minimum temperature (°C)	12.58	12.32	7.28	4.20
Average temperature (°C)	18.67	19.16	15.54	16.29
Relative humidity (%)	80.42	76.35	72.96	80.07
Photosynthetically Active Radiation (micromoles photons per square meter per second)	769.93	800.14	870.51	868.10
Solar Radiation (watts per square meter)	391.11	403.75	441.28	446.53
Rainfall (millimeters)	1019.84	1281.95	1094.14	891.44
Days between fruit set and harvest season	210−308	203−259	217−273	196−252

2.2. Preharvest Variables

Climatic conditions were monitored with a weather stations (Watch Dog 2900ET; Spectrum Technologies, Plainfield, IL, US) equipped with sensors to measure and register temperature (°C) (datalogger Watch Dog 125), relative humidity (percent) (Watch Dog 3612RHS), solar radiation (watts per square meter) (Watch Dog 3676), photosynthetically active radiation (PAR) (micromoles photons per square meter per second) (Watch Dog Quantum 3668), and rainfall (millimeters) (Watch Dog 120).

2.3. Soil: Variables and Analysis

A completely randomized design was used in combination with a simple random sampling technique with 10 replications targeted in plants at the flowering stage. The sampling depth was 0−30 cm. Any layer of litter was eliminated before soil sampling, and the sample was collected from the edge of the avocado tree crown; 40 sub-samples were collected to form and composite sample, 6 composite samples in total. The composite soil samples were air-dried to pass through a 2.0 mm sieve. In the laboratory were carried out the analyzes: cation exchange capacity (CEC); pH in relation (1:2.5); determination by atomic absorption Fe, B, Mg, Mn, S, and K; determination nitrogen (N) by Digestion Kjeldahl [12].

2.4. Harvest Maturity Follow-Up

Two months before harvest, 20 fruits were sampled every 15 d to measure dry matter as a maturity index. Fruits were analyzed at Agrosavia Research Center "La Selva" (Rionegro, Antioquia Colombia). DM content was analyzed according to the AOAC(American Organization of Analytical Chemists.) No. 934.01 [13] method.

2.5. Fruit Harvest

Harvests were carried out from 16 July 2016 until 3 February 2017. One-hundred Fruits (203−243 g) were harvested during the early, middle, and late seasons (22%, 26%, and 30% DM, respectively). Fruits were manually harvested with previously disinfected pruning scissors, leaving 5 mm of the peduncle [14]. Harvest was carried out in the morning hours, verifying that the fruit was dry to avoid lenticel damage. Each fruit was labeled, placed separately in a paper bag, and sent to the Research Center "La Selva" for further analyses.

2.6. Fruit Conditioning

Fruits were inspected to separate avocados with pests, diseases, strange substances, or mechanical damage. Then, samples were washed and disinfected following the packing house practices and protocol published by Hofman et al. [15]. Fruits were immersed (30 s) in a Prochloraz solution of 0.05% w/v (Mirage 45 ADAMA ANDINA). Then, the samples were dried at room temperature and packed into corrugated cardboard boxes.

2.7. Experiment: Storage and Ripening

Fruits were stored for different durations (0, 3, 4, and 5 weeks) under simulated export conditions (5 °C/90% relative humidity (RH), Memmert HPP 110) [4,16]. After that, fruit was ripened (20 °C/90% RH, Memmert HPP 110) according to Arpaia et al. [17], Bill et al. [16], and Burdon et al. [4].

Ripening was finished when fruits reached a rating of 5 according to White et al. [18], which corresponds to an average firmness of $\leq$ 8 N, measured in the fruit's equatorial zone using a TA. XT Plus texture analyzer (Texture Technologies Corp., New York City, NY, US) equipped with a 30 kg load cell. Two measurements were performed on unpeeled fruit with a stainless-steel compression plate (P/75, 75 mm diameter).

2.8. Fruit Quality Analyses: Area Affected by Pathological or Physiological Damage

Internal defects were evaluated by cutting fruits longitudinally in half, and the damage was identified as described in the international quality manual [18]. The internal disorders evaluated were stem end rot, body rots, vascular browning, and flesh bruising. The severity of the damage was measured on a scale as follows: 0 = without damage, 0.5 = 5%, 1: 10%, 1.5 = 15%, 2 = 25%, 2.5 = 33%, and 3 = 50% damage.

2.9. Flesh Mineral Content

The flesh of ripened fruit was homogenized and dried at 70 °C in a forced convection oven (Memmert UF 110) until constant weight. Dried samples were digested with 5 mL of HNO3 (70%) and 2 mL of HClO4 (70%) for two hours following the methods of McKean [19]

and NTC (Norma Técnica Colombiana) 5752 [20] Samples were heated at 200 °C (30 min) until a translucid liquid, and white smoke of the mineralized extract was observed. Samples were cooled, and their volume was adjusted to 15 mL with deionized water. The mineral content (K, Ca, Mg, S, and Na) was analyzed with an ICP(Inductively Coupled Plasma) emission spectrometer (Thermo Scientific iCAP 6500 duo). Atomic absorption spectroscopy (AAS, (Agilent Technologies FS 240)) was used to analyze P, Fe, Cu, Mn, and Zn. The results were expressed in mg/kg and % of the dry weight of the flesh.

Boron (B) content was measured as follows: Samples were incinerated in a muffle furnace (550 °C/4 h) following the methods of McKean [19] and NTC 5404 [21]. Then, 10 mL of H2SO4 (1 N) was added to the cooled samples and filtered out, and 10 mL of deionized water was added. One milliliter of the filtered sample was extracted, and 2 mL of the buffer solution and 1 mL of azomethine-H solution were added. The sample was then agitated in a vortex, and after 40 min, the absorbance was measured in a spectrophotometer UV-VIS (Thermo Scientific —Spectronic Genesys 10 S) at a wavelength of 430 nm.

The total nitrogen content (N) was determined using the micro Kjeldahl method according to NTC 5889 [22] and ISO (International Organization for Standardization) 5983-2 [23].

2.10. Statistical Analysis

The experimental design used was a bifactorial design (3 × 4): harvest index (DM = 22%, 26%, and 30%) and storage time (ST = 0 weeks/0 days, 3 weeks/21 days, 4 weeks/28 days, and 5 weeks/35 days). Data analysis was carried out using the statistical software XLSTAT 2020.3.1 (Addinsoft). The internal fruit disorders between orchards were analyzed using the nonparametric Kruskal–Wallis test. After that, Dunn's multiple comparisons test was applied with a Bonferroni correction ($p < 0.05$). Pearson correlation coefficients were used to identify the significant relationship between mineral content and internal disorders ($p < 0.05$). The content of the significant minerals was analyzed by ANOVA of the two-way (Orchard, Dry matter) with interaction (Orchard × Dry Matter) ($p < 0.05$). Then, Tukey's multiple range test was performed when a significant difference was found between the treatments. For each mineral significant, a linear or logistic regression analysis was performed; the models and R^2 values are shown in the figures.

To classify the orchards, Preharvest factors and flesh significant minerals were analyzed by a partial least squares discriminant analysis (PLS-DA) model (Unscrambler 11, Camo Analytics). X-variables were mineral soil content, weather conditions, mineral flesh content, whereas orchard was the Y variable. The PLS-DA model (mean-centered) was done using the kernel algorithm and random cross-validation.

3. Results and Discussion

3.1. Fruit Internal Quality

Internal disorders were different among the farms studied [24]. The lowest flesh bruising damage levels were found at the EB following by LE farms. BV and CS farms showed the highest levels of flesh bruising, but no statistical differences were found between them (Figure 1A). Fruits harvested from the LE farm had the highest presence of stem rot ($p < 0.05$), while EB farms had a low stem end rot incidence (Figure 1B). This was not found statistical differences between BV, CS, and LE for-Flesh discoloration; again, the EB farm had the lowest value of this disorder (Figure 1C). Vascular browning and body rots were shown with similar behavior with the highest values for LE and BV ($p < 0.05$), while CS and EB had low incidence for these disorders (Figure 1D,E).

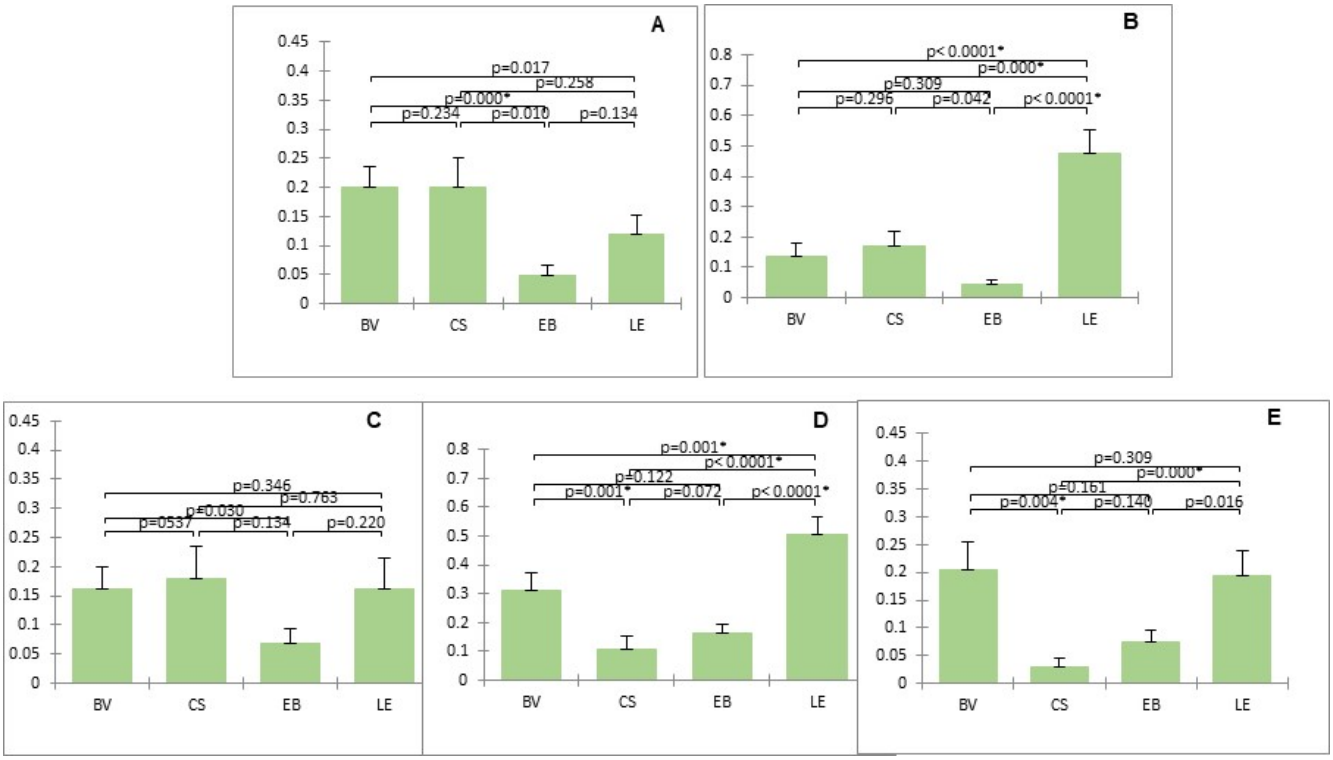

Figure 1. Fruit internal defects (mean ± standard error): flesh bruising (**A**), stem end rot (**B**), flesh discoloration (**C**), vascular browning (**D**), and body rot (**E**). * *p*-value with the "*" mean that there is a statistically significant difference between orchards ($p < 0.05$).

Moreover, for those harvest seasons, storage time had a significant effect on these disorders, especially at five weeks of storage for the LE farm (Figure 2). Maturity influenced the incidence of internal flesh disorders. At the middle of the harvest season (DM-26) was found the best flesh internal quality for all the farms evaluated (Figure 2). The results were similar to those obtained by Dixon et al. [25], who recommended harvesting at a DM content of ≥24% to avoid severe physiological disorders for New Zealand fruit. However, in that work, storage time was not considered as a studied factor, and it remained constant (5−7 °C/4 weeks). The increase in internal disorders with storage time was also found by Burdon et al. [4]. Nevertheless, the results for internal disorders in this work were lower than those of Burdon et al. [4], who stored fruit for three to six weeks at 5 °C for 'Hass' avocado fruits from New Zealand during 2002, 2003, and 2004.

These avocado internal quality differences could be due to flesh mineral composition, soil composition, and orchards weather conditions. Cutting et al. [26] showed that mineral composition plays an important role in the postharvest properties of avocado, and so determining internal avocado quality. Moreover, the avocado flesh mineral composition could vary by maturity levels, soil types, climates, altitudes, and locations [27].

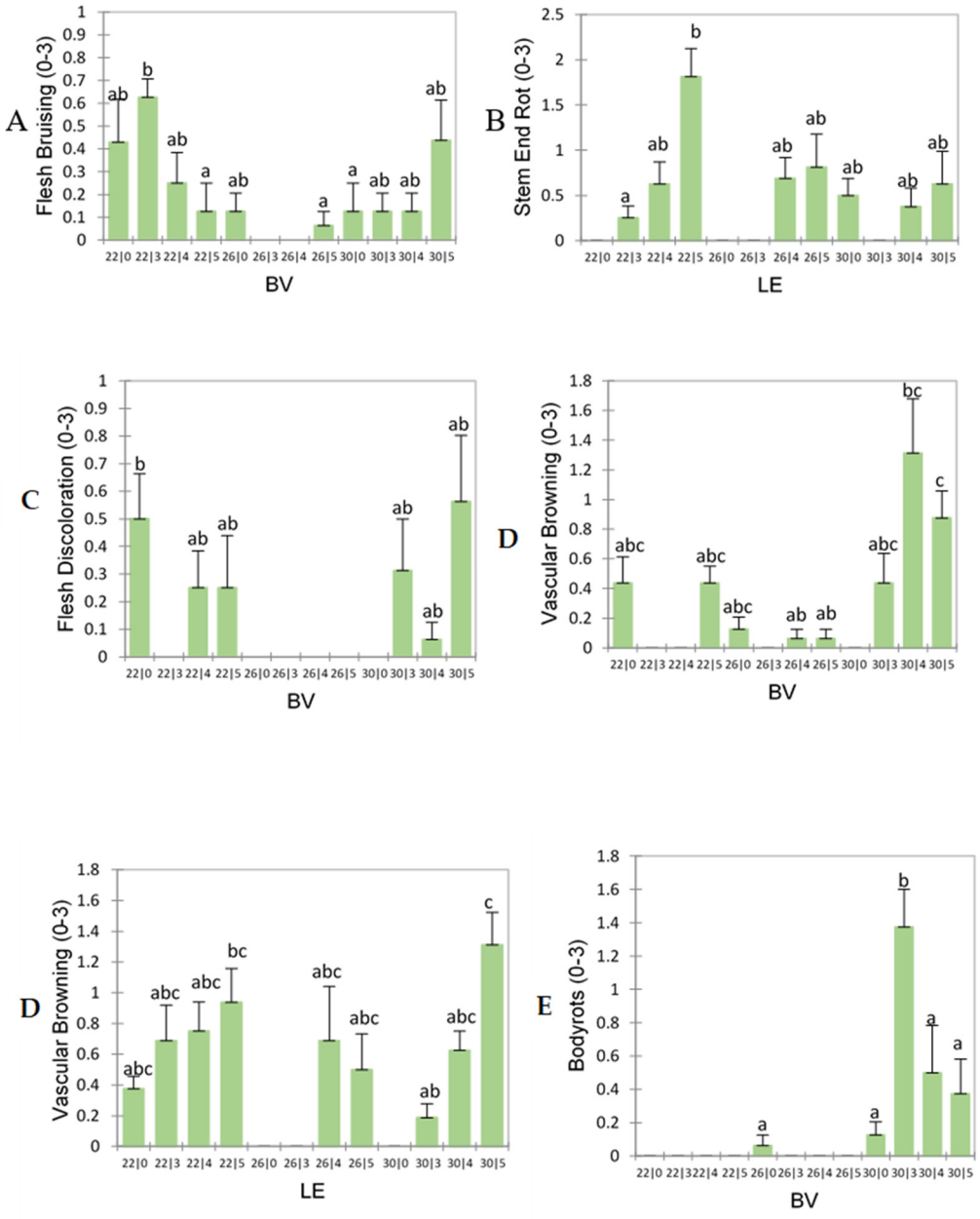

Figure 2. Fruit internal disorders (only orchards that had significant results are shown, mean ± standard error): flesh bruising (**A**), stem end rot (**B**), flesh discoloration (**C**), vascular browning (**D**), and body rots (**E**).

3.2. Flesh Mineral Content

CS and EB farms had the highest B content and did not show significant differences among their maturity indexes (Figure 3A). While BV and LE farms had the lowest B content and showed significant differences along the harvest season ($p < 0.05$). These results are related to internal flesh damage. Avocados from farms EB resisted damage for a longer storage time (five weeks) than those from the LE farm (Figure 2). Even for late harvest seasons (DM-30), internal damages were lowest for EB and CS farms (Figure 2B,D,E). That could be explained by the relationship between B content and internal quality. The regression analyses will be discussed later.

These results are in accord with those of Ferreyra and Defilippi [28], who found fewer internal disorders in avocados with a high B content. Moreover, Ferreyra and Defilippi [27] showed that the B content is the main preharvest factor that affects internal avocado quality. The results could be associated with B stored in 95% of the cellular walls. B and Ca preserve

the plasmatic membranes and reduce permeability, preventing the enzyme release that causes browning of vegetal tissue browning. Therefore, a high level of those minerals could be the key to avocado quality and shelf life [10,29–32].

The harvest season had a significant effect on the Ca, N, Mn, and Mg content, and their content decreased as the DM increased, especially for Ca ($p \leq 0.05$) (Figure 3B–E). In contrast, flesh K content increased with DM accumulation across the harvest season for the BV and LE farms (Figure 3F). For Flesh Ca content, farms were grouped as follows LE, EB, and CS had a high Ca content and not showed significant differences, while BV had the lowest Ca content. Those results (400−1000 mg·kg^{-1}) are higher than those reported by Hofman et al. [9] (200−500 mg·kg^{-1}) for Australian avocados. Although avocados from the LE farm had a high Ca content (980 mg kg^{-1}), they had the highest incidence of internal flesh disorders. These results disagree with those of Hofmann et al. [9], who reported that at high flesh Ca content, there was low flesh discoloration and anthracnose severity. Our results show that internal flesh disorders depend not only on the Ca content but also on the B content (Figure 3A).

A N content below 1% (0.73% to 0.86%) Figure 3C was found. Our results are in agreement with those of Ferreyra and Defilippi [28] and Van Rooyen and Bower [10], who reported that the total nitrogen content of flesh must not exceed 1%. These authors found that higher N content increased the incidence and severity of flesh browning. N content could be related to the low severity of the flesh discoloration and body rots found for farms BV and EB as will be discussed later.(

BV and EB had the highest Mn content. In these farms, the Mn content was decreased along the harvest season ($p < 0.05$). These results agree with Van Rooyen and Bower [10], who showed the importance of Mn on avocado quality, which could be associated with the role of the Mn in the sugar synthesis and as a co-factor in the anti-browning enzymatic reactions. The flesh sugar reduces the osmotic potential of the cytoplasm, stabilizing the cell membranes, so the water losses and the cold injury decreased in the vegetable tissues Blakey et al. [33]. Therefore, the high level of Mn in avocados from the EB farm could explain the low level of internal disorders found, even during the long storage period.

Flesh K content ranged from 1.2% to 1.8%. These findings are like those of Ferreyra and Defilippi [28] (0.9%−3.4%), showing that the highest K levels were related to a greater incidence of physiological disorders. The CS farm, followed by the BV farm, had the highest potassium levels (Figure 3F). The LE farm reported lower potassium levels. High contents of this mineral have normally been related to the higher incidence of physiological disorders in fruit [28], as will be discussed later.

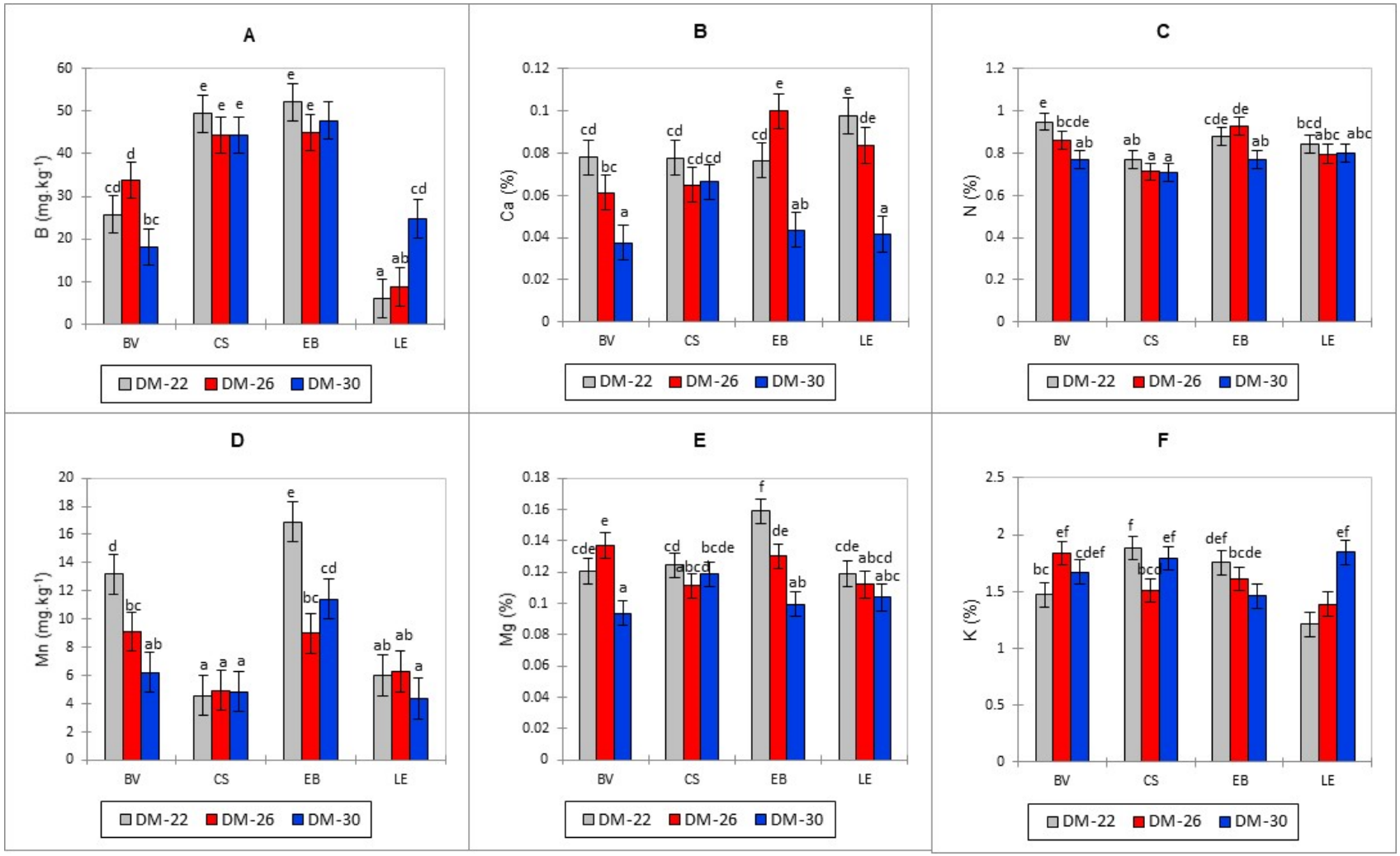

Figure 3. Mineral content by Farm and dry matter (DM-22, DM-26, and DM-30): Boron content (**A**), Calcium content (**B**), Nitrogen content (**C**), Manganese content (**D**), Magnesium content (**E**)**,** Potassium content (**F**)**.** Farms codes: EB, CS, LE, and BV.

3.3. Relationship between Flesh Mineral Content and Avocado Internal Disorders

The results of regression analyses between flesh mineral content and internal disorders (flesh bruising, flesh discoloration, body rots, stem end rot, and vascular browning) are presented in Figures 4–8). Ca, B, Mg, Mn, K, and N content and Ca + Mg/K and N/Ca ratios showed a significant relationship with internal fruit damage. For flesh bruising, an inverse linear relationship with Mg (r = −0.72), Mn (r = −0.93), and Ca had a protective effect; a concentration of >0.07% reduced fresh bruising significantly and had a significant logistic relationship (Figure 4). The results indicate that at a higher mineral content, the severity of flesh bruising damage will be lower, especially for farms in the northern Antioquia region harvested at the beginning of the season with nonstorage (BV) or storage for five weeks (CS). As previously noted [10], low manganese content contributes to the decrease in fruit firmness. The Mg results differ from those of [10], who worked with Pinkerton avocado; thus, there may be a cultivar effect on the Mg content and its relationship with flesh bruising. The results for Ca are in agreement with those of [28], which indicated that Ca is in the 'Hass' avocado cell wall and promotes cellular resistance to chilling injury, thus reducing avocado shipping damage.

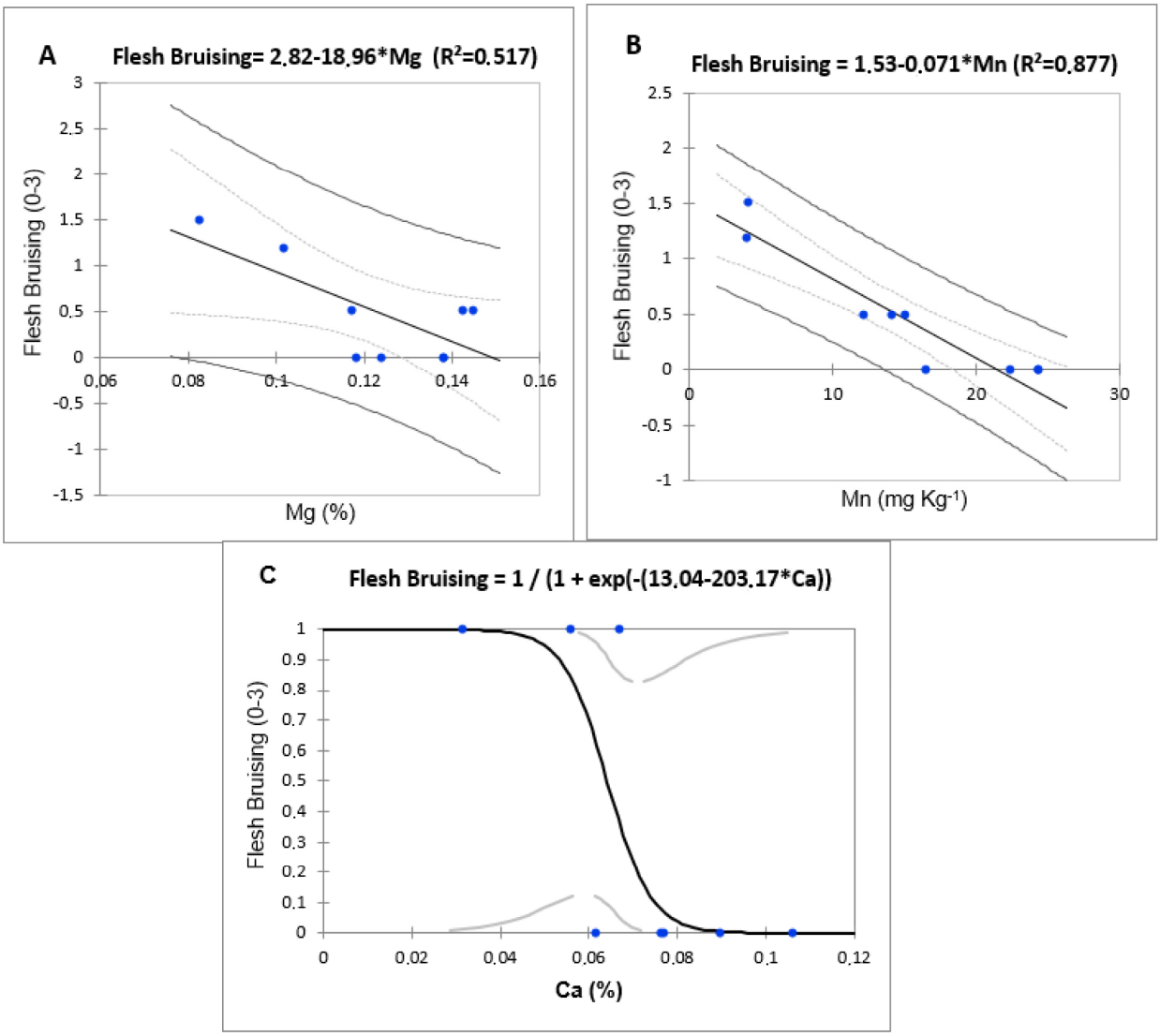

Figure 4. Magnesium and manganese content and its relationship with flesh bruising: (**A**,**B**) Lineal regression for BV farm (DM-22, ST = 0 weeks); (**C**) Logistic regression for damage and calcium content in CS farm (DM-22, ST= 5 weeks). DM: Dry matter, ST: storage time. Farms codes: CS and BV.

A significant relationship was found between minerals and flesh discoloration. A linear relationship was found with Mg (r = 0.68) and K (r = 0.67). Thus, flesh discoloration increases as Mg and K contents rise. This was observed mainly in fruit from the CS farm at the end of the harvest season stored for five weeks (Figure 5). Hofman et al. [9] also found a positive relationship between flesh K content and flesh discoloration in a range from 0.09% to 2.14%. Studies have reported that this phenomenon might be due to the composition and properties of the soil in which the avocado is growing [34]. However, there is insufficient information available regarding flesh Mg content and its influence on 'Hass' avocado flesh discoloration. N, Mn, and Ca had a logistic relationship with flesh discoloration and had a protective effect against flesh discoloration, especially above the following levels: N (0.58%), Mn (6 mg/kg), and Ca (0.06%).

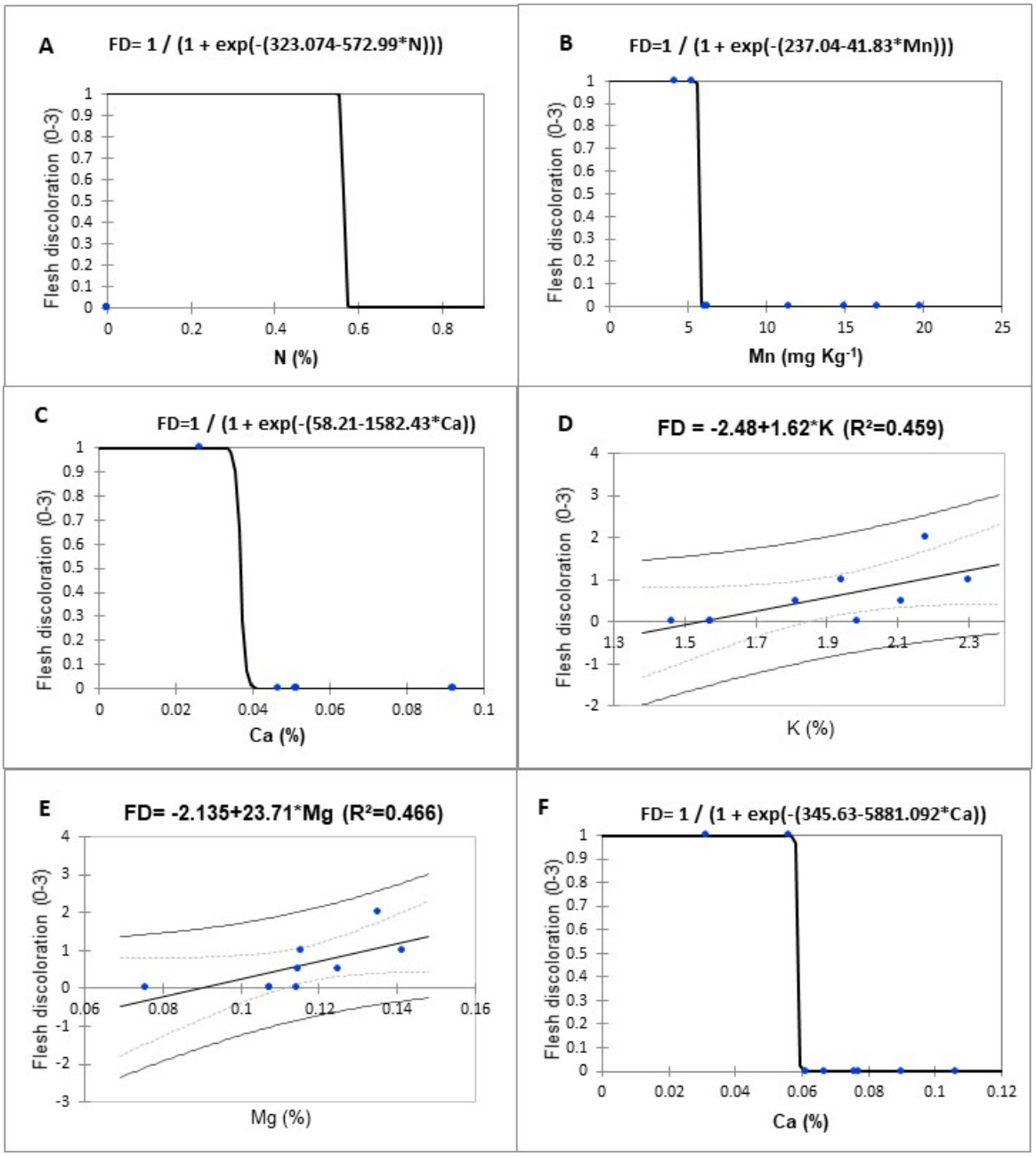

Figure 5. Mineral content and its relationship with flesh discoloration (FD): (**A**,**B**) EB farm (DM- 30, ST= 5 weeks) for N, and Mn Content. (**C**) Lineal regression CS farm (DM-30, 0 weeks) for Ca content. (**D**,**E**) CS farm, lineal regression (DM- 30, ST= 5 weeks) for K and Mg content. (**F**) CS farm (DM-22, ST= 5 weeks) for Ca content.

Figure 6 shows the relationships between body rots and flesh mineral content. For farms BV and LE, there was a negative correlation between body rots and N (r = −0.80), B (r = −0.71) and Mn (r = −0.77) contents. In contrast, the N/Ca (r = 0.72) relationship had a positive correlation with body rots, principally at 30% DM. Van Rooyen and Bower [10] found that Pinkerton avocado fruit quality decreases as the age or fruit development time increases. These authors reported that fruit harvested at the end of the harvest season has a lower Mn content. This might be associated with internal fruit damage.

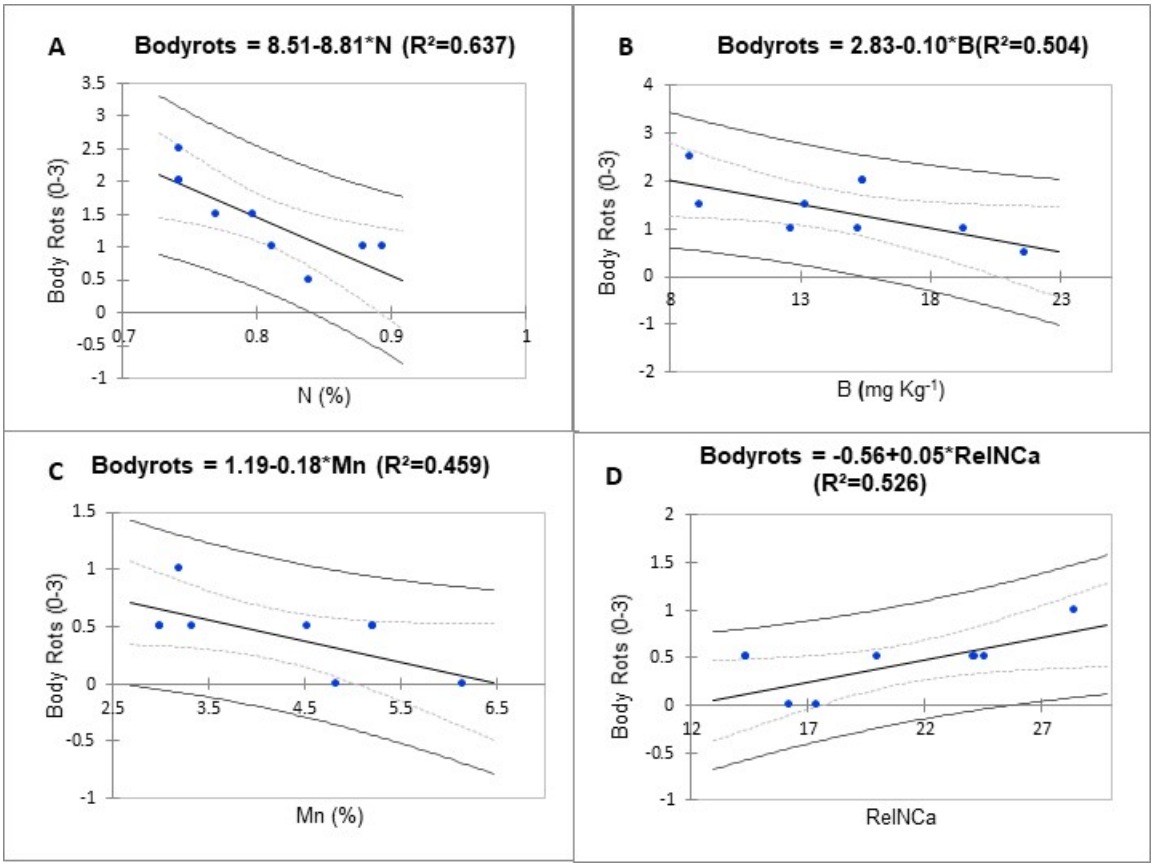

Figure 6. Minerals content (N, B, Mn, and N/Ca) and their relation to body rot: (**A**,**B**) BV farm (DM-30, ST= 3 weeks); (**C**,**D**) LE farm (DM-30, ST = 0 weeks).

Results for stem end rot showed a negative relationship with Ca and B that was greatest in the LE farm, especially when the fruit was stored for a long period. The Ca and B content could reinforce the wall cell as calcium pectates (Figure 7). This substance has been found in the middle lamella of hemicellulose and cellulose, where cellulase and polygalacturonase degrade the cellular wall [28,33]. Therefore, wall cells may be more resistant to fungal attack and thus reduce the release of deteriorative enzymes [35].

Vascular browning was a disorder found at all the farms studied. The results showed a negative linear relationship with the Ca, Mn, and B contents and the (Ca + Mg)/K relationship. The K content and the N/Ca relationship showed positive correlations for this disorder. For the EB farm, Ca content had a logistic relation with vascular browning for fruits with high DM content and storage for five weeks (Figure 8). Ca, Mn, B, and (Ca + Mg)/K deficiencies promote vascular browning as well as an increase in K content and the N/Ca relation. Research on vascular browning only reported the Ca content effect, as has been published by Ferreyra and Defilippi [28] and Thorp et al. [36]. For the other minerals discussed here, there is insufficient information available regarding its influence on 'Hass' avocado vascular browning.

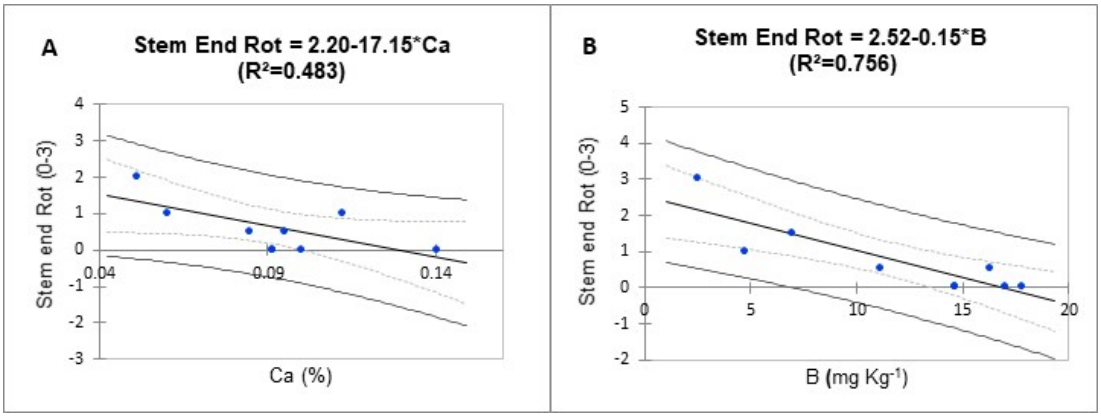

Figure 7. Mineral content and its relationship with Stem end Rot: (**A**) LE farm (DM-22, ST= 4 weeks); (**B**) LE farm (DM-26, ST= 5 weeks).

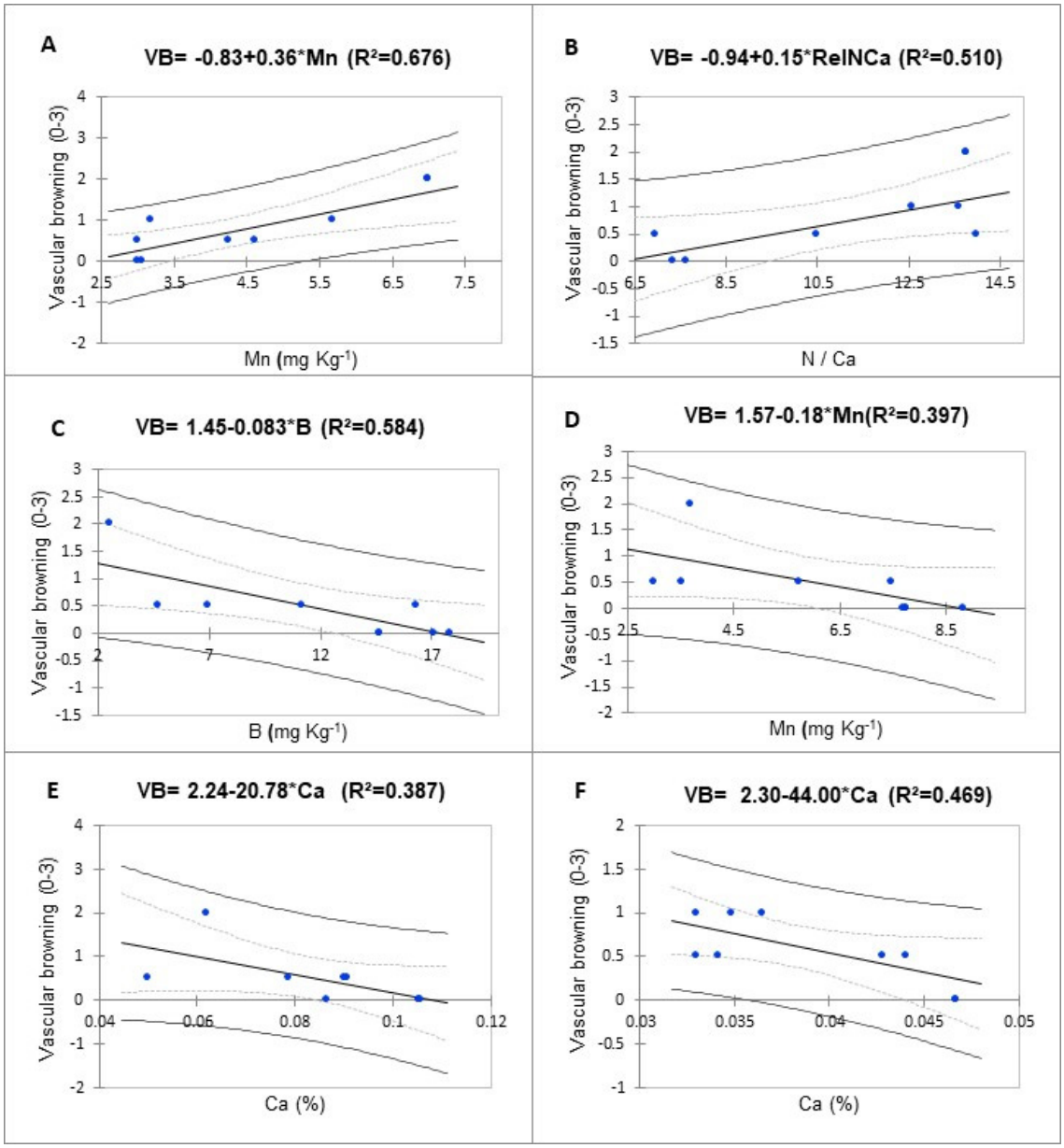

Figure 8. *Cont.*

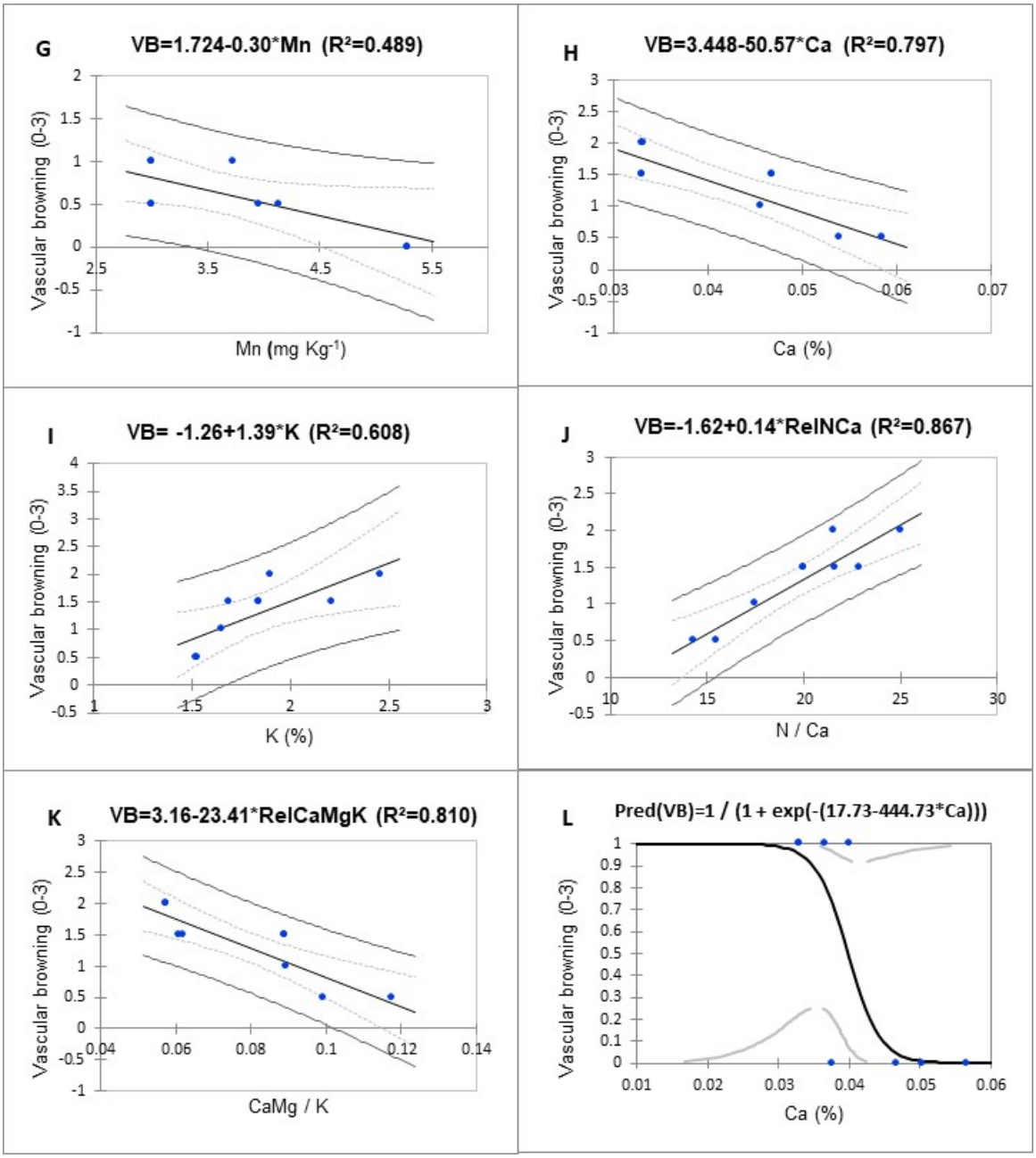

Figure 8. Minerals content (Mn, N/Ca, B, Ca, K, and CaMg/K) and their relation with vascular browning (VB): (**A**,**B**) LE farm (DM-22, ST = 3 weeks); (**C**–**E**) LE farm (DM-26, ST = 5 weeks); (**F**,**G**) LE farm (DM-30, ST = 4 weeks); (**H**–**K**) LE farm (DM-30, ST = 5 weeks); (**L**) EB farm Logistic regression (DM-30, ST = 5 weeks).

3.4. Preharvest Factors

Partial Least Squares-Discriminant Analysis (PLS-DA) results show that farms were grouped well by the weather conditions, soil, and flesh minerals content (R^2 = 0.9988). Factor 1 and 2 explained 74% and 67% of the total variation of the X and Y variables, respectively. CS and EB were different from the BV and LE farms because of their higher soil and flesh mineral content (B, Mg, Fe, Ca, and Ca + Mg/K and B, Mg, K, Mg, and Mn, respectively) (Figure 9). LE had the highest rainfall and temperature (average, minimum, and maximum) (Figure 9), whereas its soil and flesh mineral content was low. These results are similar to the above show to internal disorders (Figures 1 and 2). LE was the farm with the biggest percentage of stem end rot, vascular browning, and body rots.

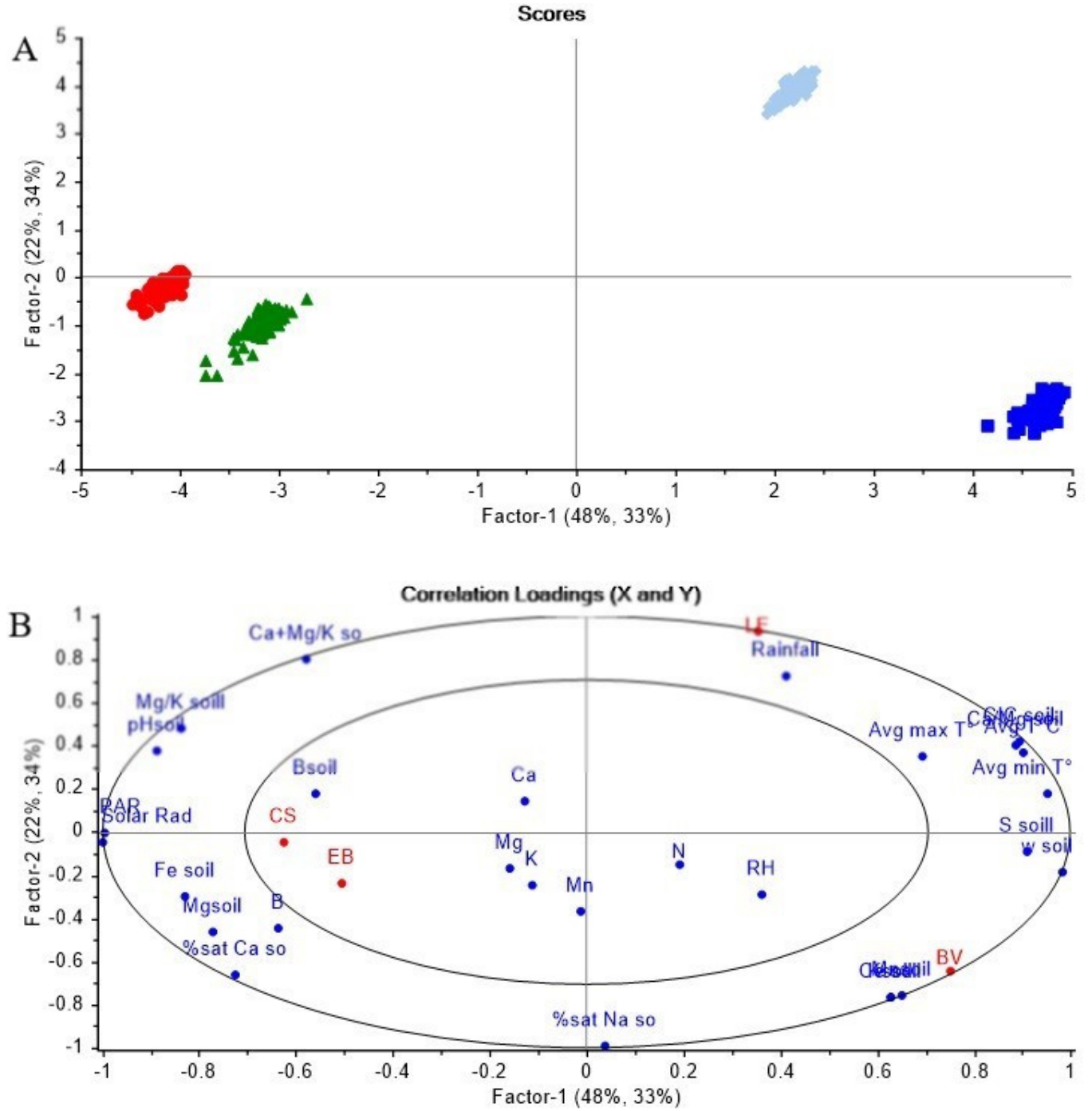

Figure 9. Score (**A**) and loading plot (**B**) of the Partial Least Squares-Discriminant Analysis (PLS-DA) for farms (LE, CS, EB, and BV) based on the preharvest parameters (weather and soil) and flesh mineral significant content.

EB and CS farms had soil pH ranges between strongly to moderately acidic (5.5−6.0) (Figure 9), allowing that the element B-3 could be available to the avocado trees [37,38]. In fruit trees, several studies indicate that B is related to different parameters of the fruit quality by its interference in the flowering and development of the seed and the fruit [39,40]. Mg/K and Ca + Mg/K ratios are related to fruit firmness and the accumulation of sugars and fats in the pulp [39], being favored under levels of soil pH ranging between 5.5 to 6.0 at the effective soil-depth (≤30 cm) of the above-mentioned farms. On the other hand, strongly to extremely acidic soil pH (5.3–4.7) was observed at BV and LE, affecting the availability of individual elements such as B, Ca, Mg, and K, and the ratios of Mg/K and

Ca + Mg/K. Lower fruit damage (%) and higher quality were observed when there was a nutritional balance of B-3, Mg + 2, K+, and Ca + 2 in the soil (Figures 2 and 3). Additionally, the plant photosynthetic activity, and fruit metabolic activity at EB and CS, were favored by the solar radiation and atmospheric temperature within the optimal ranges, as were reported by Gandolfo [41], Romero [42], and Salazar-García et al. [43].

4. Conclusions

The main defects found in the farms sampled in Antioquia were vascular browning and stem end rot. The order of farms from high to low internal disorders was LE, BV, CS, and EB. In relation to the harvest season, the lowest values of the disorders were found in the middle harvest season (DM-26). At the beginning and the end of the harvest season, flesh internal disorders increased. Moreover, storage time also significantly increased internal fruit damage. Twelve minerals were analyzed, but only B, Ca, N, Mn, K, and Mg contents had a significant relationship with 'Hass' avocado flesh quality. Increasing the B, Ca, and Mn content reduced the disorders found in the fruit flesh. However, when K, Mg, and N/Ca concentrations were reduced, the presence of flesh damage was also decreased.

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