The impact of farm-to-packing facility road condition on avocado quality

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ABSTRACT
Transportation and handling have been identified as major factors affecting postharvest losses in perishable fresh fruit. Road roughness leading to shocks and vibrations affects the quality of transported fresh produce, as higher roughness equates to higher levels of energy impacts being dissipated by the transport vehicle as well as the transported cargo. The purpose of this research was to advance the understanding of impacts during transportation on the quality of 'Hass' and 'Fuerte' avocado fruit. First, transportation impacts were simulated using a pendulum device. We then measured in-transit road condition from the farm to the packing facility by means of accelerometers and a smartphone road roughness application. Finally, a case was selected for measurement of accelerations and mechanical damage, as experienced by transported avocado fruit from the grower to the packing facility. This was the first work of its kind done on 'Fuerte' and the first study of its kind to quantify and link the shocks and vibrations during transportation from the orchard to the packing facility to the occurrence and magnitude of avocado quality defects.

INTRODUCTION

Vibration and shocks during transport are recognised as important contributors to the decrease in perishable fresh fruit quality (Gołacki *et al*., 2009). Road roughness affects the quality of transported fresh produce and higher roughness equates to higher levels of energy impacts being dissipated by the transport vehicle and transported cargo (Tabatabaekoloor *et al*., 2013). Chonhenchob *et al*. (2009) reported that shocks and vibration measured during transport can be used to develop test methods to better simulate the transportation or shipping environment and avoid product quality loss or value at sales. Bantayehu and Bizuayehu (2017) expressed the need for research leading to a reduction of postharvest losses of perishable fresh fruit. The study was conducted in the Levubu Valley of Limpopo Province in South Africa, with the aim of quantifying quality losses of avocado fruit due to transport from the orchard to the pack-house.

According to Kader (2002), postharvest losses in fresh fruit and vegetables amounts to approximately 5-35% in developed countries and 20-50% in developing countries. In order to feed the 9 billion inhabitants of planet earth in 2050, and if current unsustainable food production trends continue, the world will require 70% increase in agricultural yield by 2050 (FAO, 2011). The most cost and impact effective way to ensure additional food available for global consumption is to reduce current postharvest food losses. Hofman and Ledger (2001) recommended that a methodology should be developed for avocado growers to identify where and how bruising occurs, in order to improve postharvest practices.

MATERIALS AND METHODS

Materials

The two most popular South Africa avocado cultivars, namely 'Hass' and 'Fuerte', were used during the quantitative experiments. A pendulum impact device was used to determine the impact energy required to cause bruising in avocado fruit. The test vehicle used during the transportation experiments, was a Ford Ranger Double Cab 4x4 LDV vehicle (fitted with 17" tyres, inflated to manufacturer's specifications). Accelerations induced by the road roughness were measured with Gulf Coast Data Concepts X16-1 D accelerometers, and road roughness was measured with the RoadLab Pro smartphone application, fitted to the test vehicle's windshield. In addition, a GoPro Hero 3+ Black edition action camera was fitted to the test vehicle's nudge bar to capture video footage of the condition of the road.

Methods

The effect of road condition on the quality of transported avocado fruit was quantified by, firstly determining the bruising of avocado fruit by means of a pendulum impact device, secondly by linking bruising

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to measured road condition and associated shocks and vibration of 19 routes from orchard to the packing facility, and lastly by means of a case study where avocado fruit were transported on a selected route from orchard to pack-house, and the resulting avocado bruising measured to validate the bruise volume model.

To quantify the impact energy causing bruising of avocado, a range of fruit sizes of the two cultivars, 'Hass' and 'Fuerte', were tested by means of a pendulum impact device constructed in a similar fashion as Bauyon *et al*. (2017). Impacted fruit were allowed to ripen over 15 days at 20 ± 1°C to fully develop bruising. Fruit were dissected, bruising measured with calipers, and data captured.

To simulate the damage caused by energy exposed to fruit while in transit, road condition (roughness) and acceleration were measured and evaluated for 19 routes, serving operations of both commercial- and emerging avocado growers entering the export markets. The routes from the orchard to the packing facility included paved and unpaved roads with variable condition. Figure 1 shows typical unpaved road types encountered between the orchard and the packing facility.

The road condition was measured with RoadLab Pro, a smartphone application developed by the WorldBank. A smartphone running the RoadLab application was attached to the inside of the test vehicle's windshield. Accelerations induced by the road roughness were measured with Gulf Coast Data Concepts X16-1 D accelerometers affixed to the furthest rear, and to one-side of the vehicle and at the highest possible container position, to capture the maximum impacts (Hinsch *et al*., 1993).

Avocado fruit bruising was explored by attaching X16-1 D accelerometers to the transport vehicle and the container in which the avocado were transported. An accelerometer was also embedded in an avocado and placed in a lug box container, as depicted in Figure 2.

Method of analyses

Accelerometer data were imported into XL8R software (Gulf Coast Data Concepts) and Fast Fourier Transform (FFT) analyses performed, which provided Power Spectral Density (PSD) plots. The PSD data were exported to Microsoft Excel 2016 to calculate energy induced by the road condition by means of the Midpoint Rule. Statistical analyses were performed in R (v. 3.5.2, R Foundation for Statistical Computing, Vienna, Austria). Dependent variable results were subjected to a Shapiro-Wilk test of normality, testing the null hypothesis that the data distribution is not normal and, depending on the data distribution, Levene's Test or Bartlett test for homogeneity of variance, testing the null hypothesis that the variance is equal. To test the outcomes of impact energy, bruise area and bruise volume, Welch Two Sample t-tests or the non-parametric Welch Two Sample t-test were used, testing the null hypothesis of no difference between cultivars. An ANOVA (linear model for normal data distribution or generalised linear model where non-parametric) were employed to test the effect of cultivar, treatment and weight on impact energy and bruise volume. Pearson's product-moment correlation test was used to test the null hypothesis that the true correlation equals zero. All statistical analyses accounted for fruit firmness as

Figure 1: Orchard to packing facility roads: example of an (A) unpaved earth road and (B) unpaved gravel road

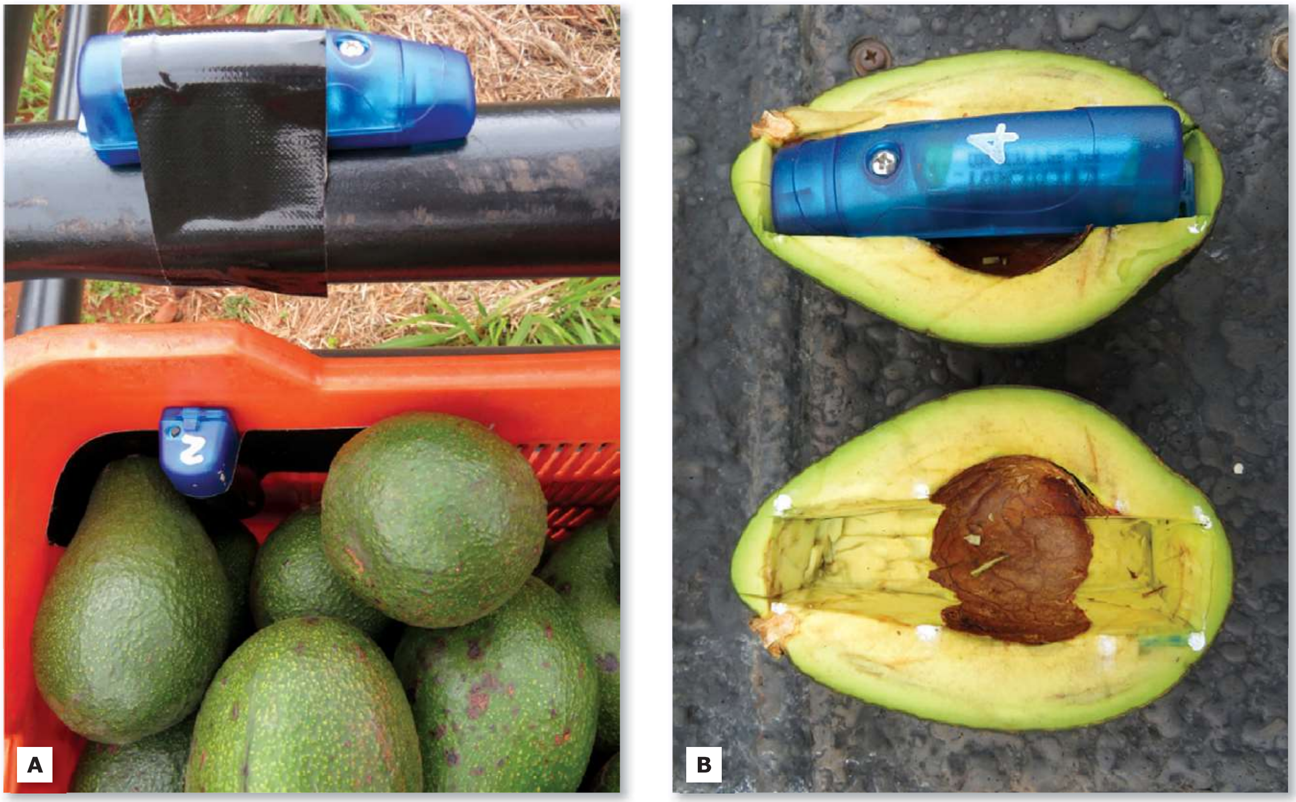

Figure 2: Accelerometer placement (A) on test vehicle as well as attached to a lug box and (B) embedded in avocado fruit

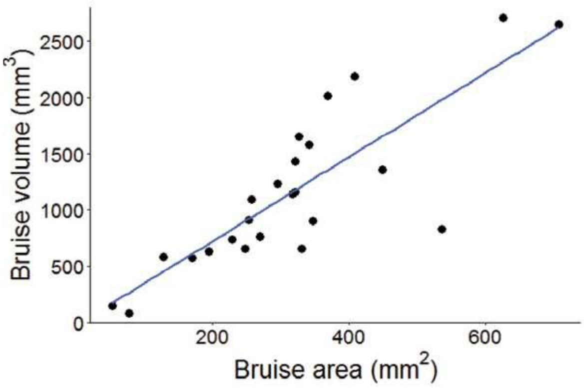

Figure 3: Correlation between avocado bruise volume and bruise area

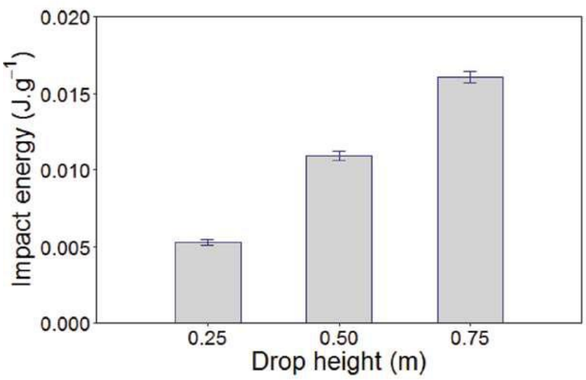

Figure 4: Correlation between impact energy and drop height

a continuous predictor in the model. A step-wise ANOVA was used to select the best predictor variable(s) explaining bruising in avocado from N = 19 routes between the orchard and pack-house.

RESULTS AND DISCUSSION

Impact energy experiment by means of a pendulum impact device

Bruise area correlated significantly with bruise volume (Fig. 3) and, irrespective of cultivar, bruise volume was significantly predicted by the impact energy. Fruit weight was a significant predictor of impact energy. Drop heights significantly affected bruise volume (ANOVA, SS = 44.03, df = 1, f-value = 25.27, p-value < 0.001) and impact energy (GLZ, Kruskal Wallis Chi-square = 2860.90, df = 1, p < 0.001) observed in the fruit (Fig. 4).

Yuwana (1997) identified the impact energy required to initiate bruising in hard green avocado as 0.49 Joules (J). Our research found the impact energy required to exceed the export quality threshold for bruising hard green avocado fruit, to be 0.53 J.

Acceleration due to condition of 19 routes from orchard to pack-house

Unpaved roads showed a spike in both vertical and lateral energy experienced during transit, and the maximum accelerations measured on the transport routes were as follows:

- 3.4 g in the x-axis (longitudinal);

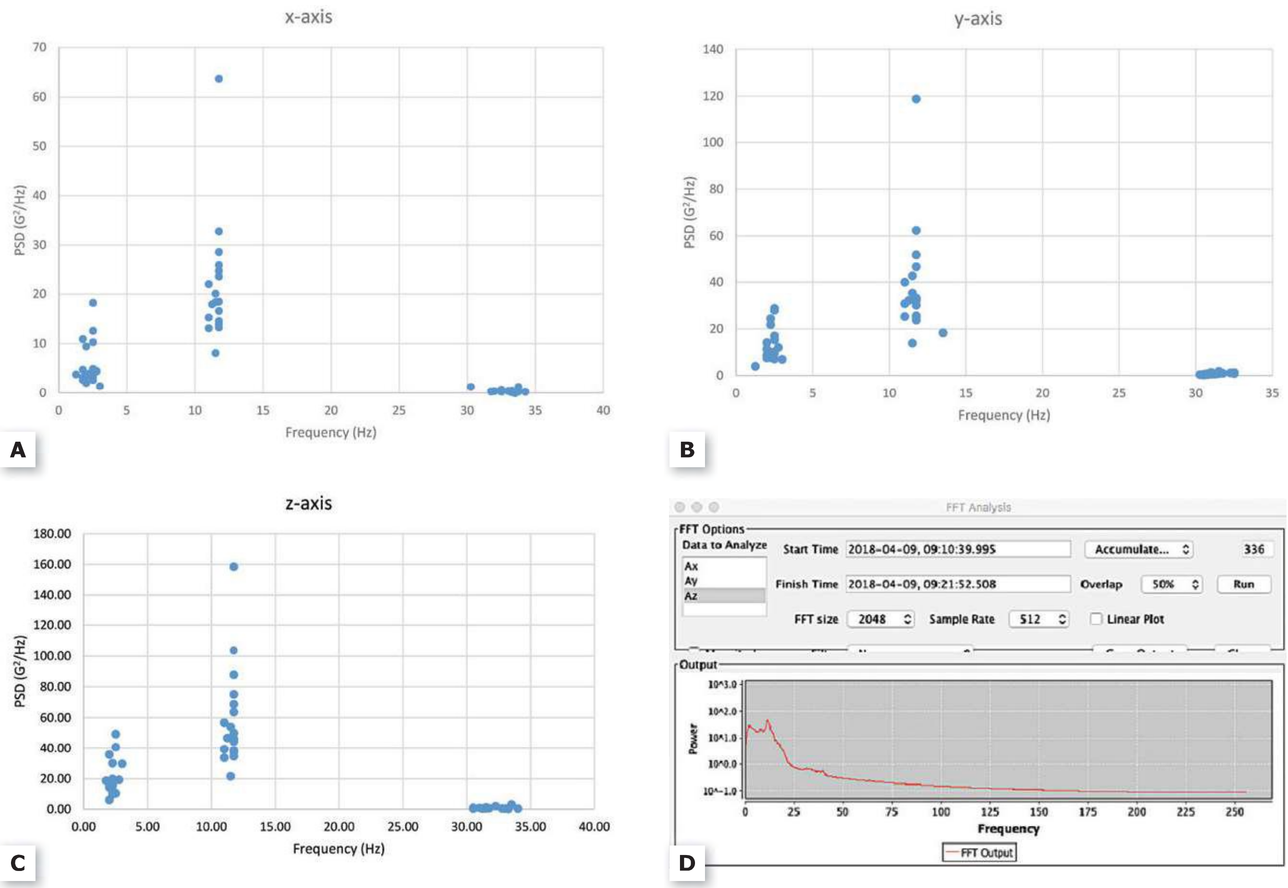

Figure 5: Accelerometer frequency distribution (A) x-axis, (B) y-axis and (C) z-axis and (D) example of Fast Fourier Transform analyses PSD plot

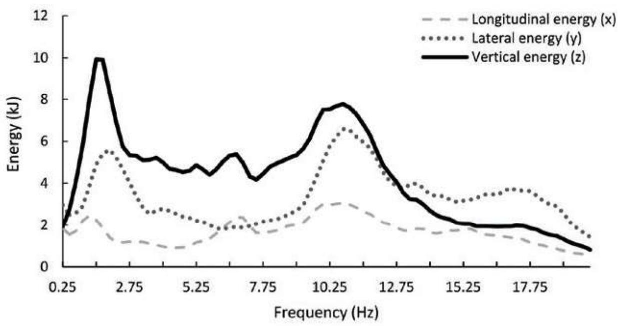

Figure 6: Accelerometer frequency distribution in x-, y- and z-axis for unpaved road section with a length of 2.5 km

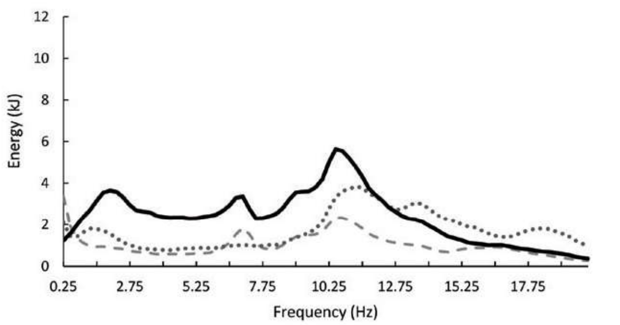

Figure 7: Accelerometer frequency distribution in x-, y- and z-axis for paved road section with a length of 11.5 km

- 7.6 g in the y-axis (lateral); and
- 12.1 g in the z-axis (vertical).

Jarimopas *et al*. (2005) identified three major frequency ranges, which can be recognised when analysing road conditions. This study confirmed these findings as evident in panels A, B and C of Figure 5.

Case study – avocado fruit bruising during transportation

To test the effect of road condition (paved vs. unpaved) on bruise volume, avocado cv. Fuerte were transported in a lug box along an unpaved road section only, and a paved road section of a road to the packing facility.

It is clearly evident that the unpaved road section induced significantly higher energy levels to be dissipated by the vehicle and cargo (avocado fruit) than the paved road section, as shown in Figures 6 and 7.

Results given in Table 1 indicate that although the unpaved road section was only 2.5 km long, the energy induced by the road condition significantly exceeded the energy levels generated by the road condition of the paved section with a length of 11.5 km.

Table 1: Energy at dominant frequencies for unpaved as well as paved sections of the case study route

Road section	Energy at dominant frequency range 0.1 – 5 Hz (body bounce)	Energy at dominant frequency range 5 – 20 Hz (axle hop)
Unpaved (2.5 km)	9.92 kJ @ 1.5 Hz	7.77 kJ @ 10.75 Hz
Paved (11.5 km)	3.64 kJ @ 2 Hz	5.63 kJ @ 10.5 Hz

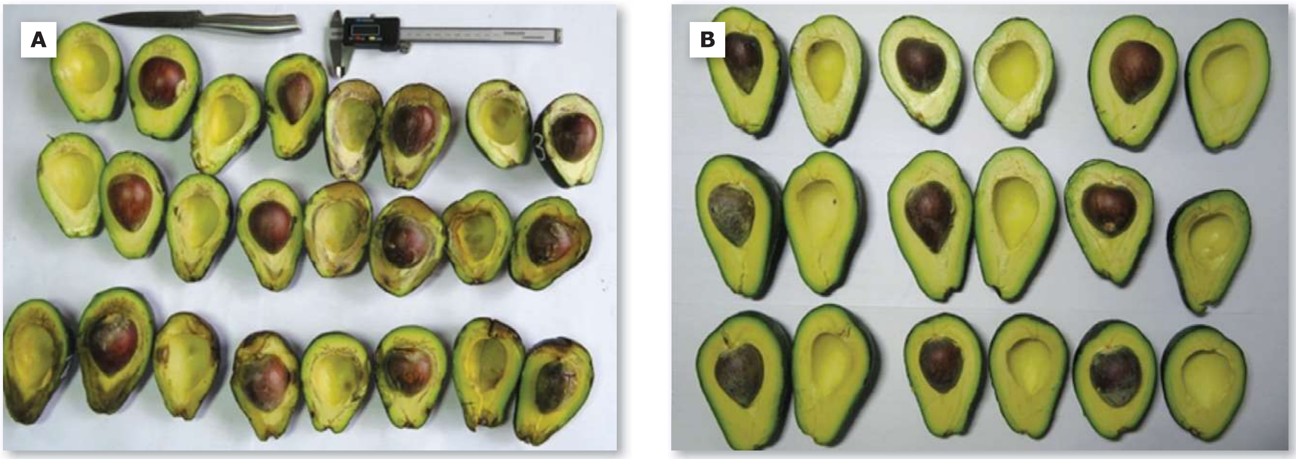

Figure 8: Sample of avocado fruit subjected to (A) route shock and vibration and (B) control sample not subjected to route shock and vibration

In addition, the dominant frequency of the unpaved road section represents the body-bounce frequency range, whereas the dominant frequency range for the paved road section represents the axle-hop frequency range.

During the case study, 83% of the avocado sample exposed to in-transit shocks and vibrations exceeded the maximum allowable export quality defects threshold, whereas the control sample, not exposed to in-transit shocks and vibrations, presented 11% avocado fruit of quality below the export threshold (Fig. 8).

Statistical model

The accelerations measured during the transport route experiment were translated to bruising, following the results from the controlled pendulum experiment. Results indicate a significant correlation between impact energy and bruise volume (r^2 = 69) as a function of fruit weight (a significant continuous predictor), where impact energy is expressed as Joules/gram and bruise volume is expressed as mm^3/gram.

Calculated bruise volumes for 19 different routes from orchard to packing facility showed bruise volume exceeded 1 000 mm^3 where the total energy in the transport system exceeded 1.46 kilojoules and the best predictors of bruising was the combination of longitudinal-, lateral and vertical energy. Bruise volume as a function of impact energy is described by $y = 628.19x + 0.81$. By applying this equation to the accelerations measured en route, the statistical model that significantly predicted bruise volume included travel time and shocks experiences in all 3 acceleration directions. The results from the case study were used to validate the statistical model's bruise predictions (Fig. 9).

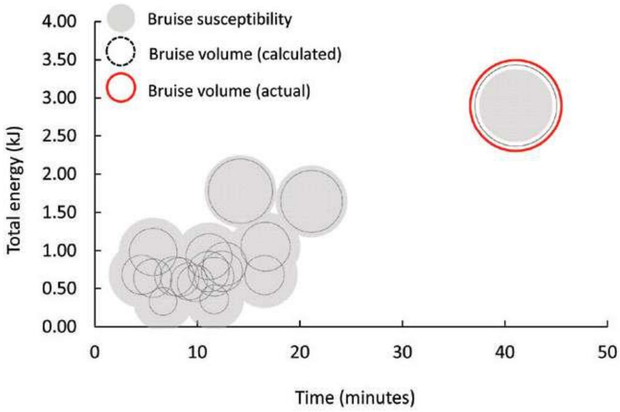

Figure 9: Statistical model prediction of bruise volume based on total energy in the transport system and the travel time

CONCLUSIONS

Uneven roads cause shocks and vibration which transfers through the transport vehicle to the transported cargo. In order to limit quality defects to avocado, road condition should be maintained to an appropriate level, limiting shock impacts and vibration transferred to the fruit. Maintained roads further contribute to mitigating climate action by reducing the rolling resistance, which result in better fuel efficiency, whilst reducing carbon emissions. Additionally, properly maintained roads equates to safer road conditions for users. Low cost tools are available to farmers to get an indication of condition of roads as well as the accelerations conveyed in-transit fruit (smartphone applications and accelerometers).

This is the first study of its kind to demonstrate that road condition (roughness) directly relate to occurrence and magnitude of vibration and impact bruising on transported avocado fruit. The longitudinal-, lateral and vertical energy are important factors to measure when avocado bruising is concerned when transporting avocado from the orchard to the pack-house.

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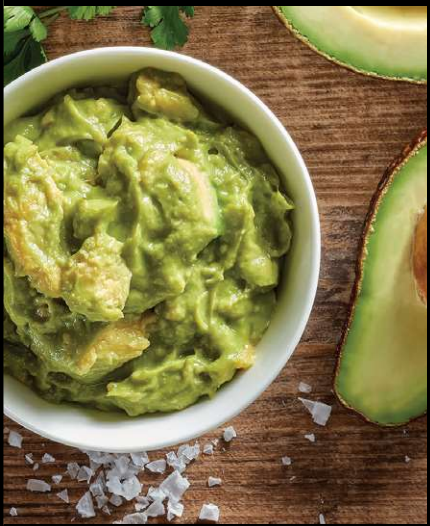

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