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Analysis of blanching and drying temperature on the physical characteristics of breadfruit chips during drying

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ABSTRACT
This study evaluated how blanching regime and drying temperature influence moisture removal dynamics and dimensional changes in breadfruit chips. We dried breadfruit chips at 55 or 65 °C following one of three pretreatments: blanching at 40 °C for 15 min, blanching at 80 °C for 30 min, or no blanching. Raising drying temperature lowered the equilibrium moisture content (EMC) and shortened the time to reach it: at 55 °C, EMC stabilized at 6.94–17.03% after 840–1290 min; at 65 °C, EMC was 4.33–14.57% after 810–1050 min. Across both temperatures, mild blanching (40 °C, 15 min) consistently produced the highest drying rate, whereas no blanching or severe blanching (80 °C, 30 min) yielded the lowest rates. Shrinkage showed a similar tendency: at 55 °C, it was greatest after mild blanching and lowest after severe blanching; at 65 °C, it remained greatest with mild blanching but was lowest without blanching. These patterns suggest that mild blanching may open cellular pathways, enhancing water diffusion and promoting structural collapse, whereas harsher conditions or no blanching restrict mass transfer and limit shrinkage. Overall, elevating the temperature accelerated drying and reduced EMC, and blanching conditions strongly modulated both drying rate and product dimensions. From a processing standpoint, pretreatments should be selected to balance throughput with textural quality; for applications prioritizing rapid dehydration, mild blanching at 40 °C for 15 min is advantageous, whereas minimizing shrinkage may require either higher-temperature drying without blanching or carefully optimized, shorter blanching steps.
Keywords: breadfruit chip, drying kinetics, moisture ratio

1. Introduction

Breadfruit (Artocarpus altilis), a member of the Moraceae family, is widely distributed across Indonesia. The fruit is ovoid, oblong, or elliptical, with either prickly or smooth skin, and is typically yellowish-green and seedless [1],[2]. Morphologically, breadfruit weighs about 0.6–1.7 kg, with a length of 13–23 cm and a circumference of 32–45 cm. Its carbohydrate content varies by region, ranging from 8.62% (40.43 kcal/100 g flesh) in Sorong to 33.37% (136.40 kcal/100 g flesh) in Madura [1]. One hundred grams of breadfruit contains about one-third the carbohydrates of rice, but when processed into flour, its carbohydrate content becomes comparable to rice, albeit with slightly lower calories [1], [2]. Like many fruits, breadfruit undergoes enzymatic and non-enzymatic browning after peeling, which adversely affects its quality and limits its utilization as a flour or chip product.

Drying is a critical step in breadfruit processing, as it reduces moisture content, prolongs shelf life, and minimizes microbial, enzymatic, and chemical spoilage [3],[4]. Drying kinetics, which describe the transfer of heat, mass, and moisture during drying, are essential for understanding and optimizing this process [5],[6]. The drying process involves heat transfer to provide the latent heat of evaporation and moisture migration from the material to the surrounding air; numerous studies on agricultural products have modeled these phenomena to guide process optimization [6]–[9]. Air temperature, velocity, and humidity primarily determine the constant-rate removal of external moisture until the material reaches the critical moisture content, after which internal diffusion governs drying [6]–[9]. To improve drying outcomes and prevent browning, pre-treatments such as blanching are commonly applied before drying [10]. Blanching not only inactivates enzymes, particularly polyphenol oxidase, but also preserves color, reduces microbial load, softens tissues, and improves texture [10]–[12].

Previous studies have examined the effects of drying temperature or blanching alone on breadfruit and other agricultural products. However, comprehensive studies that integrate blanching parameters (temperature and duration) with drying temperature to evaluate their combined effects on drying kinetics and physical quality parameters, such as moisture reduction, drying rate, and shrinkage, remain limited. A clear understanding of these interactions is important to optimize drying conditions and to produce breadfruit chips of high quality with efficient processing time.

Therefore, this study aims to systematically investigate the combined effects of blanching temperature and duration with drying temperature on the drying characteristics of breadfruit chips. The novelty of this research lies in its integrated evaluation of blanching and drying parameters to simultaneously optimize drying kinetics and structural integrity of breadfruit chips. To the best of our knowledge, this is the first study to comprehensively quantify the interactive effects of these pre-treatment and drying conditions on both the drying rate and shrinkage behavior of breadfruit chips, providing valuable insights for improving the efficiency and quality of breadfruit processing.

2. Methods

2.1. Tools and materials

The tools used in this study include HH-S2 type water baths, tray dryer type drying machines (Hasanuddin University Agricultural Engineering), a Heating Drying oven Model DHG-9030A, saucers, digital scales (Fujitsu FS-AR210 IS-14120362 accuracy 0.001g), calipers (digital krisbow 0.01 mm KW0600422), and stainless steel material molds. The materials used in this study include 0.5% NaCl solution, 1% aquades (waterone), aluminum foil, tissue paper, and fresh breadfruit (*Artocarpus altilis*) obtained from the traditional market in Makassar, Indonesia.

2.2. Research procedures

2.2.1. Material preparation

The ingredients prepared in this study are fresh breadfruit fruit and NaCl solution with a concentration of 0.5%. Breadfruit fruits are peeled, the pulp is separated, and then washed using clean water. Then the breadfruit is cut into cubes with a size of 2x2x2 cm using molds. Furthermore, the weight of each sample is weighed using a digital scale before being treated. Slices of breadfruit chips are treated with blanching and non-blanching. A total of 250 grams of breadfruit that has been reduced in size by ± 2 cm^3 is then put in a 1% NaCl 1% solution. Manufacture of 1% NaCl solution in 750 ml of Aquadest.

2.2.2. Blanching

Blanching breadfruit using a water bath by taking samples of diced breadfruit and NaCl solution. After that, the breadfruit sample is heated in NaCl solution in a water bath. Temperature variations of 40 °C, 60 °C, and 80°C with heating durations of 15 minutes and 30 minutes. After the heating process is completed, the breadfruit is separated from the electrolyte solution using a sieve and washed with clean water. Breadfruit that has passed the blanching process is then weighed to determine the weight of the sample after blanching before drying.

2.2.3. Drying

The drying process is carried out using a tray dryer with a drying air speed of 1.5 m/s, with temperature variations of 55 °C and 65 °C. Sample weight is measured at a time interval of 30 minutes to a constant moisture content for each treatment. The constant moisture content is characterized by three consecutive measurements of the difference of 0.02. Depreciation measurement is also carried out by measuring using a caliper in the middle of the sample every 60 minutes.

2.2.4. Measurement of moisture content

Measurement of moisture content in this study was carried out by putting the dried sample into the oven at a temperature of 105 °C for 72 hours. Furthermore, the weight of each sample is weighed using digital scales to obtain the final weight of the material or the solids' weight of the material.

2.2.5. Research design

The treatment used in this study can be seen in the following matrix (Table 1).

Table 1. Research treatment matrix

Code	Blanching Temperature (°C)	Heating Time (minutes)	Drying Temperature (°C)
A1	40	15	65
B1	40	30	65
C1	60	15	65
D1	60	30	65
E1	80	15	65
F1	80	30	65
G1	control	-	65
A2	40	15	55
B2	40	30	55
C2	60	15	55
D2	60	30	55
E2	80	15	55
F2	80	30	55
G2	control	-	55

2.2.6. Observation parameters

The parameter observed in this study is a change in the weight of the breadfruit sample (grams) to calculate the moisture content of the dry base (%), the drying rate, and measure the shrinkage of the dimensions to determine the degree of shrinkage of the breadfruit sample (%).

a. Moisture content

The moisture content of the dry base can be known by weighing the sample material before and after drying. The cup used as a container is also weighed and then the sample material is put into it and oven-dried. Upon reaching a constant weight during drying, the moisture content of the dry base can be known using the formula:

$$KA_{bk} = \frac{W_w - W_d}{W_d} \, x \, 100\% \tag{1}$$

where: KA_{bk} is the moisture content of dry base (%); W_w is the dry sample weight before oven-dried (grams); and W_d is the dry sample weight after oven-dried (grams).

b. Drying rate

The drying rate can be calculated using the measurement data of the initial moisture content, the final moisture content, and the interval of the drying time. To find out the resulting drying rate, a calculation is carried out using the following formula:

$$DR = \frac{w_w - w_t}{w_d} \times \frac{1}{t_2 - t_1} \tag{2}$$

where: DR is the drying rate (gram H2O/gram bk/min); w_w is the initial weight of material (grams); w_t is the material weight at time t hours (grams); w_d is the constant current material weight (grams); and t_1, t_2 are the time change t hours.

c. Depreciation

To find out the depreciation ratio of breadfruit samples, a calculation is carried out using the formula:

$$S_R = \frac{V0 - Va}{V0} \times 100 \tag{3}$$

where: SR is the percentage of depreciation (%); V0 is the initial volume of the sample before drying (cm^3); and Va is the final volume of the sample after drying (cm^3).

3. Results and Discussion

3.1. Rate of decrease in water content

Based on the studies that have been carried out, it has been shown that during the drying process, the moisture content of the material decreases over time. The drying results of breadfruit chips with a drying temperature of 55 ºC in each treatment are shown in Table 2.

Table 2. Moisture content and drying time of breadfruit chips at various temperature treatments and blanching duration (drying temperature 55 ºC)

Treatment	Initial moisture content average (%bk)	Final moisture content average (%bk)	Drying time (minutes)	Rate of decrease in moisture content (%/min)
A2	272.85	6.94	990	0.27
B2	303.55	8.40	1,020	0.29
C2	240.30	10.36	900	0.26
D2	262.36	12.04	840	0.30
E2	295.62	14.31	1,050	0.27
F2	339.16	17.03	1,050	0.31
G2	278.19	8.51	1,290	0.22

During drying, product moisture decreases over time in accordance with heat and mass transfer principles for food materials [3]–[6]. The drying outcomes for breadfruit chips at 55 °C under each blanching treatment are summarized in Table 2. Initial moisture contents ranged from 240.30% to 339.16% (dry basis), depending on the pretreatment. The lowest final moisture content occurred with A2 (6.94%), whereas the highest was observed with F2 (17.03%), indicating that high-temperature, long-duration blanching tends to retain more equilibrium moisture. The shortest drying time was obtained with D2 (840 min; 60 °C for 30 min), while the longest was the non-blanched control G2 (1,290 min). These patterns agree with the literature, where pretreatments that alter tissue structure generally facilitate surface water removal and moisture transport [3]–[6]. The rate of decrease in moisture content spanned 0.22–0.31%/min; blanched samples generally exhibited faster kinetics than the unblanched control. Notably, A2 (40 °C, 15 min) yielded the lowest final moisture with a moderate time (990 min) and rate (0.27%/min), whereas F2 (80 °C, 30 min) showed the highest final moisture despite the highest initial rate (0.306%/min). This behavior is consistent with reports that overly intense blanching can cause cell collapse or "case hardening," which impedes subsequent diffusion and leaves higher residual moisture [10]–12]. The non-blanched sample (G2) presented the longest time and slowest rate, underscoring the positive role of blanching when conditions are appropriately controlled. Overall, mild blanching (lower temperature, shorter duration) proved more effective for achieving low final moisture while maintaining reasonable drying times and rates, consistent with general drying-kinetics understanding for foods [3]–[8],[13].

At 65 °C (Table 3), trends were similar but accelerated: A1 (40 °C, 15 min) achieved the lowest final moisture (4.33%) with moderate time (990 min) and rate (0.30%/min), whereas F1 (80 °C, 30 min) reached the highest final moisture (14.57%) despite the highest rate (0.40%/min). The non-blanched G1 again required the longest time (1,050 min) and showed the lowest rate (0.22%/min), reaffirming the benefits of appropriately selected blanching.

Beyond the descriptive trends, the data lend themselves to simple kinetic descriptors that facilitate process comparison. For instance, fitting the moisture ratio versus time to common thin-layer formulations (e.g., Page, Henderson–Pabis, or logarithmic models) would enable the extraction of empirical rate constants and goodness-of-fit indicators, allowing a quantitative ranking of blanching conditions at each temperature [7],[8]. In parallel, calculating the effective moisture diffusivity (Deff) from the falling-rate period (assuming slab geometry and Fickian behavior) would connect the observed moisture-loss patterns to internal mass-transfer resistances [6],[7],[9]. If Deff values are further regressed against temperature using an Arrhenius-type relation, the apparent activation energy can be estimated to benchmark process sensitivity to temperature regardless of pretreatment [3],[5]. Such parameters would substantiate the conclusion that mild blanching (40 °C, 15 min) improves mass transfer more efficiently than severe blanching (80 °C, 30 min) at both 55 and 65 °C.

Table 3. Moisture content and drying time of breadfruit chips at various temperature treatments and blanching duration (drying temperature 65 °C)

Treatment	Initial moisture content average (%bk)	Final moisture content average (%bk)	Drying time (minutes)	Rate of decrease in moisture content (%/min)
A1	302.31	4.33	990	0.30
B1	317.86	4.59	900	0.35
C1	310.89	7.70	810	0.37
D1	316.57	8.82	840	0.37
E1	376.16	14.37	930	0.39
F1	395.16	14.57	960	0.40
G1	278.19	8.51	1050	0.22

3.2. Drying rate

The drying rate—water removed per unit time per unit mass/area—directly governs how quickly the product attains a target moisture level [6]–[8]. Here, two air temperatures (55 and 65 °C) were used with blanched and unblanched samples. As expected, 65 °C produced higher rates than 55 °C due to greater thermal energy supply and a larger driving-force temperature difference, which enhances heat transfer and vapor flux [3],[6],[7]. Comparable temperature-rate relationships have been reported for onions [6], ear corn [5], sorghum [9], garlic [15], and rice [16], as well as for thin-layer cereal systems such as malt [8]. As moisture decreases, the drying rate declines because the controlling mechanism shifts from surface evaporation (constant-rate period) to internal diffusion, governed by moisture/partial-pressure gradients from the interior to the surface [6],[7],[9]. The observed rate–moisture curves (Figures 1–2) therefore follow the classical diffusion framework (Fick-type behavior) typical of biopolymeric food matrices undergoing thin-layer drying [6],[7],[9].

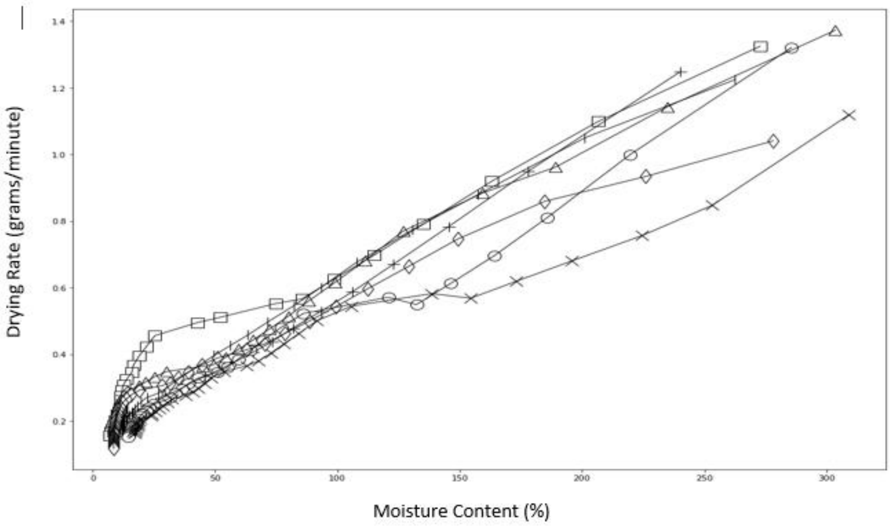

Figure 1. Drying rate of chips with a drying temperature of 65 °C

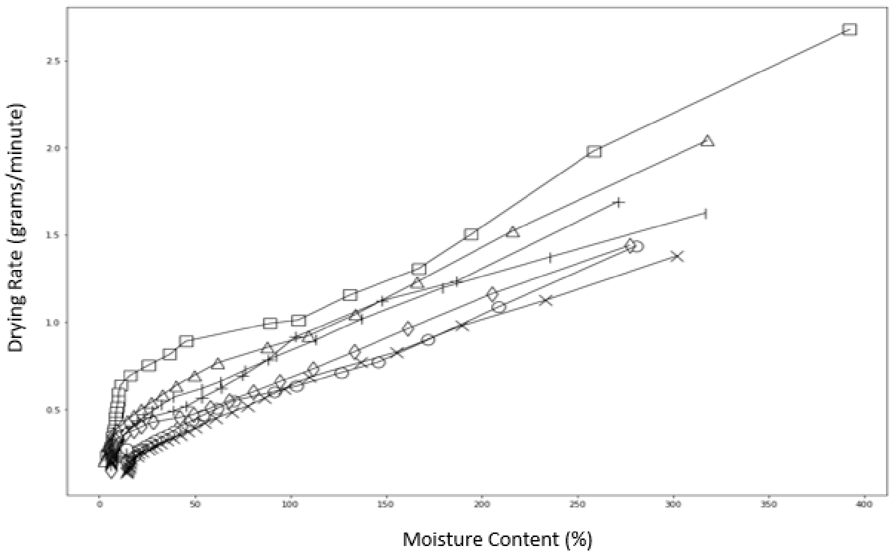

Figure 2. Drying rate of chips with a drying temperature of 55 ºC

Model-based analysis can also clarify why some treatments show a high initial rate but higher residual moisture (e.g., F1/F2). Under severe blanching, early-stage permeability improves; however, rapid crust formation or structural collapse can elevate internal resistance, shortening the constant-rate period and steepening the subsequent decline in drying rate [6,7,13]. Thin-layer model fits typically capture this behavior through higher empirical exponents in the Page model or larger shape parameters in logarithmic forms [7],[8]. Reporting these fitted parameters alongside confidence intervals would help translate the qualitative "faster at 65 °C" observation into design-ready coefficients for dryer simulation and scale-up [3],[5],[8].

From a heat-and-mass-transfer perspective, the superiority of 65 °C reflects a stronger driving force for both sensible heating and moisture removal, but the optimality is conditional on product quality endpoints. Literature on onions, corn, sorghum, garlic, rice, and malt consistently shows that raising air temperature elevates the rate constant yet can exacerbate quality penalties if not counterbalanced by air velocity or humidity control [5],[6],[8],[9],[15]. Hence, the present results support using 65 °C with mild blanching as a baseline, while leaving room to fine-tune air velocity and relative humidity to prolong the constant-rate period and delay diffusion control [3],[6],[7].

3.3. Effect of drying on shrinkage

Evaporation during drying reduces moisture and induces shrinkage, as pore and cellular structures evolve; the extent depends on process conditions (temperature, humidity, rate) and product moisture status [13],[14]. Greater water removal generally increases shrinkage because voids formerly occupied by water coalesce and the surface contracts inward, reducing volume and surface area [13],[14]. In this study, shrinkage was quantified directly from the change in sample volume. Blanching increased the initial volume (swelling) via water uptake and starch gelatinization at certain conditions—especially at 80 °C for 30 min—followed by more pronounced volume loss during drying. The literature also notes that excessively fast drying can generate internal stress, non-uniform contraction, deformation, increased hardness, and even cracking, degrading quality [13],[14]. Although shrinkage can be logistically beneficial (smaller volume/weight), texture trade-offs must be managed by tuning temperature, duration, and pretreatments to balance throughput and product quality [13],[14]. Our results—largest shrinkage with the most intense blanching (80 °C, 30 min) and smallest with no blanching—agree with comprehensive reviews on shrinkage behavior and its modeling in food drying [13],[14].

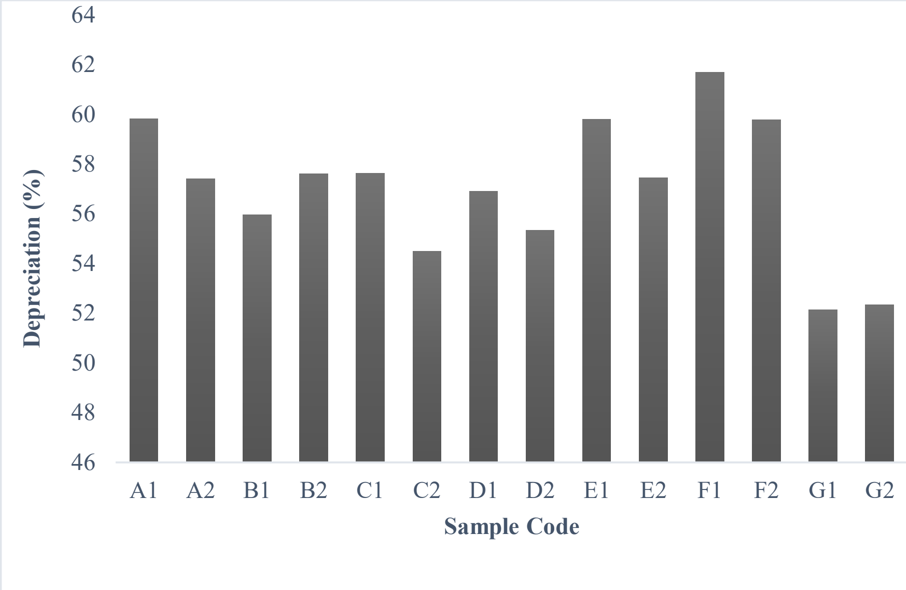

Figure 3. Percentage of material shrinkage after the drying process

Shrinkage is not merely a geometric side effect; it couples back into drying by altering porosity, tortuosity, and specific surface area, thereby changing Deff in real time [13],[14]. Ignoring shrinkage can bias kinetic parameters and lead to under- or over-design of dryer residence times. Contemporary shrinkage models incorporate volume reduction into moisture-ratio equations or link dimensional change to local moisture content using polynomial or mechanistic relationships [13]. Embedding such a shrinkage term in the thin-layer fit would likely improve the description of the late-stage data for the most intense blanching treatments.

Practically, the trade-off is clear: shrinkage lowers volume and mass—useful for packaging and logistics—but excessive shrinkage can harden texture, promote cracking, and reduce consumer acceptance [13],[14]. The present results suggest a processing window that balances throughput and quality: choose mild blanching (40 °C, 15 min) and the higher air temperature (65 °C), then mitigate shrinkage via secondary levers such as moderating air humidity in early stages, employing staged temperatures, or shortening blanching time at higher blanching temperatures [3],[6],[13],[14]. These adjustments align with reported strategies to preserve structure while maintaining favorable kinetics across diverse food matrices.

3.4. Limitations and future work

This study focused on two air temperatures and discrete blanching conditions; intermediate settings (e.g., 70 °C drying or shorter high-temperature blanching) and coupled air-velocity/humidity effects warrant exploration [3],[6],[7]. Future work should (i) estimate Deff and activation energy to generalize findings across equipment and scales [6],[7],[9], (ii) fit multiple thin-layer models with and without a shrinkage term to quantify structure–kinetics coupling [7]–[9],14], and (iii) evaluate texture and color metrics to map engineering variables onto sensory quality targets, particularly for snack-type chips [10],[11],[12]. Such extensions would convert the present treatment rankings into transferable design parameters for industrial dryers.

These findings are also consistent with the food-drying literature, in that understanding thin-layer drying curves and employing computational modeling play key roles in optimizing energy efficiency while preserving product quality. Thin-layer curve models facilitate the estimation of kinetic parameters, whereas computational approaches support the design of more controlled and sustainable low-carbon drying processes [17],[18],[19].

4. Conclusion

This study shows that drying temperature and blanching regime jointly shape moisture removal and product dimensions in breadfruit chips. At 55 °C, equilibrium moisture content (EMC) was 6.94–17.03% with 840–1290 min to reach EMC, whereas at 65 °C, EMC was 4.326–14.57% with 810–1050 min. Thus, higher temperature reduced EMC and shortened drying time. Across temperatures, blanching at 40 °C for 15 min yielded the lowest EMC (6.94% at 55 °C; 4.33% at 65 °C), while blanching at 80 °C for 30 min produced the highest EMC (17.03% at 55 °C; 14.57% at 65 °C). The drying rate followed the same trend: it was highest after blanching at 40 °C for 15 min and lowest with either no blanching or blanching at 80 °C for 30 min, depending on temperature. Shrinkage also peaked with 40 °C/15 min blanching and was lowest with 55 °C/80

°C/30 min blanching and 65 °C without blanching. Shrinkage reduces volume and eases handling and packaging, but excessive shrinkage compromises texture; therefore, processors must balance these trade-offs. Blanching increased the initial moisture content by ~70–80% relative to unblanched samples, likely due to water uptake and starch gelatinization. Overall, elevating drying temperature accelerates dehydration and lowers EMC, and mild blanching (40 °C, 15 min) maximizes drying rate but also increases shrinkage.

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