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# Effects of soaking and thermal treatment on nutritional quality of three varieties of common beans (*Phaseolus vulgaris L.*) from Madagascar

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## Abstract
The aim of this study was to evaluate the effects of soaking and thermal treatment on proteins, anthocyanins, α-galactosides (stachyose, raffinose), tannins and inositol hexaphosphate (IP6), under different conditions, of three *Phaseolus vulgaris L.* varieties from Madagascar; and evaluate correlation with surface/volume ratio. Overall, dry matter, antinutrients and anthocyanins were impacted by the process, however proteins were not. Depending on varieties and operating conditions, soaking or thermal treatment led to up to 59% losses for dry matter, 73% for tannins, 99% for IP6, 92% for total α-galactosides and 100% for anthocyanins. In certain cases, the process increased dry basis concentration of α-galactosides probably through hydrolysis phenomena from precursors. A positive correlation between the surface/volume ratio of common beans and decrease of tannins and α–galactosides was highlighted. A global antinutritional indicator was used along with the dry matter to evaluate the best conditions to subside all antinutrients and limit the loss of nutrients, combining soaking and thermal treatment. These conditions were soaking (30°C) for 1 h followed by heat treatment at 65°C with 1/5 seed-to-water ratio during 2 h. Appropriate soaking/thermal treatment of common dry bean is crucial to reduce antinutrients and limit nutrient loss.

## Novelty Impact Statement
Common bean (*Phaseolus vulgaris L.*) contains antinutrients and oligosaccharides which causes digestive discomfort. Suitable soaking and thermal treatments reduce these compounds and limit the loss of nutrients. As a final product, a common bean partially free of negative compounds could help in processing common beans and be employed as an ingredient in derived product.

KEYWORDS
geometrical properties, nutritional quality, Soaking, thermal treatment

## 1 | INTRODUCTION

Common beans (*P. vulgaris L.*) alone account for some of the most important varieties of legumes with almost 40% of the world production (Food and Agriculture Organization of the United Nations, 2016). The consumption of dried common beans varies greatly according to the cultural and dietary habits of different countries. Canned common beans are the most consumed, but they can also be cooked in the form of puree or prepared as cassoulet (Schneider & Huyghe, 2015). Common dry beans are also less expensive than animal food products and, when stored properly, have considerably longer shelf life. On a nutritional aspect, common beans are rich sources of carbohydrates, proteins, minerals, fiber, antioxidants and vitamins (Abbas & Ahmad, 2018; Parca et al., 2018). Some studies have shown that a diet high in common beans can potentially prevent cardiovascular disease, reduce the risk of developing inflammatory bowel disease and cancer (Chen et al., 2017; Ngoh et al., 2017). Red varieties are also great sources of anthocyanins, which are believed to have health benefits such as antidiabetic, anticancer and anticardiovascular properties due to their strong antioxidant activity (Mojica et al., 2017). In Madagascar, legumes are mainly produced in the highlands, the midlands and the southwest, which focus on the cultivation of common beans (*P. vulgaris*), unshelled peanuts (*Arachis hypogaea*) and black-eyed peas (*Vigna unguiculata*) (Food and Agriculture Organization of the United Nations, 2019). However, one of the specific problems with most legumes is related to the presence of antinutrients that limit their consumption (Abbas & Ahmad, 2018; Samtiya et al., 2020). These components include enzyme inhibitors, inositol hexaphosphate (IP6), tannins, lectins and α-galactosides. These antinutrients limit the nutritional properties and affect the digestibility of nutrients. Different processing techniques such as soaking, cooking or germinating are used to minimize their contents and remove heat sensitive antinutrients in the seeds (Howard et al., 2018). Shimelis and Rakshit (2007) revealed that overnight hydration of kidney common beans has resulted significant reduction in the levels of α-galactosides (40%–48%), tannins (23%–25%) and phytic acid (17%–19%). Wang et al. (2010) found out that cooking significantly reduced tannins and oligosaccharides (raffinose, stachyose and verbascose) and had no effect on IP6 contents in common beans. Coffigniez, Briffaz, Mestres, Altera, et al. (2018) found that after cooking cowpea at 95°C for 3 h, verbascose, stachyose and raffinose concentrations in seeds were reduced by 69%, 61% and 63%, respectively.

The aim of this study was to assess the effect of soaking and thermal treatment on proteins, anthocyanins, antinutrients (tannins, IP6) and intestinal gas production factors (α-galactosides) of three dry common bean varieties under various temperatures (30°C, 65°C and 100°C), seed-to-water ratios (1/1, 1/5 and 1/10) and times (1 h, 2 h and 10 h) conditions. The choice of antinutrients was based on the fact that they affect the nutritional quality of common beans and cause high digestive discomfort. These tests could help figure out how to preserve the quality and reduce the maximum amount of antinutrients. It was suggested that the soaking and thermal treatment set-up could help in processing common beans.

## 2 | MATERIALS AND METHODS

### 2.1 | Materials

Three dry common bean (*P. vulgaris L.*) varieties provided by the National Center for Rural Research Applied to Rural Development in Antananarivo were studied (Table 1). Of all varieties available, the white variety (RI 52) is the most consumed by the population and contains the highest IP6; the marbled variety (CAL 98) is rich in phenolic compounds; and the red variety (DRKF) contains a high level of proteins. The diversity of colors between these varieties is also interesting with regard to the study of the anthocyanins behavior during process. Samples of each variety were stored in plastic bags (4 kg), at room temperature, protected from humidity for 3 months until use.

### 2.2 | Soaking and thermal treatments

Prior to treatment, the seeds were hand-sorted to remove wrinkled, damaged seeds and foreign elements. A fraction of the untreated seeds was ground directly for determination of the compounds, whereas changes in the compounds studied were assessed through soaking and thermal treatment. Seeds were prepared in 20 different ways for each variety, and a sample of about 100 seeds of dry common bean was taken for each treatment. Operating conditions were chosen according to usual practices and literature data, for example, Nakitto et al. (2015) and Shi et al. (2018). The details of preparation are given below.

#### 2.2.1 | Soaking

Common beans were soaked in distilled water at 30°C (average ambient temperature) during 1, 2 and 10 h with three seed-to-water mass ratios: 1/1, 1/5 and 1/10 for each duration. The soaked seeds were drained and dried at 40°C for 3 days and finally ground with a lab mill (Perten mill 3100, USA) to a grain size of 500 μm.

#### 2.2.2 | Thermal treatment

Common beans were directly heated at 65°C (hot water) and 100°C (boiling water) during 1 and 2 h with 1/1, 1/5 and 1/10 seed-to-water mass ratios for each temperature and duration except with 1/1 ratio at 100°C (common beans were only treated during 1 h, the water was no longer sufficient). Seeds were introduced in a covered pot filled with pre-heated distilled water which was then placed in a thermostated water-bath. The temperature of water was checked with a thermometer before the immersion of seeds in the pre-heated distilled water and then was maintained thanks to the water-bath. After heating, the seeds were immediately placed in an ice cube tray to stop any chemical reaction. The treated common beans were

**TABLE 1** Morphological and agricultural characteristics of the three common bean varieties

| RI 52<br>Ranjon'omby<br>1 FOFIFA RI 52 snap bean | CAL 98<br>Vangamena<br>FOFIFA CAL 98 | DRKF<br>Ran'omby<br>3 FOFIFA DRKF |
|---|---|---|
|  |  |  |
| **Commercial class:** Large white<br>**Origin:** Generation F5, resulting from the cross line of the local variety Ranjonomby with the black variety Ikinimba (from Rwanda) and other parents with interesting characteristics.<br>**Agricultural characteristics:** Hulling yield: 72%; Vegetative cycle: 75–80 days (early); Yield: 1200–1600 kg·ha$^{-1}$.<br>Tolerant to rust, anthracnose, angular spot. Scale: 4–6.<br>Plastic variety that can adapt to agro-climatic zones from 800 to 1200 mm rainfall and from 400 to 1400 m altitude. An abundant rain at the maturation stage can however affect the seeds quality. | **Commercial class:** Speckled red<br>**Commercial class:** Speckled red<br>**Origin:** Tanzania.<br>**Agricultural characteristics:** Hulling yield: 74%; Vegetative cycle: 90 days; Yield: 1500–2200 kg·ha$^{-1}$ (Baiboho of Miandrivazo).<br>Tolerant to anthracnose, rust, angular spot.<br>Adaptation area, altitude: 400 to 1200 m; Abundant rain at the maturation stage can affect the seeds quality. | **Commercial class:** Dark red<br>**Commercial class:** Dark red<br>**Origin**: Local prospection.<br>**Agricultural characteristics**: Hulling yield: 75%; Vegetative cycle: 82–85 days; Yield: 1500–2000 kg·ha$^{-1}$.<br>Tolerant to anthracnose, rust, angular spot.<br>Healthy crop, productive in various agro-ecological areas. |

drained and dried at 40°C for 3 days and finally ground with a lab mill (Perten 3100, USA) equipped with a stainless sieve of 500 μm.

Dry matter was measured after each experimental condition (for each ratio, duration and temperature) to assess the loss of compounds in the seed.

## 2.3 | Physical properties of seeds

Randomly selected seeds were used to measure length (L), width (W) and thickness (T) by a Vernier calliper reading to 0.1 mm. Average of 100 determinations was reported (Wani et al., 2017).

The surface area S and the volume V of the seeds were evaluated according to the Equations 1 and 2 (Buzera et al., 2018). They are used to calculate the ratio S/V.

$$S = \frac{\pi L2(WT)^{1/2}}{2L-(WT)^{1/2}} \quad (1)$$

$$V = \frac{\pi WTL2}{6(2L-3)} \quad (2)$$

The seed weight of each variety was assessed by weighing 100 seeds using a balance with 0.01 mg accuracy.

## 2.4 | Chemical analysis

All analyses were determined in triplicate in accordance with the AFNOR standards and presented in dry matter percent (except for dry matter results themselves).

### 2.4.1 | Proximate composition

Dry matter was obtained gravimetrically after drying the sample at 103°C for 24 h (AFNOR, 1989).

Proteins were determined with the Kjeldahl method (AFNOR, 1993).

Fats were extracted during 6 h with petroleum ether using a Soxhlet device (AFNOR, 1993). Ashes were obtained gravimetrically after incineration of the sample at 550°C for approximately 7 h (AFNOR, 1993).

Total carbohydrates were calculated by difference (100 minus percentage, proteins, fats and ashes). The starch content was determined by the polarimetric method.

#### 2.4.2 | Anthocyanins

Anthocyanins were determined by pH differential method. For the extraction, the method from Chun et al. (2013) was used with some modifications. About 500 mg of ground common bean sample was extracted with 1 ml of formic acid 5% for 20 min using ultrasonically assisted extraction. The mixture was centrifuged at 9200× *g* for 15 min, and the extract was recovered in a tube. Three extractions were performed and then mixed. For the quantification, the method developed by Çam et al. (2009) was used with two buffer systems: potassium chloride buffer, pH 1.0 (0.025 M) and sodium acetate buffer, pH 4.5 (0.4 M). For this, 0.4 ml of the extract was mixed with 3.6 ml of each buffer and read against water as a blank at 510 and 700 nm with a UV–visible spectrophotometer DU-64 (Beckman coulter, California, USA). Anthocyanins absorbance was calculated as $A = [(A_{510nm} - A_{700nm})$ at pH 1.0] $- [(A_{510nm} - A_{700nm})$ at pH 4.5], and the total anthocyanins content was expressed in % w/w cyanidin-3-glucoside (MW = 485 g $mol^{-1}$) using an extinction coefficient of 25.74 L $mol^{-1}$ $cm^{-1}$.

#### 2.4.3 | α-galactosides

According to the literature, *P. vulgaris* is essentially constituted of raffinose and stachyose. In this study, analyses were based on these two compounds. They were extracted from common bean sample by the method described by Sanchez-Mata et al. (1998). To about 250 mg of ground common beans flour in a 50 ml polyethylene centrifuge tube, 12 ml of 80% ethanol/water (v/v) were added and mixed using a vortex and placed in a water-bath at 55°C for 45 min shaking with vortex each 10 min. The mixture was then centrifuged at 1900× *g* for 30 min at 15°C, and the supernatant was transferred to another 50 ml polyethylene tube collector. With the sample residue in the first centrifuge tube, 12 ml of 80% ethanol/water (v/v) was added, and the extraction was repeated as previously described. Three extractions were necessary to extract all the α-galactosides in the sample. After homogenizing, the extract was filtered using a 0.45 μm pore size filter. Alpha-galactosides were then determined by high performance liquid chromatography with Corona detector (Dionex, Sunnyvale, USA) which is a charged aerosol detector (CAD). HPLC Ultimate 3000 (Dionex, Sunnyvale, USA) was used with analytical column sugar SH 1011 300 × 8 mm × 5 μm (Shodex, Tokyo, Japan). The mobile phase was acetonitrile/water (70/30). The flow rate was 1.2 ml $min^{-1}$. The temperature was 30°C. Raffinose, stachyose were quantified using a calibration curve with 10-point concentrations ranging from 2 to 1000 mg $L^{-1}$ with external standards. Alpha-galactosides were quantified by comparison with the standard and expressed as % w/w dry matter.

#### 2.4.4 | Tannins

Analyses were based on determination of condensed tannins (proanthocyanidins) which have the property of forming complexes with proteins. They were assayed according to the modified method of Porter et al. (1985). Condensed tannins were hydrolyzed in the presence of hot HCl and iron sulphate. For the extraction, approximately 50 mg of sample was put into a glass tube, and 6 ml of Butanol/HCl (95/5) and 200 μl of ferric ammonium sulphate solution at 2% w/v in HCl 2 M were then added. The mixture was vortexed and heated in a 95°C bath for 45 min and centrifuged at 4025× *g* for 5 min at 4°C. The intermediate units were then converted, after autoxidation and cleavage of interflavonoid bonds, into colored (red) anthocyanidins and read at 550 nm with a UV–visible spectrophotometer DU-64 (Beckman coulter, California, USA). The tannins content in sample was deduced from a 5-point tannin calibration curve with concentrations ranging from 0.6 to 6.4 mg $ml^{-1}$, and the results were expressed as % w/w dry matter.

#### 2.4.5 | IP6

IP6 was extracted by the modified method of Talamond et al. (1998). About 100 mg of flour was mixed with 5 ml of 0.5 M HCl in a vortex screw tube and stirred magnetically. The mixture was then boiled for 6 min and cooled down on ice to stop reaction. A volume of 4 ml of 0.5 M NaOH and 1 ml of ultrapure water was added (pH at 6.5) and vortexed. The mixture was ultrasonicated for 5 min and 1.5 ml was transferred to an Eppendorf vial and centrifuged. The supernatant was then filtered using a 0.45 μm pore size filter and put into a vial. The samples were passed through an Ion Pac AS11-AC anion exchange column 4 × 250 mm (Dionex, Sunnyvale, USA) with an Ion Pac AG11-HC pre-column (4 × 50 mm) and an ion suppressor (AERS 500 4 mm). The flow rate was 1 ml $min^{-1}$. Separation was performed by an elution gradient of NaOH and water: 0–10 min: 35 mM, 11 min: 100 mM, 12–19 min: 35 mM and 20 min: 20 mM. Only IP6, majority form of phytates was quantified, and results were expressed in g IP6 per 100 g of dry matter.

### 2.5 | Optimal soaking/thermal treatment combinations

For both unit operations (soaking and thermal treatment), the ratios between the final and initial contents of each compound $C/C_0$ were chosen. This method allowed to overcome variations in initial contents and so to facilitate comparisons between the different common bean varieties. Moreover, it allowed to easily calculate the decrease of the antinutritional compound concentrations when results of the different soaking and thermal treatment combinations obtained from results were used, considering the two successive unit operations as independent (multiplication of soaking and thermal treatment $C/C_0$).

In order to get an itinerary giving the lowest levels of α-galactosides, tannins and IP6 at the same time, we defined a global antinutritional indicator ANI (Equation 3). It combined in only one value the main antinutrients in the common beans. In a nutritional point of view, it must be minimized during the process.

$$ANI = \sqrt{(\alpha - galactosides)^2 + (tannins)^2 + (phytates)^2} \qquad (3)$$

## 2.6 | Statistical analysis

Each sample was analyzed in triplicate, and values were then averaged. When distributions were normal and variances could be considered as homogeneous, the averages from different treatments were compared by analysis of variance (ANOVA) using Tukey test at a significance level of 0.05. In some cases of non-normality of the distributions or non-homogeneity of the variances the medians were compared using the non-parametric Kruskal–Wallis test at a significance level of 0.05. Pearson's correlation coefficients of properties of seeds were carried out to establish relationship between variables. Statistical analyses were realized with XLStat version 2014.5.03 (Addinsoft, Paris, France).

# 3 | RESULTS

## 3.1 | Proximate composition

Composition on nutrients, antinutrients and geometrical properties in raw seeds of the three common bean varieties (RI 52, CAL 98 and DRKF) is presented in Table 2.

RI 52, CAL 98 and DRKF resulted in a variability of raw seeds composition. RI 52 had significantly the lowest dry matter. Proteins content did not vary significantly among RI 52 and DRKF, CAL 98 had significantly the lower proteins content. Fat contents for all varieties were generally low. Ashes were the same for all varieties. The highest carbohydrates content was reported for RI 52. The anthocyanins content of CAL 98 was significantly higher than that of DRKF. For

**TABLE 2** Composition and geometrical properties of the seeds of the three common bean varieties

| Parameter | | RI 52 (white) | CAL 98 (marbled) | DRKF (red) |
|---|---|---|---|---|
| *Nutrients composition* | | | | |
| Dry matter (%) | | 87.86 ± 0.08$^b$ | 89.24 ± 0.10$^a$ | 89.29 ± 0.12$^a$ |
| Proteins (%) | | 22.01 ± 0.05$^a$ | 20.31 ± 0.19$^b$ | 22.31 ± 0.25$^a$ |
| Fat (%) | | 1.44 ± 0.04$^a$ | 1.67 ± 0.10$^a$ | 1.79 ± 0.04$^a$ |
| Ash (%) | | 4.75 ± 0.07$^a$ | 4.65 ± 0.13$^{ab}$ | 4.49 ± 0.03$^b$ |
| Carbohydrates (%) | | 71.80 ± 0.12$^b$ | 73.37 ± 0.13$^a$ | 71.42 ± 0.24$^b$ |
| Starch (%) | | 47.86 ± 1.22 $^a$ | 47.46 ± 0.71$^a$ | 38.86 ± 0.02$^b$ |
| Anthocyanins (%) | | 0.00$^c$ | 7.49 ± 0,23$^a$ | 2.19 ± 0.16$^b$ |
| *Antinutrients composition* | | | | |
| α-galactosides (%) | Raffinose | 0.59 ± 0.03$^b$ | 0.86 ± 0.03$^a$ | 0.55 ± 0.04$^b$ |
| | Stachyose | 2.28 ± 0.06$^c$ | 4.65 ± 0.15$^a$ | 3.37 ± 0.04$^b$ |
| | Total | 2.87 ± 0.09$^c$ | 5.51 ± 0.18$^a$ | 3.92 ± 0.08$^b$ |
| Tannins (%) | | 0.52 ± 0.04$^b$ | 0.63 ± 0.04$^a$ | 0.60 ± 0.03$^{ab}$ |
| IP6 (%) | | 2.09 ± 0.08$^a$ | 0.87 ± 0.08$^b$ | 1.89 ± 0.15$^a$ |
| ANI | | 3,59 | 5,61 | 4,39 |
| *Geometrical properties of seeds* | | | | |
| Length (mm) | | 14.9 ± 1.0$^c$ | 15.4 ± 1.8$^b$ | 16.3 ± 0.9$^a$ |
| Width (mm) | | 7.0 ± 0.4$^b$ | 7.8 ± 0.5$^a$ | 7.9 ± 0.4$^a$ |
| Thickness (mm) | | 5.8 ± 0.4$^b$ | 6.2 ± 0.5$^a$ | 6.2 ± 0.5$^a$ |
| Surface S (mm$^2$) | | 333.5 ± 82.2$^c$ | 416.3 ± 132.4$^b$ | 485.1 ± 100.2$^a$ |
| Volume V (mm$^3$) | | 128.4 ± 38.4$^c$ | 177.1 ± 66.9$^b$ | 207.9 ± 52.8$^a$ |
| Ratio S/V (mm$^{-1}$) | | 2.60 ± 0.16$^a$ | 2.40 ± 0.17$^b$ | 2.40 ± 0.14$^b$ |
| 100 seeds mass (g) | | 44.92 ± 1.09$^c$ | 54.57 ± 0.47$^b$ | 57.48 ± 0.99$^a$ |

*Note*: Mean values ± standard deviation of triplicate determinations of nutrients and antinutrients composition. Mean values ± standard deviation of 100 determinations of geometrical properties. All results presented as dry weight basis. Values in the same line with the same letter are not significantly different at $p \leq 0.05$.

antinutrients, α-galactosides were significantly different for all varieties. CAL 98 had the highest content whereas RI 52 had the lowest content. All varieties contain similar quantity of tannins. IP6 were similar except with CAL 98 which had the lowest content.

About seed size, CAL 98 and DRKF had the same width, thickness and S/V ratio whereas surface, volume and 100 seeds weight were significantly different for all varieties.

The proximate composition of the three common bean varieties differed from one variety to another. RI 52 contained the lowest amount of dry matter, had low α-galactosides and the highest carbohydrates and IP6. CAL 98 contained the lower amount of proteins, was richest in anthocyanins, in terms of antinutrients, it was richest in α-galactosides but had the lowest IP6. DRKF was between the two varieties.

## 3.2 | Effects of soaking on composition

The influence of soaking on the levels of dry matter, proteins, anthocyanins, α-galactosides, tannins and IP6 on three *P. vulgaris L.* varieties were studied.

### 3.2.1 | Effects of soaking on dry matter

Dry matter was affected by soaking (Table 3). It decreased significantly after 10 h of soaking for CAL 98 with all seed-to-water ratios. For RI 52, it was reduced significantly after 2 h of soaking with a 1/10 ratio. For DRKF, significant losses were observed after 2 h of soaking with all ratios.

### 3.2.2 | Effects of soaking on proteins

Soaking seeds under different conditions did not significantly affect proteins contents for any varieties (Table S1).

### 3.2.3 | Effects of soaking on anthocyanins

The evolution of anthocyanins for colored varieties (CAL 98 and DRKF) during soaking is presented in Table 4. Leaching of anthocyanins in the soaking water was observed for all varieties regardless of the seed-to-water ratio. Maximum decrease was observed after 10 h of soaking. Short-time soaking with high seed-to-water ratio was necessary to avoid anthocyanins reduction.

### 3.2.4 | Effects of soaking on α-galactosides

The concentrations of α-galactosides in the samples have been affected by soaking as shown in Figure 1. During the first 2 h, in most cases concentration rates of $C/C_0 > 1$ for raffinose and $C/C_0 < 1$ for stachyose with RI 52 and CAL 98 are observed. For RI 52, soaking for 2 h resulted in a −5% to −58% content reduction of the α-galactosides compared with a −80% to −87% reduction for 10 h; for CAL98, the α-galactosides content dwindled from −11% to −49% in 2 h and from −61% to −74% in 10 h. The DRKF presented different trends, in some cases concentrations of $C/C_0 > 3$ for raffinose and in most cases concentrations of $C/C_0 > 1$ for stachyose.

In this study, in order to remove maximum of total α-galactosides, soaking seeds with 1/5 ratio for 10 h was necessary for all varieties: loss of 87% for RI 52, 74% for CAL 98 and 61% for DRKF.

### 3.2.5 | Effects of soaking on tannins

The evolution of tannins from the experimental plan is shown in Table 4 for the three varieties.

Soaking seeds for 2 h did not result in a significant loss of tannins overall. Significant reduction was observed after 10 h with high seed-to-water ratio except for CAL 98 where no significant decrease was noted under any soaking conditions. The most important loss was observed with RI 52.

**TABLE 3** Influence of soaking at 30°C, under various seed-to-water ratios (1/1, 1/5 and 1/10) and times (1, 2 and 10 h) conditions, on the ratio between the final and initial dry matter ($C/C_0$) of the three common bean varieties

| Seed ratio | Duration | RI 52 (white) | CAL 98 (marbled) | DRKF (red) |
|---|---|---|---|---|
| 1/1 | 1 h | $0.67 \pm 0.04^{b}$ | $0.94 \pm 0.00^{a}$ | $0.78 \pm 0.00^{a}$ |
| | 2 h | $0.65 \pm 0.02^{bc}$ | $0,78 \pm 0.01^{ab}$ | $0.64 \pm 0.00^{b}$ |
| | 10 h | $0,65 \pm 0.03^{bc}$ | $0.57 \pm 0.03^{cd}$ | $0.61 \pm 0.00^{bcd}$ |
| 1/5 | 1 h | $0.57 \pm 0.02^{cd}$ | $0.80 \pm 0.02^{ab}$ | $0.63 \pm 0.01^{bc}$ |
| | 2 h | $0.53 \pm 0.01^{d}$ | $0.71 \pm 0.13^{bc}$ | $0.56 \pm 0.03^{de}$ |
| | 10 h | $0.54 \pm 0.00^{d}$ | $0.50 \pm 0.00$ | $0.51 \pm 0.02^{ef}$ |
| 1/10 | 1 h | $0.85 \pm 0.03^{a}$ | $0.82 \pm 0.03^{ab}$ | $0.79 \pm 0.01^{a}$ |
| | 2 h | $0.55 \pm 0.00^{d}$ | $0.74 \pm 0.06^{bc}$ | $0.59 \pm 0.02^{cd}$ |
| | 10 h | $0.54 \pm 0.01^{d}$ | $0.49 \pm 0.02^{d}$ | $0.50 \pm 0.01^{f}$ |

*Notes*: Mean values ± standard deviation of triplicate determinations. All results presented as dry weight basis. Values in the same column with the same letter are not significantly different at $p \le 0.05$.

**TABLE 4** Influence of soaking at 30°C, under various seed-to-water ratios (1/1, 1/5 and 1/10) and time (1, 2 and 10 h) conditions, on the ratio between the final and initial anthocyanins, tannins and IP6 concentrations ($C/C_0$) of the three common bean varieties

| Seed ratio | Duration | RI 52 (white) | CAL 98 (marbled) | DRKF (red) |
|---|---|---|---|---|
| *Anthocyanins* | | | | |
| 1/1 | 1 h | | 0.58 ± 0.04[c] | 0.97 ± 0.15[a] |
| | 2 h | | 0.58 ± 0.05[c] | 0.63 ± 0.08[cd] |
| | 10 h | | 0.47 ± 0.04[c] | 0.55 ± 0.09[d] |
| 1/5 | 1 h | | 0.79 ± 0.10[b] | 0.94 ± 0.10[ab] |
| | 2 h | | 0.76 ± 0.09[ab] | 0.73 ± 0.12[cd] |
| | 10 h | | 0.26 ± 0.02[d] | 0.56 ± 0.07[d] |
| 1/10 | 1 h | | 0.94 ± 0.07[a] | 0.99 ± 0.09[a] |
| | 2 h | | 0.70 ± 0.07[b] | 0.77 ± 0.12[bc] |
| | 10 h | | 0.55 ± 0.02[c] | 0.76 ± 0.12[bc] |
| *Tannins* | | | | |
| 1/1 | 1 h | 0.75 ± 0.10[cd] | 0.94 ± 0.14[abc] | 1.02 ± 0.12[a] |
| | 2 h | 0.85 ± 0.14[abc] | 0.97 ± 0.12[ab] | 0.92 ± 0.11[ab] |
| | 10 h | 0.94 ± 0.09[a] | 0.89 ± 0.14[abc] | 0.78 ± 0.06[bcd] |
| 1/5 | 1 h | 0.54 ± 0.10[e] | 0.86 ± 0.10[abcd] | 0.88 ± 0.06[ab] |
| | 2 h | 0.52 ± 00.06[ef] | 0.78 ± 0.13[bcde] | 0.87 ± 0.08[ab] |
| | 10 h | 0.27 ± 0.04[g] | 0.68 ± 0.08[def] | 0.67 ± 0.07[cde] |
| 1/10 | 1 h | 0.60 ± 0.10[de] | 0.97 ± 0.12[ab] | 0.88 ± 0.09[ab] |
| | 2 h | 0.46 ± 0.07[ef] | 0.95 ± 0.09[abc] | 0.67 ± 0.07[cde] |
| | 10 h | 0.29 ± 0.04[g] | 0.87 ± 0.07[abcd] | 0.65 ± 0.05[de] |
| *IP6* | | | | |
| 1/1 | 1 h | 0.15 ± 0.01[d] | 0.13 ± 0.01[f] | 0.03 ± 0.00[f] |
| | 2 h | 0.11 ± 0.01[de] | 1.13 ± 0.17[abc] | 0.72 ± 0.06[bc] |
| | 10 h | 0.70 ± 0.09[b] | 0.17 ± 0.02[f] | 0.19 ± 0.04[f] |
| 1/5 | 1 h | 0.68 ± 0.03[b] | 1.13 ± 0.16[bc] | 0.63 ± 0.07[cd] |
| | 2 h | 0.78 ± 0.06[b] | 0.98 ± 0.15[cd] | 0.85 ± 0.10[ab] |
| | 10 h | 0.03 ± 0.00[de] | 0.83 ± 0.15[de] | 0.61 ± 0.08[cd] |
| 1/10 | 1 h | 0.64 ± 0.06[b] | 1.33 ± 0.24[a] | 0.04 ± 0.00[f] |
| | 2 h | 0.01 ± 0.00[e] | 1.23 ± 0.15[ab] | 0.01 ± 0.00[f] |
| | 10 h | 0.07 ± 0.00[de] | 0.90 ± 0.13[cde] | 0.65 ± 0.12[cd] |

*Note*: Mean values ± standard deviation of triplicate determinations. All results presented as dry weight basis. Values in the same column with the same letter are not significantly different at $p \leq 0.05$.

In this study to decrease the maximum of tannins, soaking seeds during 10 h with high seed-to-water ratio was necessary with all varieties.

Maximizing the reduction of IP6 required the seeds to be soaked for 2 h with high seed-to-water ratio for RI 52 (99%) and DRKF (99%), and for 1 h with a limited seed-to-water ratio for CAL 98 (87.13%).

### 3.2.6 | Effects of soaking on IP6

The changes occurred on IP6 are shown in Table 4. Soaking significantly reduced IP6 of all varieties but no clear trend was detected. Seeds with the longest soaking times did not present the highest reduction. Increase with CAL 98 was observed with all seed-to-water ratios in 2 h of soaking, albeit this variety was the least affected. In this study, IP6 of white and red varieties were almost removed.

## 3.3 | Effects of thermal treatment on composition

### 3.3.1 | Effects of thermal treatment on dry matter

Thermal treatment affects the quantity of dry matter as shown in Table 5. Approximately 50% of the dry matter was removed during thermal treatment for all varieties. A significant reduction was obtained with high seed-to-water ratio.

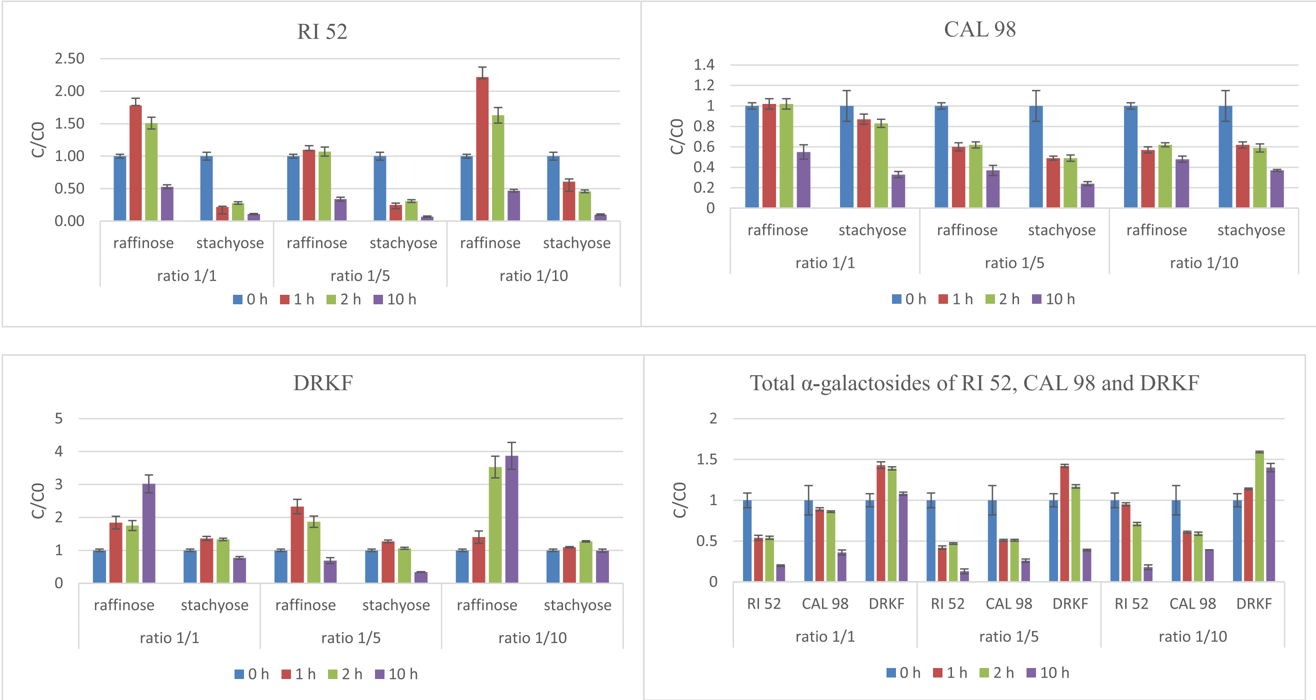


**FIGURE 1** Influence of soaking at 30°C, under various seed-to-water ratios (1/1, 1/5 and 1/10) and times (1, 2 and 10 h) conditions, on the ratio between the final and initial raffinose, stachyose and α-galactosides concentrations ($C/C_0$) of RI 52 (white variety), CAL 98 (marbled variety) and DRKF (red variety). Mean values ± standard deviation, triplicate determinations. Results are presented as dry weight basis

**TABLE 5** Influence of thermal treatment, under various temperatures (65 and 100°C), seed-to-water ratios (1/1, 1/5 and 1/10) and times (1 and 2 h) conditions, on the ratio between the final and initial dry matter ($C/C_0$) of the three common bean varieties

| Temperatures | Seed ratio | Duration | RI 52 (white) | CAL 98 (marbled) | DRKF (red) |
|---|---|---|---|---|---|
| 65°C | 1/1 | 1 h | 0.56 ± 0.01[b] | 0.55 ± 0.04[a] | 0.54 ± 0.01[a] |
| | | 2 h | 0.55 ± 0.01[bc] | 0.53 ± 0.01[ab] | 0.54 ± 0.02[a] |
| | 1/5 | 1 h | 0.48 ± 0.03[de] | 0.46 ± 0.01[cde] | 0.46 ± 0.01[cd] |
| | | 2 h | 0,47 ± 0.01[de] | 0.44 ± 0.00[e] | 0.45 ± 0.00[cd] |
| | 1/10 | 1 h | 0.46 ± 0.01[de] | 0.47 ± 0.00[cde] | 0.49 ± 0.01[b] |
| | | 2 h | 0.48 ± 0.01[de] | 0.45 ± 0.01[de] | 0.46 ± 0.01[bc] |
| 100°C | 1/1 | 1 h | 0.66 ± 0.01[a] | 0.56 ± 0.01[a] | 0.52 ± 0.01[a] |
| | 1/5 | 1 h | 0.50 ± 0.01[cd] | 0.49 ± 0.01[bc] | 0.45 ± 0.00[cd] |
| | | 2 h | 0.45 ± 0.01[e] | 0.47 ± 0.02[cde] | 0.43 ± 0.02[de] |
| | 1/10 | 1 h | 0.54 ± 0.01[bc] | 0.48 ± 0.00[cd] | 0.45 ± 0.01[cd] |
| | | 2 h | 0.54 ± 0.02[bc] | 0.45 ± 0.01[cde] | 0.41 ± 0.01[e] |

*Note*: Mean values ± standard deviation of triplicate determinations. All results presented as dry weight basis. Values in the same column with the same letter are not significantly different at $p \leq 0.05$.

Short-time thermal treatment with low seed-to-water ratio was more interesting for keeping the maximum dry matter at 100°C for RI 52, CAL 98, and at 65°C for DRKF.

### 3.3.2 | Effects of thermal treatment on proteins

Thermal treatment under different conditions did not affect protein contents in any varieties (Table S2).

### 3.3.3 | Effects of thermal treatment on anthocyanins

Thermal treatment decreased anthocyanins significantly for the two varieties with time and with high seed-to-water ratio (Table S3). CAL 98 anthocyanins were removed after 1 h of thermal treatment at 65°C with 1/5 and 1/10 ratios; at 100°C, they were only eliminated after 2 h, with high seed-to-water ratio. In comparison, at 65°C, DRKF anthocyanins disappeared after 1 h with 1/5 and 1/10 ratios, and after 2 h with a limited quantity of water (1/1 ratio). At 100°C, the anthocyanins were totally removed after 2 h of thermal treatment with 1/5 and 1/10 ratios.

### 3.3.4 | Effects of thermal treatment on α-galactosides

Figure 2 presents the evolution of α–galactosides of the three common beans varieties during thermal treatment under different conditions. In most cases $C/C_0 < 1$ for raffinose and stachyose in 2 h of thermal treatment except in some cases where $C/C_0 > 1$ for raffinose and stachyose. The reduction is a function of time but not of temperature. For RI 52 thermal treatment at 65°C reduced α-galactosides from 42% to 88%, for CAL 98 from 57% to 90% and for DRKF from 6% to 73%. Thermal treatment at 100°C decreased α-galactosides of RI 52 from 65 to 77%, of CAL 98 from 36 to 99% and of DRKF from 1 to 73%.

For RI 52 and CAL 98, most of the losses of total α-galactosides were observed at 65°C after 2 h with high seed-to-water ratios. For DRKF, the maximum decrease was observed at 100°C with a ratio of 1/5 after 2 h.

### 3.3.5 | Effects of thermal treatment on tannins

The evolution of tannins are presented in Table 6. Tannins in all varieties were significantly reduced by thermal treatment with time except for RI 52 with limited seed-to-water ratio where there was no reduction. For RI 52 and DRKF, the maximum reduction was observed with high seed-to-water ratio in 2 h at 100°C. For CAL 98, most loss was observed after 2 h of thermal treatment with 1/5 ratio at 65°C.

### 3.3.6 | Effects of thermal treatment on IP6

Table 6 presents the evolution of IP6 during thermal treatment under different conditions. Thermal treatment decreased significantly IP6 for all varieties except for CAL 98 in some points, where increases were observed, the higher was observed at 100°C (1/10 ratio after 1 h).

## 3.4 | Correlation between physical and final seed composition

Pearson's correlation coefficients between the contents of various properties compounds in the processed common beans of the three varieties and the shape of the seeds showed that during soaking, anthocyanins, tannins and total α-galactosides had significant negative correlation with S/V ratio. The higher the S/V, the greater the loss of these compounds in the seed. During thermal treatment, only IP6 had significant negative correlation with S/V ratio.

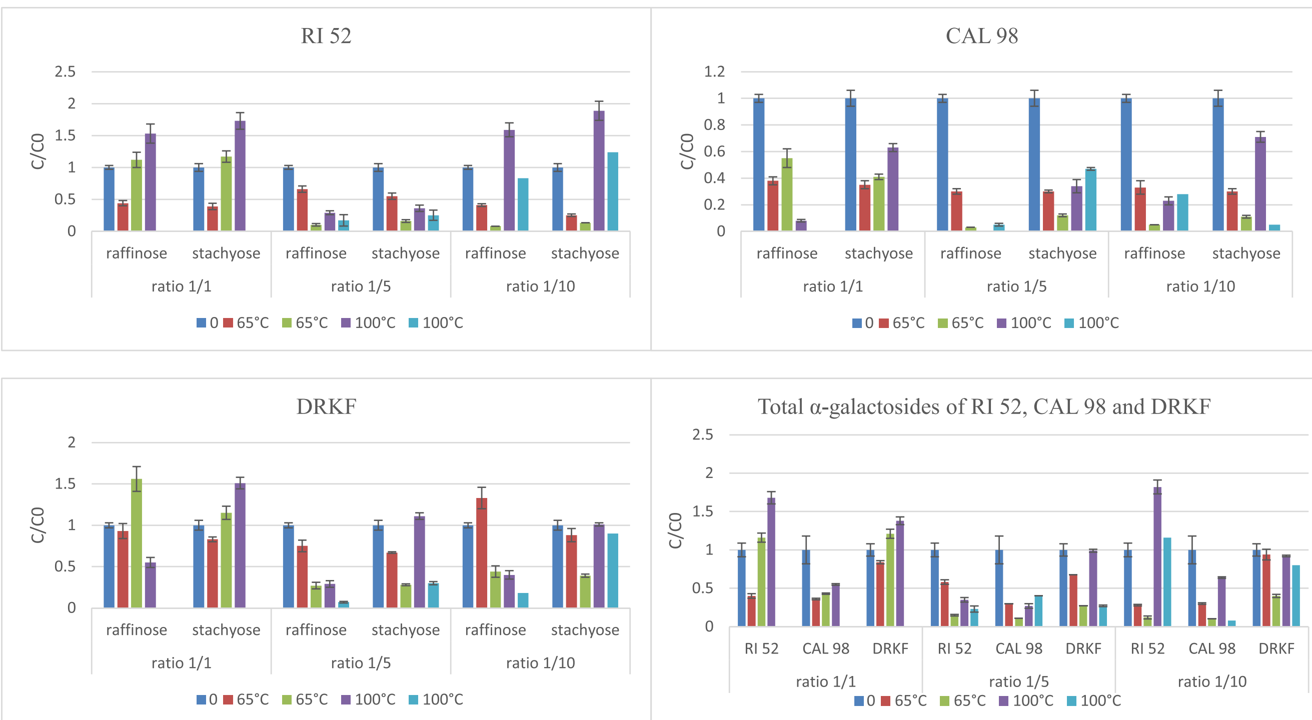


**FIGURE 2** Influence of thermal treatment, under various temperatures (65 and 100°C), seed-to-water ratios (1/1, 1/5 and 1/10) and times (1 and 2 h) conditions, on the ratio between the final and initial raffinose, stachyose and α-galactosides concentrations ($C/C_0$) of RI 52 (white variety), CAL 98 (marbled variety) and DRKF (red variety). Mean values ± standard deviation, triplicate determinations. Results are presented as dry weight basis

**TABLE 6** Influence of thermal treatment, under various temperatures (65 and 100°C), seed-to-water ratios (1/1, 1/5 and 1/10) and times (1 and 2 h) conditions, on the ratio between the final and initial tannins and IP6 concentrations ($C/C_0$) of the three common bean varieties

| Temperatures | Ratio | Duration | RI 52 (white) | CAL 98 (marbled) | DRKF (red) |
|---|---|---|---|---|---|
| *Tannins* | | | | | |
| 65°C | 1/1 | 1 h | 0.94 ± 0.15$^{a}$ | 0.87 ± 0.09$^{abcd}$ | 0.87 ± 0.09$^{ab}$ |
| | | 2 h | 0.87 ± 0.11$^{abc}$ | 0.62 ± 0.07$^{efg}$ | 0.62 ± 0.10$^{ef}$ |
| | 1/5 | 1 h | 0.92 ± 0.15$^{ab}$ | 0.83 ± 0.10$^{abcd}$ | 0.78 ± 0.09$^{bcd}$ |
| | | 2 h | 0.54 ± 0.08$^{ef}$ | 0.38 ± 0.06$^{h}$ | 0.48 ± 0.07$^{fgh}$ |
| | 1/10 | 1 h | 0,50 ± 0.10$^{bcd}$ | 0.83 ± 0.10$^{abcd}$ | 0.82 ± 0.11$^{bc}$ |
| | | 2 h | 0.56 ± 0.10$^{e}$ | 0.44 ± 0.06$^{gh}$ | 0.62 ± 0.08$^{ef}$ |
| 100°C | 1/1 | 1 h | 0.87 ± 0.12$^{abc}$ | 0.81 ± 0.11$^{abcd}$ | 0.45 ± 0.06$^{gh}$ |
| | 1/5 | 1 h | 0.56 ± 0.08$^{e}$ | 0.95 ± 0.12$^{abc}$ | 0.47 ± 0.07$^{fgh}$ |
| | | 2 h | 0.48 ± 0.08$^{ef}$ | 0.54 ± 0.07$^{fgh}$ | 0.42 ± 0.04$^{h}$ |
| | 1/10 | 1 h | 0.52 ± 0.10$^{ef}$ | 0.98 ± 0.16$^{a}$ | 0.58 ± 0.06$^{efg}$ |
| | | 2 h | 0.37 ± 0.05$^{fg}$ | 0.76 ± 0.11$^{cde}$ | 0.40 ± 0.05$^{h}$ |
| *IP6* | | | | | |
| 65°C | 1/1 | 1 h | 0.63 ± 0.04$^{a}$ | 1.11 ± 0.11$^{b}$ | 0.65 ± 0.10$^{bc}$ |
| | | 2 h | 0.08 ± 0.00$^{de}$ | 0.15 ± 0.01$^{d}$ | 0.43 ± 0.06$^{d}$ |
| | 1/5 | 1 h | 0.36 ± 0.02$^{bc}$ | 0.10 ± 0.01$^{d}$ | 0.93 ± 0.11$^{a}$ |
| | | 2 h | 0.01 ± 0.00$^{e}$ | 0.76 ± 0.13$^{c}$ | 0.52 ± 0.05$^{cd}$ |
| | 1/10 | 1 h | 0.05 ± 0.00$^{e}$ | 0.98 ± 0.11$^{b}$ | 0.52 ± 0.06$^{cd}$ |
| | | 2 h | 0.03 ± 0.00$^{e}$ | 0.03 ± 0.00$^{d}$ | 0.69 ± 0.07$^{b}$ |
| 100°C | 1/1 | 1 h | 0.08 ± 0.00$^{de}$ | 1.03 ± 0.19$^{b}$ | 0.17 ± 0.03$^{e}$ |
| | 1/5 | 1 h | 0.44 ± 0.07$^{b}$ | 0.72 ± 0.09$^{c}$ | 0.70 ± 0.14$^{b}$ |
| | | 2 h | 0.34 ± 0.04$^{c}$ | 1.01 ± 0.15$^{b}$ | 0.76 ± 0.09$^{b}$ |
| | 1/10 | 1 h | 0.14 ± 0.02$^{d}$ | 1.36 ± 0.21$^{a}$ | 0.65 ± 0.14$^{bc}$ |
| | | 2 h | 0.07 ± 0.00$^{de}$ | 0.03 ± 0.04$^{d}$ | 0.07 ± 0.01$^{e}$ |

*Note*: Mean values ± standard deviation of triplicate determinations. All results presented as dry weight basis. Values in the same column with the same letter are not significantly different at $p \leq 0.05$.

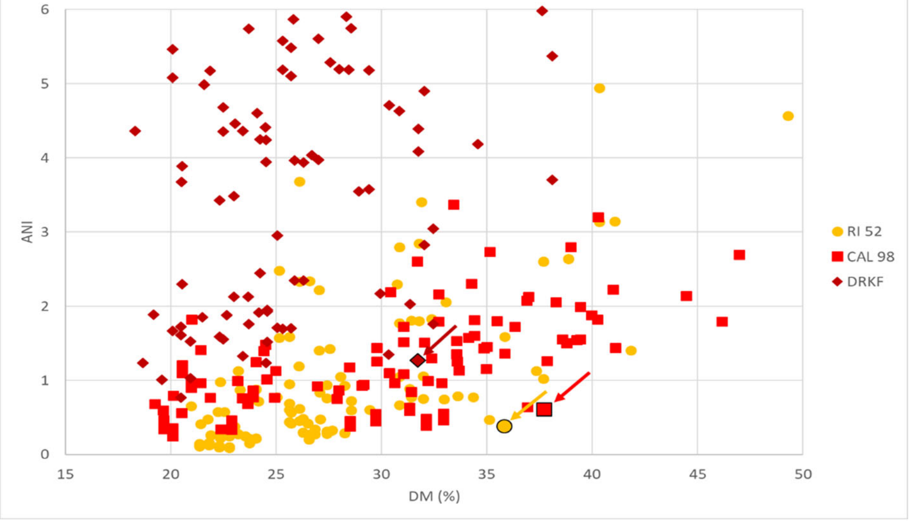


**FIGURE 3** Antinutritional indicator (ANI) and dry matter (DM) calculated for all soaking/thermal treatment combinations for RI 52 (white variety), CAL 98 (marbled variety) and DRKF (red variety). Identification of the best combinations (big symbols and arrows) allowing to reach low ANI keeping DM as high as possible

### 3.5 | Optimal soaking/thermal treatment combinations

Figure 3 presents the antinutritional indicator as a function of the final dry matter of the processed common beans using all the possible combinations of soaking and thermal treatment: seeds-to-water ratio and time for soaking; temperature, seeds-to-water ratio and time for thermal treatment. As previously mentioned, the DRKF variety differed from the other two clearly, with higher ANI.

According to the analyses above, the more suitable soaking and thermal treatment itinerary for each variety is given in Table 7. This study showed a long soaking at 30°C was not useful and 1 h was sufficient to obtain good results. The antinutritional indicator we defined was divided by 3.4 to 9.7 depending on varieties while maintaining the dry matter content above 32%.

## 4 | DISCUSSION

### 4.1 | Proximate composition

Raw seeds composition of the three common bean varieties were comparable with those obtained in previous studies on common beans (Anino et al., 2019; Celmeli et al., 2018; Rezende et al., 2018; Silva-Cristobal et al., 2009). The corresponding values of anthocyanins content of colored common beans have been found by Han et al. (2015) with adzuki bean (2.8% and 9.7%). The differences between CAL 98 and DRKF are probably due to the chemical structure and maturity of each variety (Cavalcanti et al., 2011). For antinutrients, α-galactosides were significantly different for all varieties. Stachyose constituted between 79% and 86% of α-galactosides in raw seeds. The raffinose level was relatively low and constituted between 14% and 21% of α-galactosides. These results are similar than those found with cowpeas with 0.4%–2.5% for raffinose and 1.7%–6.0% for stachyose (Coffigniez, Briffaz, Mestres, Altera, et al., 2018; Gonçalves et al., 2016; Ibrahim et al., 2002). Concerning the quantity of tannins, same values were found by Shimelis and Rakshit (2007) with kidney bean (0.5% to 2.9%). For IP6, previous study conducted by Lehrfeld (1994) found similar values (0.6%–2.4%) with kidney bean, whereas Parmar et al. (2017) found lower IP6 content (0.2%) also with kidney bean.

Size is an important physical attribute of seeds used in storing or processing into different foods.

Ozturk et al. (2010) and Wani et al. (2017) reported similar results with common beans and kidney beans, respectively.

### 4.2 | Effects of soaking on composition

Dry matter was affected by soaking. The reduction of dry matter is due to seed rehydration and to diffusion of the water-soluble compounds of the seed to the soaking water. In fact, during soaking, water enters the seed via the micropyle and in return, the soluble compounds in the seed can diffuse to the soaking water. Low quantity of soaking water restricts loss of compounds as the water is completely absorbed by the seeds to reach equilibrium and little diffusion of compounds was observed. However, high water volume increased the diffusion of molecules into the soaking water due to change of seed coat structure. In fact, common bean cell wall enzymes become hydrated, thus activating pectin hydrolysis and other cell wall polysaccharides, thereby further affecting water imbibition and solubility. The alteration of cell could lead to the diffusion of water-soluble compounds which could explain the significant loss of dry matter. Leaching compounds include antinutrients and soluble nutrients such as carbohydrates, minerals and vitamin compounds which has negative impacts on nutritional composition leading to lower nutritional density.

Logically, short-term soaking with low seed-to-water ratio was more interesting for keeping the maximum dry matter, except for RI 52. The reasons that explain this surprising result for RI 52 are multiple and complex because several mechanisms take place simultaneously. The behavior of nutrients, especially their diffusion speed, is different with respect to the matrix and the treatment conditions. Furthermore, diffusion occur in the seed but other phenomena can also be present such as chemical reactions, enzyme activations, pH change

**TABLE 7** Soaking-thermal treatment conditions recommended for each variety and final composition of the processed common beans

| | RI 52 (white) | CAL 98 (marbled) | DRKF (red) |
|---|---|---|---|
| Soaking conditions (30°C) | Ratio 1/10 | Ratio 1/1 | Ratio 1/10 |
| | Duration 1 h | Duration 1 h | Duration 1 h |
| Thermal treatment conditions | Temperature 65°C | Temperature 65°C | Temperature 65°C |
| | Ratio 1/10 | Ratio 1/10 | Ratio: 1/5 |
| | Duration 2 h | Duration 2 h | Duration 2 h |
| DM (%) | 36.0 | 37.8 | 32.1 |
| Total α-galactosides (%) | 0.32 | 0.55 | 1.25 |
| Tannins (%) | 0.18 | 0.26 | 0.25 |
| IP6 (%) | 0.04 | 0.01 | 0.04 |
| ANI | 0.37 | 0.61 | 1.28 |

Abbreviations: ANI, antinutritional indicator; DM, dry matter.

and so on. As an example, the pH change during the first hours of soaking is probably more important when water proportion is lower that could favor the action of hydrolytic enzymes allowing a greater diffusion of small molecules (Blöchl et al., 2008; Carmona-García et al., 2007; Nakitto et al., 2015). Of course, further investigations are needed to understand all these phenomena and support these assumptions. It may be also due to the high water content of RI 52 which is characterized by seed coat impermeability and either closed or narrowly opened micropyle which could lead to a slower diffusion of soluble molecules during soaking in a large volume of water.

Proteins contents were not affected by soaking under different conditions. Similar trends were observed with studies conducted by Pujolà et al. (2007) and Shimelis and Rakshit (2007). In fact, proteins are not altered by soaking due to their structure, whereas other compounds are solubilized when soaking.

Soaking reduced significantly anthocyanins. In fact, anthocyanins are highly water-soluble pigments and soaking led their loss by diffusion in water soaking with time which explains their maximum reduction after 10 h (Rodriguez-Amaya, 2018). In the case of CAL 98, anthocyanins were higher when soaking with 1/10 seeds-to-water ratio as compared with the other seeds-to-water ratios. Here again, the results show that the observations cannot be described only through a simple diffusive phenomenon and that other mechanisms probably take place at this level (reactions). In the specific case of anthocyanins, co-pigmentation phenomena which depend on the concentration and thus on the seed-to-water ratio and which can modify the reactivity of these compounds could be involved also (Dangles & Deluzarche, 1994; Dangles & Fenger, 2018).

Reduction of α-galactosides observed at 30°C can be imputed to diffusion in soaking water but also to enzymatic hydrolysis of α-galactosides. In fact, the α-galactosides in common beans have a sucrose-galactose ($n$) structure: for stachyose $n = 2$ and for raffinose $n = 1$. Therefore, endogenous α-galactosidases enabled the production of one (1) molecule of raffinose by degradation of one (1) molecule of stachyose which could explain increase of raffinose if production overcomes losses by diffusion. Similar results were found by Siddiq et al. (2006) with red kidney beans after soaking them for 12 h. The DRKF results were unexpected, considering that this variety was behaving differently. Increase of stachyose could be due to synthesis of stachyose from a precursor which could happen during soaking.

Despite differences in the behavior of varieties due probably to heterogeneity of the spatial distribution of α-galactosides in the seed, stachyose was the most affected by soaking in all varieties. Shimelis and Rakshit (2007) reported that soaking kidney beans for 12 h reduced 35%–38% of raffinose and 41%–47% of stachyose.

Time is also a factor in soaking extraction efficiency. By leaving seeds in the aqueous solvent for a longer period of time, further diffusion and metabolism of the α-galactosides is enabled. Coffigniez, Briffaz, Mestres, Riccia, et al. (2018) found that soaking cowpea seeds for 12 h at 35°C could reduce the α-galactosides content by enzymatic degradation.

The variations observed in α-galactosides contents are complex to be explained because they result from diffusion in the soaking water, enzymatic hydrolysis and metabolic process.

Tannins were affected by soaking with some conditions. According to the study by Helbig et al. (2003) and Yasmin et al. (2008), soaking did not result in tannins reduction, whereas other studies found a 17%–30% loss of tannins in various varieties of common beans (Barampama & Simard, 1994; Shimelis & Rakshit, 2007). Condensed tannins are composed of soluble (ranging from 8% to 28%) and insoluble (1%–5%) compounds that are located in the seed coat (Díaz et al., 2010). During soaking, their reduction is probably due to the diffusion of soluble tannins into the water. The lower reduction in some varieties could be explained by the fact that some tannins may diffuse into the cotyledon endosperm and bind with the proteins during soaking limiting their solubilization. In addition, when tannins are bound to proteins, they are usually not detected by routine methods due to insolubility in solvents used. The increase in tannins content of RI 52 with the 1/1 ratio after 10 h raises questions. In the case of tannins, the phenomena involved are probably even more complex. Indeed, tannins include a large variety of compounds which probably do not all behave in the same way. A priori, the only tannins that can be extracted are those found in vacuoles as opposed to those associated with parietal structures. Their ability to move out of the matrix therefore depends on the level of cellular decompartmentalization but also on their molar mass (Le Bourvellec et al., 2004, 2005; Renard et al., 2001; Varzakas et al., 2005). Moreover, they are more or less chemically labile and can be retained by other cell constituents through weak bonds (adsorption). A specific research work on this family of compounds would be worthwhile to better understand what happens during the processing.

Unclear trend was observed with reduction of IP6. Increase in IP6 content (31%) during the processing of whole seeds was already reported (Deshpande et al., 1982). On one hand, it is put forward that in most cases, soaking leads to a reduction in IP6 contents, mainly because of their solubility in water and leaching in the soaking water. Water imbibition might also activate phytase enzymes present in the common beans which degrade and reduce IP6. On the other hand, increase in some cases may be due to a greater IP6 extraction in soaked than in raw seed. This could be explained by an improved extractability of IP6 due to the destruction or alteration of other common bean components interfering with IP6 extraction, such as proteins (Greiner & Konietzny, 1998). The unclear trend could also be explained by the fact that only IP6 and not all phytates were determined.

### 4.3 | Effects of thermal treatment on composition

Reduction of dry matter during thermal treatment could be attributed to the thermal degradation of seed compounds and their diffusion into the heating water. Proteins, starch and pectin are denatured, gelatinized and solubilized during thermal treatment, which results in losses in nutritional quality. In addition, thermal treatment increases seed coat pore diameter and its water permeability, thereby increasing diffusivity (Chigwedere et al., 2019).

The result in present study with proteins contradicts those of Rehman and Salariya (2005) who revealed that the protein contents were reduced during thermal treatment. Protein behavior in the present study could be explained by the fact that heat processing can improve the digestibility of proteins due to structural changes in globulins, by destroying protease inhibitors and opening the protein structure through denaturation (Clemente et al., 1998). The other reasons are that proteins become insoluble and therefore do not diffuse, or that leaching of soluble nutrients and some antinutrients would increase proteins concentrations (Obong & Obizoba, 1996; Wang et al., 2010). Furthermore, Khattab et al. (2009) reported that processing treatments such as soaking, cooking increased total essential amino acids.

Decrease and remove were observed with anthocyanins. A previous study found that boiling black bean decreased anthocyanins ranging from 78.2% to 96.5% (Xu & Chang, 2009). In fact, temperature increases the degradation reaction of the anthocyanins by hydrolysis of the glycosidic bond due to the contact of the seeds with water leading to loss of anthocyanins and color by leaching.

Thermal treatment affected α-galactosides under different conditions. According to Shimelis and Rakshit (2007), thermal treatment of red common beans resulted in a decrease of raffinose by 43%–46% and stachyose by 50%–55%. At higher temperatures, the seed coat is more permeable, allowing more α-galactosides to escape by diffusion. The loss can also be attributed to the endogenous activity of α-galactosidase at 65°C. In fact, Baldini et al. (1985) showed that at 55°C, α-galactosidase from *Phaseolus vulgaris* had optimal activity. However, with longer incubation times, the higher the temperature, the lower enzyme activity over time, due to thermal denaturation of the enzyme. Thirunathan and Manickavasagan (2018) reported that when common beans are cooked without pre-soaking treatment, the levels of α-galactosides increase. This phenomenon can be attributed to some α-galactosides content being bound to proteins within the seed. As the raw seed, these bounded oligosaccharides are not quantified, but when these proteins are denatured by the thermal treatment, the α-galactosides are released and become free within the seed.

Differential solubility of the different oligosaccharides, their rate of diffusion and the variety of common beans are factors that could influence losses during thermal treatment.

Tannins were reduced by thermal treatment with time. In fact, the permeability of the cell membrane is affected and therefore more materials can diffuse out such as tannins (Schwimmer, 1972). The decrease can also due to the high processing temperatures that alter the chemical structure of polyphenols, promoting decomposition of their aromatic tannins leading to formation of insoluble association of tannins with seed proteins that cannot be determined by available chemical methods like with soaking (Sharma & Sehgal, 1992).

IP6 were reduced or increased with variety. According to a study by Shimelis and Rakshit (2007), with kidney bean the reduction of IP6 was 25% after 35 min thermal treatment time. Another study on chickpeas showed reduction of 29%, after thermal treatment for 90 min (Alajaji & El-Adaway, 2006). However, Lestienne et al. (2005) observed increase of IP6 in soybean during thermal treatment. The raise in temperature could enhance the reduction of IP6 by the transfer of heat in the seed leading to degradation reactions, it may also be partly due to leaching into the thermal treatment medium or formation of insoluble complexes between IP6 and other components, such as proteins and minerals. For CAL 98, increments can be explained by the fact that IP6 are formed by the activation of the enzyme phosphoinositol kinase at the beginning of thermal treatment which creates links between the phosphate groups and the myo-inositol phosphate, raising the amount of IP6. It may be also due to a greater IP6 extraction in heated than in raw seed. However, further study would be necessary to evaluate the reasons for this phenomenon in order to be able to avoid it.

### 4.4 | Correlation between physical and final seed composition

During soaking, relation between the contents of various compounds in the processed common beans and the shape of the seeds suggested that diffusion was probably the leading phenomenon which explained these losses. However, during thermal treatment no clear relationship between the shape of the seeds and the loss of the antinutrients, except the IP6, were observed. In this second stage, diffusion is probably less involved in the losses which are rather explained by enzymatic or thermal degradations.

### 4.5 | Optimal soaking/thermal treatment combinations

All results allowed the identification of soaking or thermal treatment conditions allowing maximum decrease of each antinutrient. In order to choose the best operating conditions for the preparation of the common beans, we have to find combinations which allowed to decrease as much as possible ANI of course but also at the same time which avoided to drop down dry matter too much. Indeed, lower dry matter content decreased the nutritional load of the food, that is to say less energy and proteins for a standard intake. The Figure 3 shows how strong processing conditions could impact both antinutritional indicator and dry matter. It seemed essential to find compromises between low ANI and high dry matter and so optimal combinations could be identified for each variety, which were very close whatever the variety. Thermal treatment at 100°C was not necessarily suitable as long thermal treatment at low temperature was more effective and probably allowed to consume less energy also. In these conditions, the soaking and thermal treatment process could drastically reduce antinutrients while limiting the decrease of dry matter content. Because these results were obtained through calculation considering soaking and thermal treatment as independent, the final ANI and dry matter obtained should be confirmed combining both unit operations at the same time.

## 5 | CONCLUSIONS

The geometrical properties and composition of the three common bean varieties showed significant differences between varieties, principally in regard to dimensions, mass, anthocyanins and α-galactosides.

Antinutrients studied could be drastically decreased by using soaking and thermal treatment in adequate operating conditions. Each step was found to reduce tannins, IP6, stachyose and raffinose through diffusion phenomena or degradation reactions. Thermal treatment was the most effective step in loss of antinutrients in the common beans. However, thermal treatment alone was clearly not sufficient to optimize the process. Control of the soaking and thermal treatment conditions is essential to avoid dry matter drop and at the same time to decrease antinutrients. On the basis of the results obtained, a deeper kinetic approach is also essential to understand the involved transfer and reactional phenomena and optimize the soaking and thermal treatment process before final cooking.

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### CONFLICT OF INTEREST

The authors declare no conflict of interest.

### DATA AVAILABILITY STATEMENT

All data in this publication are freely available.

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