Food Research International 138 (2020) 109810

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Mapping the variability in physical, cooking, and nutritional properties of *Zamnè,* a wild food in Burkina Faso

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A R T I C L E I N F O

Keywords:
Senegalia macrostachya
Acacia
Wild legume
Terroir food
Hard-to-cook defect

A B S T R A C T

Zamnè is an *Acacia* seed used as a terroir food in Burkina Faso. It has been introduced as a famine-resilience crop and has become a cultural diet. However, little is known about its culinary and nutritional properties. This study aimed to explore the cooking and nutritional properties of *Zamnè (Senegalia macrostachya* (Reichenb. ex DC.) Kyal. & Boatwr.). *Zamnè* presented characteristics of medium size, flattened, dry, and hard-to-cook legume. The moisture, cylindrical ratio, diameter, thickness, weight, true density, coat percentage, coat thickness, and cooking time of the seeds were in the range of 4.5–5.8%, 1.1, 7.4–8.0 mm, 1.6–1.8 mm, 65.0–76.4 mg, 1.1 g/ml, 16.8–22.2%, 9.0–11.9 mg/cm^2, and 180 min, respectively. The raw *Zamnè* showed 39.8–43.6, 9.7–11.5, 16.6–29.4, 13.3–20.2, 16.6–26.4, and 3.7–3.9 (g/100 g dry weight) of protein, fat, total dietary fiber, insoluble dietary fiber, digestible carbohydrate, and ash contents, respectively. The traditional cooking process improved most of the parameters determining the proximate compositions but resulted in 51–52% of protein and 47–50% carbohydrate losses into the cooking wastewater. Besides, *pseudoZamnè*, a famine-emergency crop similar to *Zamnè*, revealed inferior cooking quality than *Zamnè*. The data reported here provide a basis for alternative cooking techniques and further investigations of *Zamnè* and *pseudoZamnè* seeds' nutritional quality.

1. Introduction

The ongoing COVID-19 pandemic emphasized the vulnerability of several parts of the world to hunger and the urgency to rethink the current food system's sustainability. FAO/IFAD/UNICEF/WFP/WHO (2020) has reported that the lockdown compromised food supply in several hunger-prone regions of the world and might add up 83 to 132 million people to the ranks of undernourished in 2020. United Nations agenda to end hunger, reduce nutrition-associated health problems, and mitigate climate-change costs by 2030 is falling short (FAO/IFAD/UNICEF/WFP/WHO, 2020; Galanakis, 2020). Under the lockdown, people have been compelled to rely on local food supply (ECLAC/FAO, 2020; Galanakis, 2020). The concept of "local production for local consumption" can reconcile the global food system's resilience with biodiversity preservation, environment protection, agriculture sustainability, food security, and public health (ECLAC/FAO, 2020; Galanakis, 2020). Local food resources, such as *Zamnè*, have then been put back in the spotlight.

Zamnè is an endogenous legume seed in Burkina Faso, which can be promoted in human diets to tackle the frequent food shortage in several West African countries or globally in the growing market for healthy foods. The name *Zamnè* designates both to the raw and cooked seeds from *Senegalia macrostachya* (Reichenb. ex DC.) Kyal. & Boatwr. The species belongs to *Acacia sensu lato* and is mainly spread in the semi-arid lands from West to Northcentral Africa (Arbonnier, 2000). To our knowledge, *Zamnè* is only known in Burkina Faso, where it first has been used as a famine-resilience crop but rising nowadays in traditional diets as a cultural and health-promoting food. *Zamnè* is eaten as a main dish or ingredient in salads or sauces.

The scarcity of research on *Zamnè* does not give a clear insight into

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https://doi.org/10.1016/j.foodres.2020.109810
Received 9 June 2020; Received in revised form 12 October 2020; Accepted 13 October 2020
Available online 21 October 2020
0963-9969/

the previously reported compositional variabilities and culinary properties. In general, *Zamnè* is considered as a wild protein-rich legume (38% dry weight (dw) on average) (Guissou, Parkouda, Ganaba, & Savadogo, 2017; Hama-Bâ et al., 2017; Msika, Saunois, Leclere-Bienfait, & Baudoin, 2017). However, in contrast, Savadogo, Ilboudo, and Traore (2011) reported significant variations in the proximate compositions (10–13 and 11–36% dw of proteins and starches, respectively). Besides, Guissou et al. (2017) surveyed the cooking practices and reported very extensive alkali hydrothermal processes. The cooking processes include highly varying alkalinization levels (between 1 and 5% m/m alkali/cooking water), two distinct boiling steps of between 47 and 147 min each, and hot soaking (3 h or overnight) or steaming (30 min) (Guissou et al., 2017). The cooking processes' variations suggest variability of the seed quality in terms of cookability and quality of the end food products. On the other hand, related species to *Zamnè*, known as *pseudoZamnès*, could be mixed up. The ethnic group *Samo*, from Burkina Faso, uses the seeds from *Senegalia senegal*, *Senegalia dudgeonii,* and *S. ataxacantha* as *pseudoZamnès* during food scarcity times. The *pseudoZamnès* are not supposed to be sold in the markets but could be a source of fraud. Compared to *Zamnè*, they are not much appreciated due to the hard-to-cook problem and the lower palatability.

Easy processability and high nutritional profile of legumes are the main prerequisites for their wider acceptance as human food. The hard-to-cook trait is a common concern with legumes (Mubaiwa, Fogliano, Chidewe, & Linnemann, 2017; Shehata, 1992). It implicates excessive expenditure of energy (fuel and labor) and time for cooking, the degradation of essential nutrients (associated with the required longer cooking), and the under-utilization of legumes (Mubaiwa et al., 2017; Shehata, 1992). Understanding the basis of the hard-to-cook problem, such as specific physical and chemical properties and responses to processings, allows to improve the cooking techniques and to develop alternative processing of legumes into concentrated-protein, nutritive and healthy foods (Duranti, 2006; Mubaiwa et al., 2017; Shehata, 1992). *Zamnè* is not a well-known legume, and there is scarce information on its nutritional properties and processability. Therefore, this study aimed to map the variability in the physical, chemical, and cooking properties of *Zamnè* obtained from the local markets in Burkina Faso. Besides, the differences in nutritional values and cookability between *Zamnè* and *pseudoZamnè* were identified.

2. Material and methods

2.1. Sampling

S. macrostachya seeds, as control *Zamnè*, were harvested from a wild field (GPS N 12°39′ W −3°00′, Village Kamba) in January 2018. A specimen (a branch with leaves, pods, and flowers) was identified and deposited at the herbarium (INFOBIO N° 6885, University Joseph Ki-Zerbo). Five markets, namely three in Ouagadougou, one in Ouahigouya, and one in Dedougou (Burkina Faso), were inspected. Besides, two local enterprises of forest-based products were visited in Dedougou and Gassam, respectively. One sample (about 3 kg) of seeds was purchased (between January and February 2018) at each visited place. The seeds collected from the market in Dedougou were suspected as false *Zamnè* and designated as *pseudoZamnè*. All the samples were manually cleaned to remove foreign matters and damaged seeds.

2.2. Physical examination

The weight of thousand seeds was determined by counting and weighing a duplicate of 100 seeds and multiplying by 10 (Kumar, Prasad, Chandra, & Debnath, 2016). The dimensions (diameters and thickness) of 15 random seeds were measured using a digital caliper (precision = 0.01 mm). According to the shape similarity principle of Mohsenin (1986), the geometric features of the seeds were calculated using the following formulas :

$$Diameter\ (mm) = \frac{Major\ diameter + Minor\ diameter}{2} \quad (1)$$

$$Cylindrical\ ratio = \frac{Major\ diameter}{Minor\ diameter} \quad (2)$$

$$Seed\ surface\ area\ \left(mm^2\right) = \pi^*Diameter^*\left(\frac{Diameter}{2} + Thickness\right) \quad (3)$$

Seed coat percentage and thickness were gravimetrically determined. Briefly, 50 g of samples were boiled for 90 min until the seed coats were removable by squeezing between fingers. Then, duplicates of fifteen random seeds were picked, and the coats and cotyledons were separated and dried (at 105 °C for 4 h) until constant weight. The coat percentage and thickness were calculated using the following formulas (Avola & Patane, 2010) :

$$Coat\% = \frac{100^*Coat\ (g)}{(Coat\ (g) + Cotyledon\ (g)\ )} \quad (4)$$

$$Coat\ thickness\ \left(mg/cm^2\right) = \frac{Coat\%^*Thousand\ seeds\ weight\ (mg)}{1000^*Seed\ surface\ area\ (cm^2)} \quad (5)$$

Seed bulk density, true density, and porosity were determined, according to Mpotokwane, Gaditlhatlhelwe, Sebaka, and Jideani (2008). A container (1000 ml cylinder) was filled with the seeds, and the content was weighed (bulk weight). Then, 10 g of seeds were accurately weighed, placed in a 100 ml measuring cylinder, and immersed with 15 ml of water. The water level was read and converted to the true volume of the seeds. The analyses were performed in duplicate, and seed densities and porosity were accounted as follows:

$$Bulk\ density\ (mg/ml) = \frac{Bulk\ weight\ (g)}{Container\ volume\ (ml)} \quad (6)$$

$$True\ density\ (mg/ml) = \frac{Sample\ weight\ (g)}{True\ volume\ (ml)} \quad (7)$$

$$Porosity = 100^*\left(1 - \frac{Bulk\ density}{True\ density}\right) \quad (8)$$

2.3. Hydration tests

Fifteen g of samples (~250 raw seeds) were soaked in tap water (28 ± 1 °C), boiled water (99 ± 1 °C), boiled potash solution (potash/water 1% m/m, 99 ± 1 °C), and boiled baking soda solution ($NaHCO_3$/water 1% m/m, 99 ± 1 °C). Duplicates of 10 random seeds were picked after 1, 3, and 6 h, the free water was removed using a blotting towel, and the seeds were dried (105 °C for 4 h) until constant weight. The hydration indices were calculated using the formula (Avola & Patane, 2010):

$$Hydration\ index\ (g/100\ g\ dw) = 100^*\frac{Absorbed\ water\ (g)}{Seed\ dry\ weight\ (g)} \quad (9)$$

All the experiments were performed at room temperature (30 ± 1 °C). The pH and temperature drops of the soaking solutions were monitored using a digital pH meter and thermometer.

2.4. Determination of hydration indices and cooking times

Samples (50 g each) were placed in boiling distilled water and continuously boiled (99 ± 2 °C). The hydration indices were determined at different time points up to 6 h of cooking, as described above. According to Avola and Patane (2010), the hydration capacity and rate were defined as the maximum water absorption after 6 h and the slope in the linear phase between 0 and 60 min, respectively. Besides, the softening degree was continuously monitored using the finger-pressing method. The cooking times were determined when the seeds were perceived well-soften (Kinyanjui et al., 2015).

2.5. Cooking trial and preparation of samples

The traditional cooking process of *Zamnè* was performed in the laboratory, as summarized in Fig. 1. Briefly, 500 g of selected *Zamnè* and *pseudoZamnè* samples were separately precooked (first step boiling) in ~ 1.5% m/m of cooking aid/water for 90 and 150 min, respectively. Then, half of the precooked *Zamnè* and *pseudoZamnè* underwent a second boiling step for 90 and 180 min, respectively, to obtain fully cooked seeds. The proportion of the boiling water to seeds was kept constant throughout the cooking by adding lukewarm water when necessary. The precooked and cooked seeds were dried in a ventilated oven (50 °C for 20 h). The precooking and cooking wastewaters were pooled and dried (105 °C for 24 h). After all, the recovered leached solids and the cooked, precooked, and raw seeds were finely ground to pass 0.5 mm mesh (IKA M20, 25000 rpm) and further dried overnight (50 °C for 16 h).

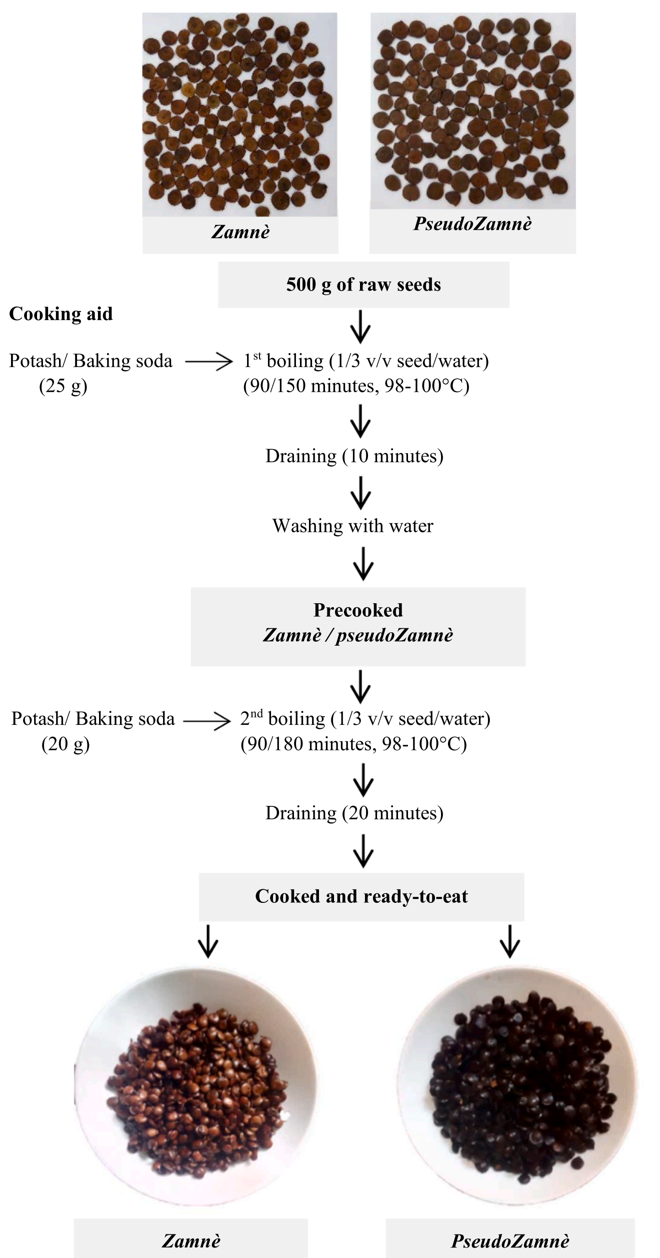

Fig. 1. Traditional cooking process of *Zamnè* and *pseudoZamnè*. Adapted according to Guissou et al. (2017) and the cooking time as determined above.

2.6. Compositional analysis

Total moisture, ash, nitrogen, and fat contents were determined according to AOAC 925.09, AOAC 923.03, AOAC 979.09 (AOAC, 1995), and Thiex, Anderson, and Gildemeister (2003), respectively. Total protein was calculated by converting the nitrogen content using the general factor 6.25. Dietary fiber composition (total and insoluble) was analyzed following AOAC 991.43 (AOAC, 1995). Total carbohydrate, digestible carbohydrate, and soluble dietary fiber contents were calculated according to the differential methods. The effect of the cooking on the protein dispersibility index (PDI%) was assessed following AOCS Ba 10–65 (AOCS, 1990). All the analyses were performed in duplicate.

2.7. Cooking loss analysis

The leached solids' proximate compositions (total dry weight, ash, fat, protein, and carbohydrate) were determined as described above. The nutrient losses were calculated, according to Murphy, Criner, and Gray (1975):

$$Loss\% = 100^{*}\frac{Nutrient\%\ of\ leached\ solid^{*}total\ leached\ solid\ dw\ (g)}{Nutrient\%\ of\ used\ raw\ seeds^{*}total\ used\ raw\ seeds\ dw\ (g)} \quad (10)$$

2.8. Data analysis

The data were analyzed using R program version 3.6.1. The results were expressed as means ± standard deviations and subjected to one or two way ANOVA. The differences among the means were determined using Tukey's HSD post-hoc analyses at p-value ≤ 0.05, and the principal component analysis was performed to examine the distribution. The interrelationships among the parameters were investigated by determining the coefficients r of Pearson.

3. Results and discussion

3.1. Variability in the chemical properties

The proximate compositions of the raw *Zamnè* seeds are shown in Table 1. The fat and ash contents were similar to previous reports (Guissou et al., 2017; Hama-Bâ et al., 2017; Msika et al., 2017). The total dietary fiber content varied significantly between the samples. Still, the values were in between the values reported by Msika et al. (2017) (38% dw) and Hama-Bâ et al. (2017) and Guissou et al. (2017) (15–16% dw). This study showed that 20–35% of the total dietary fiber is present in the soluble form and is comparable with the content in soybeans but higher than in faba beans (El-shemy, Abdel-rahim, Shaban, Ragab, & Fujita, 2000). Subsequently, the carbohydrate composition significantly varied, suggesting a difference in carbohydrate digestibility among the samples and probably hard-to-cook defects (Gwala et al., 2019). Seeds' hard-to-cook defects have been attributed to their harvest maturity and storability (Iliadis, 2001; Mubaiwa et al., 2017; Shehata, 1992). Further research is needed to determine the impact of harvest maturity and the storability of *Zamnè* on the hard-to-cook phenomena.

Compared to the collected *pseudoZamnè* (Table 1), *Zamnè* had higher fat and protein contents but lower ash and dietary fiber contents. While the protein contents of both *Zamnè* and *pseudoZamnè* were similar to the values (35–40% dw) in recent literature on *Zamnè* (Guissou et al., 2017; Hama-Bâ et al., 2017; Msika et al., 2017), there is a huge discrepancy with the values (10–13% dw) reported by Savadogo et al. (2011). Furthermore, both *Zamnè* and *pseudoZamnè* exhibited higher or comparable protein, fat, dietary fibers, and ash contents, but lower or similar digestible carbohydrate contents to most staple legumes (FAO/INFOOD, 2017).

Table 1
Physical, chemical, and cooking properties of *Zamnè* and *pseudoZamnè* purchased from the local markets in Burkina Faso.

Sample description	Species	*Zamnè*							*PseudoZamnè*	p-value
	Origin	Ouagadougou			Ouahigouya	Toma. Gassam	Toma. Kamba	Dedougou	Dedougou	
	Code	ZWr1	ZWr2	ZWr3	ZOr	ZTGr	ZTKr	ZDr	spZDr	
Chemical Properties (% dw)	Protein	43.27 ± 1.84^{a}	40.36 ± 2.28^{a}	41.02 ± 1.71^{a}	41.28 ± 0.49^{a}	43.45 ± 1.93^{a}	43.55 ± 0.55^{a}	39.81 ± 0.86^{ab}	35.99 ± 0.07^{b}	0.010
	Fat	10.68 ± 0.08^{abc}	11.53 ± 0.08^{a}	11.24 ± 0.14^{ab}	10.15 ± 0.10^{bc}	9.72 ± 0.01^{c}	10.26 ± 0.03^{bc}	10.50 ± 0.10^{abc}	4.70 ± 0.08^{d}	< 0.001
	Total dietary fiber				23.26 ± 3.43^{ab}	16.61 ± 2.84^{a}	22.03 ± 0.86^{ab}	29.35 ± 2.54^{bc}	32.63 ± 1.70^{c}	0.005
	Insoluble dietary fiber				17.93 ± 1.21^{a}	13.25 ± 1.11^{b}	14.26 ± 0.33^{a}	20.16 ± 0.22^{a}	22.54 ± 3.52^{a}	0.013
	Soluble dietary fiber				5.33	3.35	7.77	9.19	10.08	
	Digestible carbohydrate				21.48	26.43	20.22	16.60	21.56	
	Ash	3.74 ± 0.28^{a}	3.78 ± 0.23^{a}	3.54 ± 0.12^{a}	3.83 ± 0.17^{a}	3.78 ± 0.15^{a}	3.93 ± 0.20^{a}	3.74 ± 0.13^{a}	5.13 ± 0.15^{b}	< 0.001
Physical properties	Moisture	4.45 ± 0.43^{a}	4.84 ± 0.14^{ab}	4.79 ± 0.15^{ab}	4.80 ± 0.36^{ab}	4.85 ± 0.14^{ab}	5.37 ± 0.31^{bc}	5.84 ± 0.29^{cd}	6.45 ± 0.07^{d}	< 0.001
	Diameter (mm)	7.46 ± 0.48^{a}	7.38 ± 0.71^{a}	7.97 ± 0.48^{a}	7.78 ± 0.60^{a}	7.59 ± 0.59^{a}	7.37 ± 0.61^{a}	7.76 ± 0.39^{a}	8.87 ± 0.33^{b}	< 0.001
	Cylindrical ratio	1.07 ± 0.03^{a}	1.06 ± 0.05^{a}	1.06 ± 0.5^{a}	1.07 ± 0.07^{a}	1.06 ± 0.05^{a}	1.12 ± 0.11^{a}	1.07 ± 0.04^{a}	1.08 ± 0.09^{a}	0.365
	Thickness (mm)	1.73 ± 0.24^{a}	1.56 ± 0.25^{a}	1.76 ± 0.02^{a}	1.74 ± 0.24^{a}	1.71 ± 0.19^{a}	1.62 ± 0.26^{a}	1.65 ± 0.23^{a}	1.70 ± 0.13^{a}	0.236
	1000 seeds weight (g)	65.00 ± 2.33^{a}	65.92 ± 0.42^{a}	76.38 ± 0.51^{b}	71.18 ± 1.17^{c}	68.49 ± 0.02^{ac}	65.56 ± 0.53^{a}	71.86 ± 0.15^{c}	92.68 ± 0.47^{d}	< 0.001
	Bulk density (g/ml)	0.75 ± 0.01^{a}	0.75 ± 0.01^{a}	0.77 ± 0.01^{ab}	0.79 ± 0.01^{b}	0.79 ± 0.02^{b}	0.75 ± 0.01^{a}	0.77 ± 0.01^{ab}	0.90 ± 0.01^{c}	< 0.001
	True density (g/ml)	1.06 ± 0.01^{ab}	1.05 ± 0.02^{ab}	1.08 ± 0.01^{ac}	1.01 ± 0.01^{b}	1.12 ± 0.02^{c}	1.07 ± 0.01^{ac}	1.07 ± 0.01^{abc}	1.20 ± 0.02^{d}	< 0.001
	Porosity %	28.77	28.85	28.71	22.33	29.47	30.41	27.58	24.97	
	Coat (% dw)	22.24 ± 0.36^{a}	22.03 ± 0.32^{a}	20.07 ± 0.50^{ab}	20.07 ± 0.36^{ab}	18.20 ± 0.59^{bc}	20.03 ± 0.57^{c}	16.80 ± 0.88^{ab}	33.89 ± 0.94^{d}	< 0.001
	Coat thickness (mg/cm^2)	11.22 ± 0.18^{ab}	11.93 ± 0.18^{a}	10.71 ± 0.26^{ab}	10.39 ± 0.19^{cd}	9.51 ± 0.31^{bc}	8.98 ± 0.47^{d}	10.68 ± 0.30^{abc}	18.36 ± 0.51^{e}	< 0.001
Cooking properties	Cooking time (min)				180	180	180	180	330	
	Hydration rate (g H_2O /100 g dw. min)				5.46 ± 0.11^{a}	5.29 ± 0.30^{a}	5.40 ± 0.54^{a}	6.50 ± 0.42^{a}	2.15 ± 0.06^{b}	< 0.001
	Hydration capacity (g H_2O / 100 g dw)				312.7 ± 10.5^{a}	340.4 ± 30.3^{a}	319.5 ± 5.4^{a}	300.5 ± 1.0^{a}	348.2 ± 9.4^{a}	0.091

Z, spZ, (W, O, TG, TK, D), and the indices (1–3) designate *Zamnè*, *pseudoZamnè*, town, and the number of the markets inspected, respectively. The values are expressed as the means ± SD (n = 2). % dw = per 100 g dry weight. The values in the same row with the different superscripts are significantly different ($p < 0.05$).

3.2. *Variability in the physical properties and the processability*

The physical properties of the *Zamnè* samples and the collected *pseudoZamnè* are summarized in Table 1. Both *Zamnè* and *pseudoZamnè* were dry, round, and flattened seeds (~5% moisture, cylindrical ratio = 1.1, diameter = 7–9 mm, and thickness = 1.7 mm), and had brown seed coats and yellow dicotyledons. The seeds were both marked by a sickle-form areole on both sides and were difficult to differentiate visually. *Zamnè* had a lower weight, true density, and bulk density than *pseudoZamnè*. The porosity of both seed species, for instance, were comparable. Seed coat percentage and thickness were found to be almost twice higher for *pseudoZamnè* than *Zamnè*. The morphological characteristics of *Zamnè* have high similarities to brown lentils (Khazaei, Fedoruk, Caron, Vandenberg, & Bett, 2018; Kumar et al., 2016). Both seed species had lower or similar porosity to Bambara groundnut (Mubaiwa et al., 2017), Jack bean (Mpotokwane et al., 2008), and lentil (Kumar et al., 2016). The coat weight percentage of *Zamnè* was higher compared to chickpeas (5–7%) (Avola & Patane, 2010), lentils (8–11%) (Dueñas, Hernández, & Estrella, 2002), and faba beans (15–17%) (Avola, Gresta, & Abbate, 2009), but similar to lupins (22–32%) (Miao, Fortune, & Gallagher, 2001). Still, the coat thickness of *Zamnè* (9–12 mg/cm^2) was lower compared to faba beans (16–28 mg/cm^2) (Avola et al., 2009) but similar to chickpeas (8–12 mg/cm^2) (Avola & Patane, 2010).

The different physical properties are directly associated with the processability of seeds. The moisture content indicates *Zamnè* as hard and dry seeds, which must have good storability (Mubaiwa et al., 2017; Shehata, 1992). The physical dimensions will determine operations for the grading, sorting, and storage of *Zamnè*. For instance, the flat shape will enable *Zamnè* seeds to slide and occupy less volume or space, which is interesting for designing storage facilities. Bulk density is useful for monitoring the seeds' quality, while true density will support cleaning and grading operations (Kumar et al., 2016; Mpotokwane et al., 2008; Mubaiwa et al., 2017). Porosity is supposed to ease fluid, air, and heat flow through seed bulk during processing operations (Kumar et al., 2016; Mpotokwane et al., 2008; Mubaiwa et al., 2017). The low porosity of *Zamnè* may, therefore, pose constraints in operations such as soaking, heating, cooling, and drying. Finally, the coat may provide numerous functional properties to *Zamnè*, such as biofunctional nutrients and protection against insect attacks during storage (Dueñas et al., 2002; Miao et al., 2001; Mubaiwa et al., 2017). Besides, the coat can pose hard-shell concerns, such as low digestibility, hydration properties, and processability or cookability (Miao et al., 2001; Mubaiwa et al., 2017) - which is discussed in sections below.

3.3. *Variability in the cooking properties*

PseudoZamnè were twice harder to cook than *Zamnè* (Table 1) and were associated with darker (Fig. 1) and hard coat after cooking. Nonetheless, both seed species were identified as hard-to-cook legumes (cooking time more than 120 min) (Kinyanjui et al., 2015). Guissou et al. (2017) reported that *Zamnè* is traditionally cooked by boiling for 140–300 min in an alkaline solution. The cooking times' differences may be associated with either the seed qualities (like hard-to-cook defects), a mix-up of *Zamnè* with *pseudoZamnè*, or the culinary practices. *Zamnè* showed a comparable cooking time to several staple legumes, *i.e.* lentils (75–180 min), cowpeas (~145 min), common beans (90–450 min), soybeans (~220 min), and Bambara groundnuts (180–240 min) (de León, Elías, & Bressani, 1992; Iliadis, 2001; Kinyanjui et al., 2015; Mubaiwa et al., 2017). As cited, staple legumes also require variable cooking intensity according to the seeds' quality and cooking techniques.

The hydration kinetics and indices of selected *Zamnè* and *pseudoZamnè* samples during cooking were assessed, and the results are presented in Fig. 2 and Table 1, respectively. The hydration kinetics of the selected *Zamnè* samples overlapped and reached maximum hydration after 45 min of boiling. In contrast, the *pseudoZamnè* showed a twice slower hydration rate but reached a similar hydration capacity after 2 h. The hydration capacity has been reported to be between 80 and 200 g H_2O/ 100 g dw for common legumes (Avola et al., 2009; Kinyanjui et al., 2015; Kumar et al., 2016; Mubaiwa et al., 2017; Uzogara, Morton, & Daniel, 1988). The higher hydration capacity of *Zamnè* and *pseudoZamnè* can be explained in that *Acacia* species can develop superior drought tolerance through high cell wall elasticity and large cell sizes with high water holding capacity (Diallo, Nielsen, Kjær, Petersen, & Ræbild, 2016). Moreover, Kinyanjui et al. (2015) reported a slower hydration rate (<1.5 g H_2O / 100 g dw.min) during the cooking of both selected easy- and hard-to-cook beans. These observations mean that *Zamnè* had quite good hydration properties and that the hard-to-cook problem was not only associated with the hydration ability (Avola & Patane, 2010; Kigel, 1999; Shehata, 1992).

3.4. Mapping of the overall variability in the physicochemical properties

As mapped in Fig. 3, *Zamnè* had low overall variability, and most of the samples (ZKr, ZOr, ZWr1, ZWr2, and ZWr3) formed a cluster. Only ZTGr and ZDr were isolated due to the difference in their carbohydrate digestibility. The *pseudoZamnè* sample (spZDr) was separated from *Zamnè* through fat and ash contents, seed weight, seed density, hydration rate, coat percentage, and coat thickness. The visual identification of the collected *pseudoZamnè* was not conclusive. In line with indigenous people's assertion, *pseudoZamnès* are mainly identified through their hard-to-cook characteristics compared to *Zamnè*. The case of the fraudulent seeds (spZDr) let us suppose that people can be easily fooled with *pseudoZamnès* for *Zamnè*. The compositional properties and the edibility for humans of *pseudoZamnès* are scarcely substantiated. Since the toxicological profiles of *Acacia* seeds are not well documented, consumers must be cautious not to eat the not well-known species (Rinaudo, Patel, & Thomson, 2002).

3.5. Hard-to-cook phenomenon examination

Table 2 designates Pearson's correlations between the chemical, physical and cooking properties of the purchased *Zamnè* and *pseudoZamnè*. The correlations were explored to identify interrelationships that may indicate the development of the hard-to-cook phenomenon. Only few parameters showed significant ($p < 0.01$) correlations. Protein content, insoluble dietary fiber content, seed diameter, seed weight, coat percentage, and coat thickness were strongly correlated negatively. Also, fat content, ash content, seed diameter, seed weight, seed densities, coat percentage, and coat thickness were strongly correlated negatively. On the other hand, ash content, seed diameter, seed weight, seed bulk density, coat percentage, coat thickness, and cooking time were strongly correlated positively. The hydration rate, for instance, strongly correlated positively with fat content but negatively

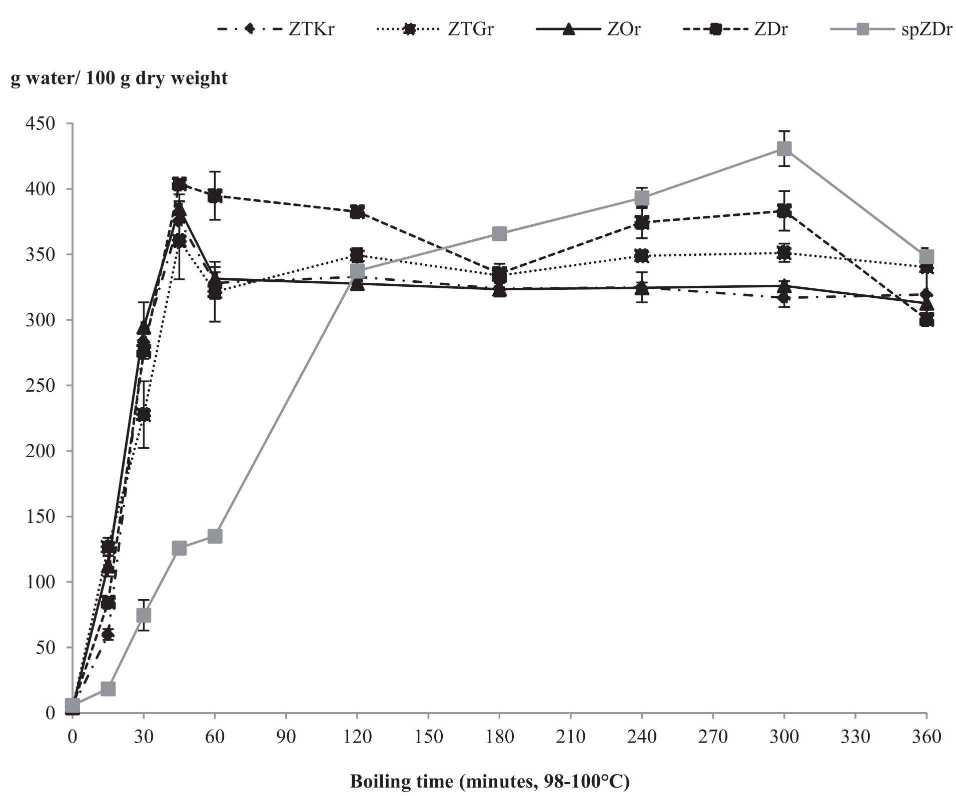

Fig. 2. Compared hydration kinetics of *Zamnè* and *pseudoZamnè*. The values are expressed as the means ± SD (n = 2). ZTKr, ZTGr, ZOr, and ZDr represent harvested control *Zamnè* from the field in Toma-Kamba and purchased *Zamnè* samples from the local markets in Toma-Gassam, Ouahigouya, and Dedougou. spZDr represents the *pseudoZamnè* purchased from the local market in Dedougou.

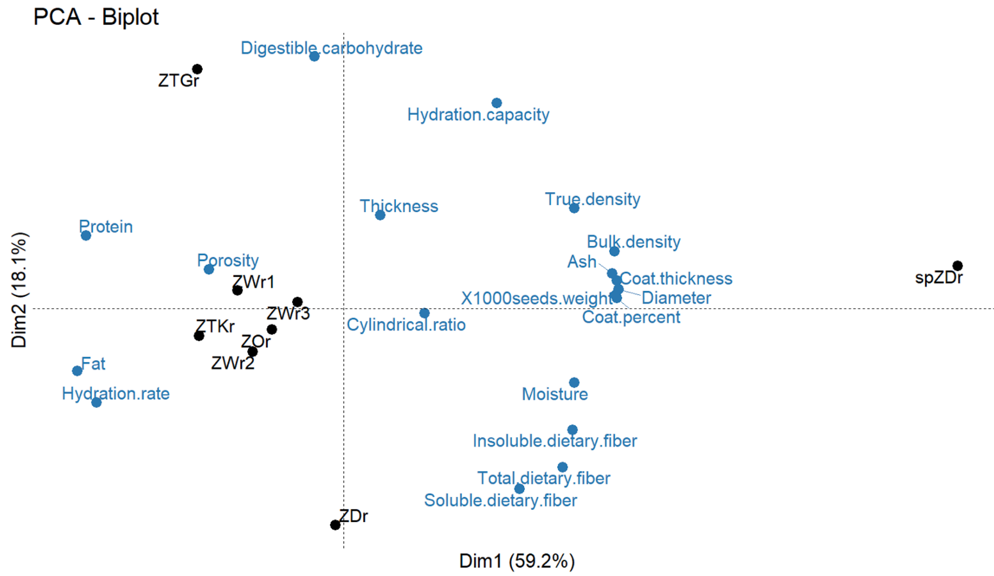

Fig. 3. Mapping of the variability in the physicochemical characteristics of *Zamnè* and *pseudoZamnè* purchased from the local markets in Burkina Faso Z, spZ, (W, O, TG, TK, D), and the indices (1–3) designate *Zamnè*, *pseudoZamnè*, towns (Ouagadougou, Ouahigouya, Toma-Gassan, Toma-Kamba, and Dedougou), and the number of the markets inspected, respectively. ZTKr represents the control sample harvested from field.

Table 2
Interrelationships (r of Pearson) among the chemical, physical and cooking properties of *Zamnè* and *pseudoZamnè* purchased from the local markets in Burkina Faso.

	Fat	TDF	IDF	SDF	Ash	Moist.	Da	Sw	Bd	Td	Coat %	Ct	H. rate	C. time
Protein	0.70	−0.91	−0.97	−0.71	−0.74	−0.76	−0.86	−0.87	−0.80	−0.58	−0.86	−0.85	0.70	−0.86
Fat		−0.60	−0.65	−0.46	−0.97	−0.77	−0.89	−0.86	−0.95	−0.85	−0.85	−0.86	0.97	−0.99
TDF			0.95	0.92	0.66	0.88	0.75	0.76	0.62	0.38	0.75	0.70	−0.47	0.69
IDF				0.75	0.66	0.79	0.83	0.83	0.74	0.40	0.82	0.76	−0.51	0.71
SDF					0.56	0.88	0.54	0.57	0.38	0.31	0.57	0.53	−0.35	0.56
Ash						0.79	0.84	0.82	0.90	0.79	0.88	0.89	−0.97	0.99
Moist.							0.73	0.74	0.72	0.69	0.62	0.67	−0.60	0.79
Da								1.00	0.96	0.78	0.87	0.86	−0.89	0.97
Sw									0.94	0.79	0.84	0.85	−0.89	0.97
Bd										0.81	0.87	0.87	−0.91	0.96
Td											0.72	0.82	−0.83	0.85
Coat %												0.98	−0.90	0.98
Ct													−0.91	0.98
H. rate														−0.96

TDF, IDF, and SDF designate total, insoluble, and soluble dietary fiber contents, respectively. Moist., Da, Sw, Bd, Td, Ct, H. rate and C. time designate moisture content, seed arithmetic diameter, seed weight, bulk density, true density, coat thickness, hydration rate, and cooking time, respectively. Dark gray, medium gray, light gray and white background highlight value with $p < 0.001$, < 0.01, < 0.05 and > 0.05, respectively. The parameters without any significant correlation are omitted.

with ash content. The relationships between the physicochemical and cooking properties of legumes vary (Avola & Patane, 2010). Nonetheless, comparable correlations have been reported for chickpeas and faba beans (Avola et al., 2009; Avola & Patane, 2010). Several of the correlations suggest that *Zamnè* is exposed to the development of the hard-to-cook phenomenon. For instance, the negative correlation of the hydration rate and the positive correlation of the cooking time with the ash content suggest that the seeds might have accumulated different divalent cations (*i.e.* calcium and magnesium) contents. The cations can complex with cell wall structures (including pectins, phytate, and lignins) and render the seeds resistant to water hydration and cooking (Kigel, 1999; Mubaiwa et al., 2017; Shehata, 1992). Also, the negative correlations between protein content, insoluble fiber content, and the coat thickening indicate hard-to-cook traits that can develop during the storage. In fact, during storage, seeds undergo critical changes, which implicate hard-to-cook defects, protein degradation, lignification, and accumulation of several insoluble and indigestible polymers (Gwala et al., 2019; Iliadis, 2001; Kigel, 1999; Mubaiwa et al., 2017; Shehata, 1992). *Zamnè* is a famine-resilience commodity that can be stored for several years before consumption. There is, therefore, a need to further assess the development of the hard-to-cook phenomenon in *Zamnè*.

3.6. Cooking aids properties

Zamnè is traditionally boiled in an alkaline solution (traditional potash or baking soda) to facilitate the cooking. The influence of the cooking aids and the heat on the hydration properties were examined (Fig. 4). In most soaking conditions, *Zamnè* showed higher hydration indices than *pseudoZamnè,* except for the first hour of soaking in the fresh and boiled tap water. As an effect of the initial soaking water temperature, the hydration was accelerated (after 3 h of soaking) for both seed species. In contrast, the hydration capacity (after 6 h of soaking) was improved for only *Zamnè*. Kumar et al. (2016) and Kinyanjui et al. (2015) also reported that the water temperature improves the hydration rate and capacity. The heat loosens the seeds' tissue structures and, thus, triggers and accelerates the hydration (Kinyanjui et al., 2015; Kumar et al., 2016). The non-improvement in the hydration capacity of the *pseudoZamnè* provided evidence that hydration and hardness are more dependent on the cotyledon hardness and permeability than the coat hardness and permeability. Moreover, the

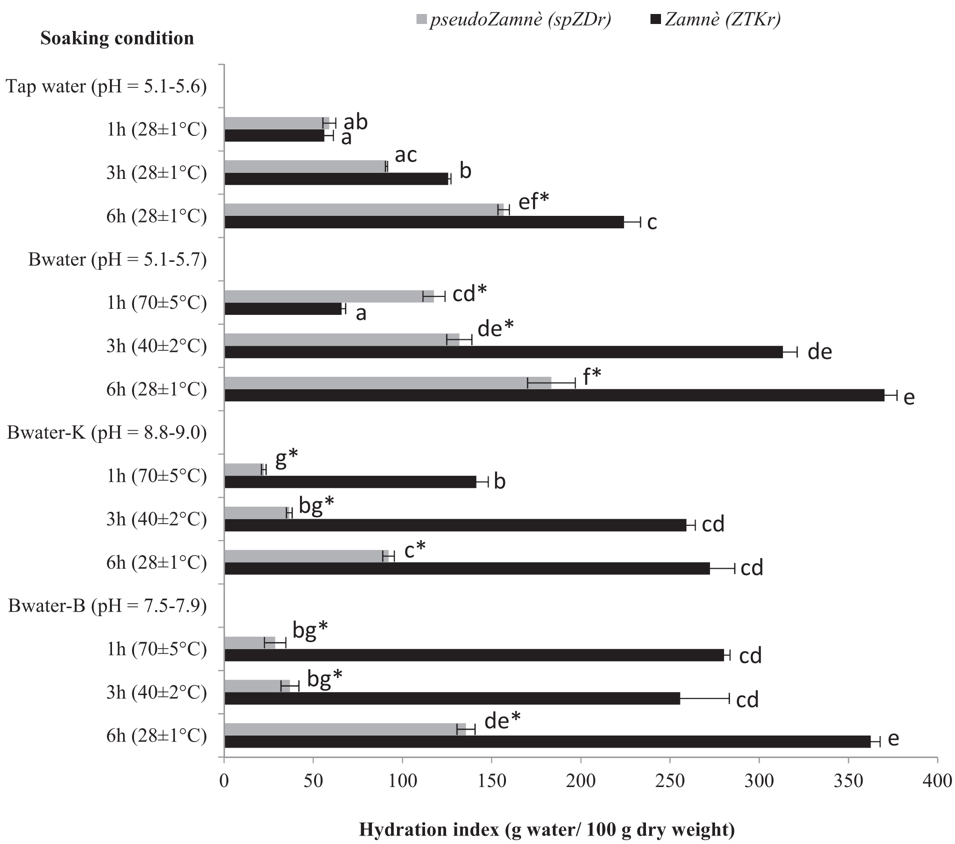

Fig. 4. Influence of the heat and cooking aids on the hydration ability of *Zamnè* and *pseudoZamnè*. Bwater, Bwater-K, and Bwater-B designate respectively boiled tap water, boiled potash solution (1% m/m), and boiled baking soda solution (1% m/m). The values are expressed as the means ± SD (n = 2). The hydration indexes sample-wise (same color) with the different letter superscripts are significantly different ($p > 0.05$). The superscript * indicates the significant differences between the hydration indexes of *Zamnè* and the *pseudoZamnè* at a specific soaking condition and time.

cooking aids, synergistically with the heat, improved the hydration activation (after 1 h of soaking), rate, and capacity for *Zamnè*. The cooking aids, similar to the heat, have also been shown to induce cell wall constituents' release and, thus, improve hydration, too (Kinyanjui et al., 2015; Mubaiwa et al., 2017). The hydration ability of the *pseudoZamnè* was, contrary, hampered by the use of the traditional potash. In agreement, Avola and Patane (2010) noted a slight decrease in chickpeas' hydration capacity when soaked in a sodium bicarbonate solution. The different effects suggest that the actions of cooking aids depend on the seed species, probably related to their intrinsic chemical compositions and the ion compositions of the cooking aids (de León et al., 1992; Kigel, 1999; Kinyanjui et al., 2015; Mubaiwa et al., 2017; Shehata, 1992).

Compared to the traditional potash, the baking soda elicited a more considerable improvement in both seed species' hydration. The baking soda has a lower (trace) amount of divalent cations (*i.e.* calcium and magnesium) and a higher amount of carbonate anions compared to the traditional potash (unpublished data), which would have favored the water absorption. It has been proposed that divalent cations permeate into the seeds, induce stable cross-links between cell wall structures (pectins, phytate, phenolics, proteins), and thus prone hardness and resistance to hydration (de León et al., 1992; Kigel, 1999; Kinyanjui et al., 2015; Mubaiwa et al., 2017; Shehata, 1992). Moreover, alkali has been demonstrated to induce protein denaturation and cross-links (Guo, Wei, & Zhu, 2017; Mubaiwa et al., 2017), which can also result in the tightness of the tissue structures of the seeds (Kigel, 1999; Shehata, 1992), counteracting the effect of the cooking aid. Conversely, monovalent cations have been shown to alter pectins or cell wall structures and facilitate the soaking and cooking of seeds (de León et al., 1992; Kigel, 1999; Kinyanjui et al., 2015; Mubaiwa et al., 2017; Shehata, 1992). The carbonate anions, for instance, play a buffer role, prevent protein denaturation, and partially with the alkaline condition reduce the hard-to-cook problem (Mubaiwa et al., 2017; Shehata, 1992). These observations mean that one must be cautious in choosing the alkali salt as a cooking aid - taking into account the seeds' specific response to the cooking process and the alkali salt pH, buffer systems, and ion compositions.

3.7. Impact of the traditional cooking on the nutritional values

The compositional changes associated with the traditional alkaline and hydrothermal cooking of selected *Zamnè* and *pseudoZamnè* samples are summarized in Table 3. Total protein contents were significantly increased only after cooking (second boiling) for *Zamnè* while it was observed through the precooking (first boiling) in the case of *pseudoZamnè*. As a consequence of the cooking, the protein dispersibility index in water significantly decreased by 4–6% and 13% for *Zamnè* and *pseudoZamnè*, respectively. The protein dispersibility indexes of the cooked *Zamnè* and *pseudoZamnè* were comparable to the values reported for adequately heat processed soybean meal (40–45%), suggesting protein digestibility improvement (Batal, Douglas, Engram, & Parsons, 2000). In contrast, the cooking process highly decreased carbohydrate digestibility. The digestible carbohydrates and soluble dietary fibers were almost all lost, and only insoluble dietary fibers were left. Similarly, Guissou et al. (2017) reported a significant decrease in total carbohydrate content and an increase in crude fiber content after *Zamnè* cooking. Only fat content showed to be affected by the cooking aid choice. Processing *Zamnè* in baking soda showed significant improvements in fat content compared to the processing in potash solution. The fat content increased stepwise between precooking and cooking for *pseudoZamnè* while it first increased after precooking and then decreased after cooking for *Zamnè*. Guissou et al. (2017) had reported a much higher decrease (more than 85%) in fat content in potash-cooked *Zamnè*. Nonetheless, the fat content has been well preserved in most of the legumes after boiling (FAO/INFOOD, 2017; Murphy et al., 1975). Moreover, an increase has also been reported for related *Acacia* seeds (10.9 to

Table 3
Effect of the cooking processes on the nutritional properties of *Zamnè* and *pseudoZamnè*.

Sample	*Zamnè* (ZTKr)					*PseudoZamnè* (spZDr)				
	Raw	Precooked		Cooked		Raw	Precooked		Cooked	
Cook aid		Potash	Baking soda	Potash	Baking soda		Potash	Baking soda	Potash	Baking soda
Protein	43.55 ± 0.55^{a}	44.66 ± 0.01^{a}	43.53 ± 0.01^{a}	49.80 ± 1.40^{b}	46.28 ± 0.41^{ab}	35.99 ± 0.07^{c}	43.85 ± 0.21^{a}	45.48 ± 0.08^{a}	45.31 ± 0.54^{a}	44.53 ± 0.63^{a}
PDI%	50.05 ± 1.15^{a}			44.39 ± 1.75^{b}	46.35 ± 0.01^{bc}	61.65 ± 0.14^{d}			48.36 ± 0.22^{ac}	48.61 ± 0.21^{ac}
TDF	22.03 ± 0.86^{a}			27.74 ± 1.21^{ab}	26.01 ± 1.78^{ab}	32.63 ± 1.70^{b}			31.82 ± 2.25^{b}	28.08 ± 1.48^{ab}
IDF	14.26 ± 0.33^{a}			22.00 ± 1.50^{ab}	24.08 ± 0.34^{b}	22.54 ± 3.52^{ab}			24.07 ± 1.36^{b}	21.53 ± 6.13^{ab}
SDF	7.77			5.75	1.92	10.08			7.74	6.56
DCHO	20.22			1.05	3.60	21.56			9.51	11.52
Fat	10.26 ± 0.03^{a}	20.97 ± 0.94^{b}	23.65 ± 0.19^{c}	14.61 ± 0.44^{d}	17.18 ± 0.38^{e}	4.70 ± 0.08^{f}	5.33 ± 0.21^{fg}	7.24 ± 0.11^{h}	6.02 ± 0.01^{g}	8.42 ± 0.01^{i}
Ash	3.93 ± 0.20^{a}	4.76 ± 0.06^{b}	4.07 ± 0.37^{ab}	6.80 ± 0.01^{cd}	6.93 ± 0.12^{cd}	5.13 ± 0.15^{b}	6.41 ± 0.43^{c}	5.57 ± 0.28^{e}	7.35 ± 0.01^{d}	7.45 ± 0.11^{d}

PDI% = Protein dispersibility index, TDF = total dietary fiber, IDF = insoluble dietary fiber, SDF = soluble dietary fiber and DCHO = digestible carbohydrate. The values are expressed as the means ± SD (n = 2) per 100 dry weight. The values in the same row with the different superscripts are significantly different ($p < 0.05$).

18.9% of fat per dw) (Adewusi, Falade, & Harwood, 2003). Finally, the cooking aids' minerals increased stepwise the ash contents between precooking and cooking for both seed species.

Food matrix composition changes after cooking are associated with leaching, restructuration, and destruction of nutrients (Deng et al., 2015; Murphy et al., 1975). Accordingly, the leached solids were analyzed to understand the changes associated with the traditional cooking process of *Zamnè* (Table 4). *Zamnè* exhibited extensive and higher leaching of total dry matter, protein, carbohydrate, and ash compared to the *pseudoZamnè*. In contrast, the total leaked solids have been, generally, reported to be <20% for common legumes and composed mainly of carbohydrates (57–80% dw), proteins (6–21% dw), and ash (7% dw) (Güzel & Sayar, 2012; Uzogara et al., 1988). Nutrient retention during cooking of legumes can significantly vary depending on the seeds' cooking quality and the cooking process. Contrary to common legumes, *Zamnè* underwent a long precooking, which might have promoted the nutrients' leaching. The washing and the renewing of the boiling solution have been shown to accentuate solutes exchanges and leaching (Mubaiwa et al., 2017). In the present study, the hardness (resistance to cell disintegration) and the higher fiber contents of the *pseudoZamnè* might have entrapped the nutrients and prevented their leaching, despite the longer boiling time, compared to *Zamnè*. Besides, nutrient solubility was also demonstrated essential in the loss through leaching (Deng et al., 2015). For instance, the leached carbohydrate should probably be composed of soluble fibers and digestible carbohydrates, as shown through the large decrease in the cooked seeds (Table 3). On the other hand, despite the higher reduction of the seeds' fat content after cooking in the potash solution compared to the cooking in the baking soda solution (Table 3), a higher fat content was recovered in the baking soda solution. Potash has higher alkaline and saponification potential than baking soda (Mubaiwa et al., 2017) and might have induced a higher fat reduction in the form of alkali fatty salts.

The current trend in food processing is to achieve optimal utilization of food raw materials (Galanakis, 2012). The traditional cooking of *Zamnè* exposes the seeds to high alkaline and long heat treatment, which, in addition to the leaching of water-soluble nutrients, might lead to potentially toxic breakdown products (Friedman & Levin, 2012; Hou et al., 2017). There is a need to explore alternative processes to optimize the use of *Zamnè* raw seed material. Several techniques have been developed to address the hard-to-cook defects in legumes (Mubaiwa et al., 2017; Shehata, 1992) and apply to *Zamnè*. Moreover, the recycling of nutrients from food wastewater receives more attention in food processing (Galanakis, 2012). The enzymatic hydrolysate of *Zamnè* carbohydrate and protein extracts have already been exploited in formulations of nutraceuticals and cosmetics against hair loss, adipose tissue alterations, and vascular disorders (Msika et al., 2017). The wastewater after *Zamnè* cooking is, as shown, a source of nutrients, including dietary fibers and proteins. Further processing of *Zamnè* wastewater can recover the fibers and proteins, valuable as nutraceuticals and cosmetics supplements.

4. Conclusion

This study showed low variability in the physical, chemical, and cooking properties among *Zamnè* seeds and confirmed a mix-up of *Zamnè* and *pseudoZamnè*. The collected *pseudoZamnè* exhibited low cooking quality, harder coat, and longer cooking time, while *Zamnè* showed comparable cooking quality traits to several common legumes. However, the traditional cooking process of *Zamnè* exhibited over processing defects, including fat destruction and extensive leaching of nutrients. It would be useful to investigate other processing alternatives, such as milling into flour or fermentation, to increase the acceptability of *Zamnè*. Moreover, further research is needed to identify the factors that influence the variability in the physicochemical properties of *Zamnè*.

Table 4
Proximate composition of the combined leached solids after the precooking and cooking of *Zamnè* and *pseudoZamnè*.

Samples	Cook aid	Dry matter	Protein	Total carbohydrate	Fat	Ash
Zamnè (ZTKr)	Potash	49.24	45.29 ± 0.43^{a} (51.20)	40.75 (47.49)	0.20 ± 0.03^{a} (0.97)	13.76 ± 0.09^{a}
	Baking soda	50.40	45.21 ± 0.76^{a} (52.32)	42.11 (50.23)	0.63 ± 0.11^{b} (3.08)	12.06 ± 0.15^{b}
PseudoZamnè (spZDr)	Potash	32.38	46.46 ± 1.06^{a} (41.81)	45.57 (27.23)	0.24 ± 0.06^{a} (1.66)	7.72 ± 0.05^{c}
	Baking soda	39.48	44.71 ± 1.01^{a} (49.04)	47.28 (34.44)	0.31 ± 0.09^{ab} (2.59)	7.71 ± 0.13^{c}

The values are expressed as the means ± SD (n = 2) per 100 dry weight. The values in the same row with the different superscripts are significantly different ($p < 0.05$). The parentheses represent % nutrient loss (dry weight) from the used raw seeds for the cooking trial.

CRediT authorship contribution statement

Moustapha Soungalo Drabo: Conceptualization, Investigation, Methodology, Formal analysis, Writing - original draft. **Habtu Shumoy:** Formal analysis, Writing - review & editing. **Hama Cissé:** Resources. **Charles Parkouda:** Resources. **Fulbert Nikiéma:** Resources. **Ismail Odetokun:** Resources. **Yves Traoré:** Resources. **Aly Savadogo:** Conceptualization, Validation, Writing - review & editing, Supervision. **Katleen Raes:** Validation, Formal analysis, Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

Acknowledgments

The authors are grateful to the National Laboratory of Public Health (Burkina Faso) for the laboratory facilities and reagents. The first author is granted by UEMOA, Burkina Faso national, and Ghent University – BOF Ph.D. scholarships.

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