

Full Length Research Paper

Effects of microwave heating on textural properties of morama (*Tylosema esculentum*) beans

Pius Emesu^{1*}, Oarabile Dambe² and Rosemary Ikalafeng Kobue-Lekalake²

¹Department of Agricultural and Biosystems Engineering, Botswana University of Agriculture and Natural Resources, Sebele, Private Bag 0027, Gaborone, Botswana.

²Department of Food Science and Technology, Botswana University of Agriculture and Natural Resources, Sebele, Private Bag 0027, Gaborone, Botswana.

Received 11 July, 2024; Accepted 7 November, 2024.

Morاما beans were heated for 60, 90, and 120 s at 200, 600, and 1000 W using a domestic microwave oven to assess their potential as a pre-decortication treatment and to evaluate the effects on peak force, work, and modulus of deformability, which are key textural properties determined by compression using a texture analyzer. One sample was left unheated as a control for comparison. Bean temperatures after microwave heating ranged from 33 to 86°C, with rates of temperature increase of 0.09, 0.32, and 0.61°C/s at 200, 600, and 1000 W, respectively. Peak force significantly decreased ($p < 0.05$) from 579.3 N in the control sample to 437.2 N in the sample heated for 60 s at 600 W, while the work done during compression did not differ significantly with microwave heating ($p > 0.05$) and ranged from 469.9 to 313.7 Nmm. Similarly, the modulus of deformability did not change significantly ($p > 0.05$) with microwave heating and ranged from 34.3 to 24.2 MPa. It can be concluded, therefore, that microwave heating of morاما beans can affect their textural properties in a way that facilitates cracking during decortication, and there is potential for further optimization of the process.

Key words: Microwave heating, morاما beans, textural properties, pre-decortication treatment.

INTRODUCTION

Morاما (*Tylosema esculentum*), also known as marama or gemsbok bean, is a nutritious wild legume native to the hot and arid regions of Southern Africa. It occurs in the desert areas of Botswana and Namibia, as well as in the western and north-western Transvaal and northern Cape regions of South Africa, where it forms an important part of the diet of local indigenous communities (Castro et al., 2005; van der Maesen, 2006). In Botswana, it is found in the districts of Ghanzi, Kgalagadi, Kweneng, Southern, and Kgatleng. Morاما is a perennial plant that produces trailing, prostrate stems up to 3 m long. It yields two to

three seeds enclosed in a thick pod and also has an edible underground tuber. Fresh morاما beans are bitter and require cooking to make them palatable, while dry beans may be roasted and consumed as a tasty snack. The cotyledons can also be pressed for oil, ground into powder, or milled into a paste to be used in various applications, such as ingredients in baked goods or as morاما butter (Kgosikoma et al., 2020; Patterson et al., 2018). Morاما seeds contain approximately 30% protein, 40% oil, and several biologically active phytonutrients (Kobue-Lekalake et al., 2022; Mazimba et

*Corresponding author. E-mail: pemesu@buan.ac.bw; pemesu@yahoo.com.

al., 2011; Mosele et al., 2011). Although currently underutilized, the bean has garnered attention as a plant species with the potential to improve food and nutrient security, as well as to increase household incomes through value-added processing (Cullis et al., 2023; Jackson et al., 2010).

The morama seed coat (cortex) has high mechanical strength due to its woody nature, making it difficult to decorticate by cracking (Emesu and Mabuza, 2014; Tijparuro, 2013). This presents a major challenge for its processing and utilization. Traditionally, to aid cracking, the beans are mixed with sand and roasted in a pot for 15 to 45 min, after which they are manually cracked by hitting them with sticks or stones. During traditional roasting, it is difficult to control the temperature and achieve uniform heat distribution, which often leads to the beans being burned (Patterson et al., 2018). Additionally, these traditional methods lack the sanitary conditions necessary for commercial processing. Studies by Mmonatau (2005) and Maruatona (2008), where morama was roasted at 100 to 150°C for 20 to 40 min, have shown that roasting at 150°C for 20 min is optimal for developing desirable sensory characteristics and inactivating trypsin inhibitors. These optimal conditions were later adopted by Nyembwe et al. (2015), who used an electric forced convection roaster and found that roasting for longer than 20 min increased bitterness. However, none of these studies examined the effects of roasting on the textural properties of the beans, which are crucial for decortication. Furthermore, to reduce electricity costs, it would be ideal to shorten the processing time.

Nguyen et al. (2019) utilized microwaves to decorticate tamarind seeds—whose mechanical properties are similar to those of morama beans (Mohite et al., 2019; Emesu and Mabuza, 2014)—and found that heating the samples at 850 W for at least 180 s completely removed the seed coat. However, prolonged heating for 210 s produced darker end products. Bolek and Ozdemir (2017) examined the effects of microwave power and heating time on various properties of *Pistacia terebinthus* beans and found that, as microwave power and heating time increased, the breaking force significantly decreased. In a study comparing microwave and conventional oven roasting of sunflower seeds, Goszkiewicz et al. (2020) did not observe significant differences in texture and sensory characteristics as a function of the roasting methods and their intensities. Nevertheless, the study recommended microwave heating over conventional roasting because microwave treatment seemed to improve seed oil quality and protect against oxidative rancidity, as it did not adversely affect seed porosity. Additionally, Schouteten et al. (2023) found that microwave roasting of cocoa produced superior product quality compared to conventional roasting—though the difference was not statistically significant—while achieving a notable 75% reduction in energy consumption. Shayanfar and Kashaninejad (2012) and Kouchakzadeh (2013) used

microwaves to split pistachio nuts, reporting 25% splitting at 900 W for 3 min, and 100% splitting at 540, 720, and 900 W after 16 min of irradiation, respectively. The comprehensive review by Kutlu et al. (2022) on the impacts of microwaves on food texture under different application scenarios highlighted the time-saving, rapid heat generation, and good product quality advantages of the technology, though it also emphasized the need for process optimization to maximize these benefits. Given the potential of microwaves to reduce heating time and save energy while preserving the quality of various foods, the current report investigates the effects of microwave heating on the textural properties of morama, which are relevant to its mechanical decortication.

Textural properties of foods, as defined by Bourne (2002), refer to a group of physical characteristics resulting from the structural elements of the food, which are primarily sensed by consumers through touch. These properties are related to the deformation, disintegration, and flow of food under force and can be measured objectively through functions of mass, time, and distance using instruments such as texture analyzers. These properties are essential in describing food product quality, consumer acceptance, process control, and the design of machinery for handling and processing solid foods (Alade et al., 2020; Jokanović et al., 2012; Rao and Quintero, 2014; Sinha and Bhargav, 2020). Parameters that can be derived from texture analyzers to describe food texture include peak force (N), work (Nmm or Joule), and modulus of deformability (Pa), which are related to terms such as firmness, hardness, strength, and stiffness of food materials.

MATERIALS AND METHODS

Microwave treatment procedure

Raw morama beans were obtained from various locations in southern Botswana, and random samples of 20 beans at a time were heated at 200, 600, and 1000 W for 60, 90, and 120 s in a 34 L capacity domestic microwave (Model DMO 343, Defy Appliances, Durban, South Africa) with an input power rating of 1300 W and a microwave power output rating of 1000 W at 2450 MHz. The treatments were conducted in triplicate, and compression testing was performed after the beans had cooled to room temperature. An infrared thermometer (Model HE8830, Huato, Shenzhen, China) was used to measure the average surface temperature of the beans immediately after each run, and the rate of temperature increase, dT/dt (°C/s), was calculated as follows:

$$dT/dt = \frac{T_f - T_i}{t}$$

where T_f and T_i represent final and initial temperature (°C), respectively, and t is the heating duration (s). For each power level, an average rate of temperature increase was computed from the three time settings used. Morama bean moisture content was determined using the AOAC method 925.10 (AOAC, 2005) by oven drying at 130°C for 1 h.

Determination of textural properties

To measure the textural properties of morama beans, a universal materials testing machine (Model LR 10K Plus, Lloyd Instruments/Ametek Inc., West Sussex, UK) equipped with a 10,000 N load cell was used to compress individual beans along the lateral axis (with the bean lying normally on its side) using a 140 mm diameter flat aluminium plate. The crosshead was set to run at a speed of 30 mm/min and to stop compression at 20% strain. The diameter and thickness of each morama bean were measured using a digital vernier caliper (Model M5 0-300 mm, TA, China) with 0.01 mm precision for calibration prior to each test, which was repeated 20 times to complete one batch. Using the pre-installed NEXYGEN Plus Data Analysis Software (Lloyd Instruments/Ametek Inc., West Sussex, UK), peak force or maximum load (N), work or energy (Nmm), and modulus of deformability or apparent Young's Modulus (MPa) were calculated as descriptors of morama's textural properties.

Data processing and analysis

Microsoft Excel Spreadsheet (Microsoft 365, Release 16.0) was used to capture and process data, while the R Statistical Environment, version 4.4.0 (R Core Team, 2024), was used to establish statistical inferences at $\alpha = 0.05$ through analysis of variance (ANOVA) and Tukey HSD tests. R was also used to visualize treatment effects using response surface and contour plots from the response surface methodology (RSM) package (Lenth, 2009). Prior to generating the surface and contour plots, mean normalization was applied to scale all variables (x_c) to lie within the range $-1 \leq x_c \leq 1$, using the following formula adopted from Kocabaş (2001):

$$x_c = \frac{x - \mu}{s}$$

where x is variable value being scaled, μ is the mean value for the variable, and s is the range (difference between the maximum and minimum value) for the variable.

RESULTS AND DISCUSSION

Moisture content and rate of temperature increase

Moisture content in foods influences their ability to absorb microwave energy and, consequently, their heating characteristics (Sahin and Sumnu, 2006; Singh and Heldman, 2009). Water molecules, being polar, undergo back-and-forth rotation induced by the rapidly alternating polarity of the microwave electric field, generating heat through molecular friction (Meloni et al., 2023). The mean moisture content of morama beans was determined to be 8.1%, which is higher than the 6.4-6.9% range reported by Jideani et al. (2009). In a study examining the relationship between moisture content and the texture of green coffee beans, Pittia et al. (2007) found that the fracture mechanism shifted from brittle failure at low moisture content to plastic failure at intermediate and higher moisture content.

Temperature changes before and after heating morama beans, along with the computed rates of temperature increase at the different power levels, are presented in

Table 1. As expected, heating the beans for a longer duration resulted in higher final bean temperatures, ranging from 33 to 86°C. The rate of temperature increase also rose with increasing power levels, from 0.09°C/s at 200 W to 0.61°C/s at 1000 W. Combined with technical parameters such as microwave field strength, sample volume, and the dielectric properties of the material being heated, the current results can be used to compute the heating rate of morama beans, which is useful for controlling the microwave heating process (Heldman, 2011; Meloni et al., 2023).

Textural properties

Textural properties are presented in Table 2 as mean values, including standard deviations, while a comparison of the data-fitting models and a summary of the canonical analysis of the second-order RSM model used to fit the data are shown in Tables 3 and 4, respectively. The first-order RSM model was not employed to fit the response variables due to a significant lack of fit for peak force as a function of time and microwave power at the $p < 0.05$ level of significance. The second-order model was deemed suitable and was therefore utilized to fit the data, as all the response variables showed no significant lack of fit at the $p > 0.05$ level of significance (Kocabaş, 2001; Lenth, 2009). Response surface plots, superimposed over their corresponding contours for the textural parameters, are presented in Figures 1 to 3.

The mean peak force required to compress the beans to 20% strain decreased steadily as microwave power and heating time increased, as shown in Figure 1. However, beyond 600 W, peak force was observed to increase with heating time, though this change was not statistically significant. The lowest peak force value was recorded for the sample heated for 60 sec at 600 W, which differed significantly from the control sample at the $p < 0.05$ level of significance. Bolek and Ozdemir (2017) also reported a reduction in hardness as a textural property of microwave-heated *P. terebinthus* beans roasted for 5 to 17 min. The observed reduction in peak force in this study suggests that microwave heating of morama beans has the potential to serve as a pre-decortication thermal treatment, effectively weakening the beans. As shown in Table 4, the canonical analysis of the second-order RSM model predicts that the minimum peak force would occur at a time of approximately 201 sec and a power of approximately 616 W, since both eigenvalues are positive (Kocabaş, 2001; Lenth, 2009).

Work, as a textural parameter, is a measure of the energy expended by the texture analyzer while compressing the sample (Bourne, 2002). During the compression of morama beans, the work done—or energy expended—decreased as a function of microwave power and heating time but did not differ significantly from the control sample. The curvature of the response surface plot (Figure 2) shows that the magnitude of work

Table 1. Rate of temperature increase (°C/s) of morama beans at different microwave power levels (W).

Microwave power (W)	Heating time (s)	Initial bean temperature (°C)	Final bean temperature (°C)	Rate of temperature increase, dT/dt (°C/s)	Mean rate of temperature increase per power level (°C/s)
200	60	27.0	33.0	0.10	0.09
	90	27.1	36.0	0.10	
	120	27.9	38.0	0.08	
600	60	28.3	44.0	0.26	0.32
	90	29.7	60.3	0.34	
	120	28.2	71.7	0.36	
1000	60	32.0	79.4	0.79	0.61
	90	30.0	81.0	0.57	
	120	31.0	86.0	0.46	

Table 2. Textural properties of morama beans as a function of microwave power (W) and heating time (s).

Microwave power (W)	Time (s)	Peak force (N)	sd	Work (Nmm)	sd	Modulus of deformability (MPa)	sd
0 (Control)	0 (Control)	579.3 ^a	159.7	469.9	160.3	34.3	8.6
200	60	506.3	145.0	383.3	178.1	32.2	16.6
	90	483.5	84.1	364.2	117.0	24.2	5.4
	120	484.4	139.3	386.3	166.0	26.1	10.8
600	60	437.2 ^a	91.0	347.2	133.0	24.9	9.2
	90	450.1	149.6	347.0	219.6	24.2	8.5
	120	448.2	136.5	313.7	157.2	25.2	10.0
1000	60	564.7	119.6	466.1	196.3	29.3	9.6
	90	542.0	127.2	389.7	189.4	34.2	23.5
	120	507.4	129.7	354.5	139.0	27.9	5.4

For each parameter, values with the same superscript are significantly different at $p < 0.05$ level of significance.

Table 3. Comparison of RSM models for data fitting.

Parameter	p-value		Lack of fit	
	First order	Second order	First order	Second order
Peak force	0.009724	0.0002409	0.029810	0.882379
Work	0.01582	0.008904	0.37179	0.9694
Modulus of deformability	0.03034	0.01797	0.08243	0.20348

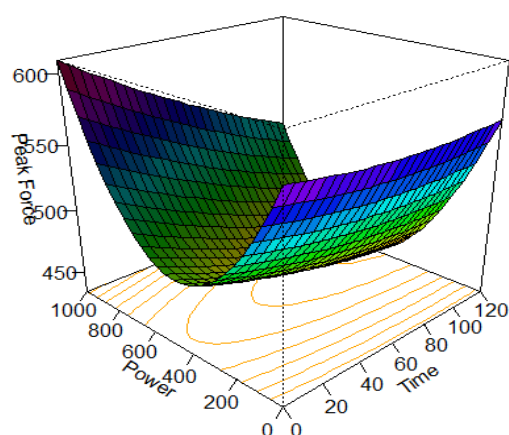
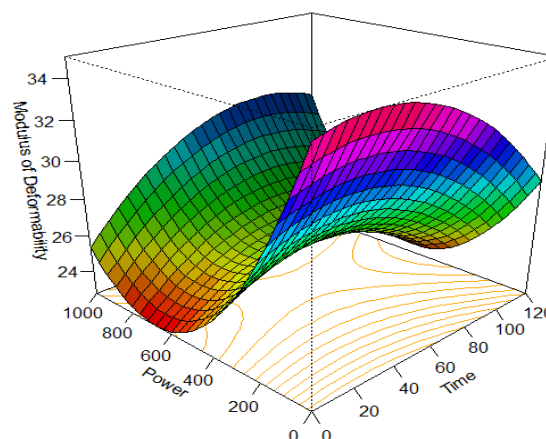
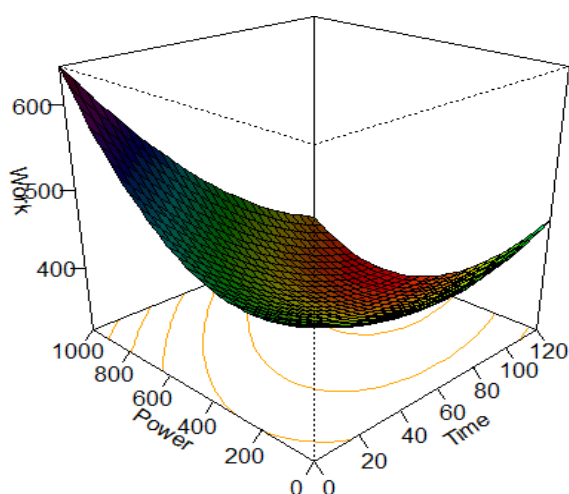
was responsive to both microwave power and heating time. This aligns with the prediction derived from the RSM model, which indicated that increasing microwave power and heating time would lead to further reductions in work (Table 4). During food roasting processes aimed at facilitating cracking, brittle fracture, characterized by low energy absorption (or less work done) up to fracture, is desirable (Bourne, 2002; Rao and Quintero, 2014).

According to Bourne (2002), the term Young's modulus of elasticity is a textural property that measures the

stiffness of elastic materials, whereas "modulus of deformability" or "apparent Young's Modulus" is suggested to refer to the stiffness of non-elastic materials, such as foods. On this basis, the term modulus of deformability is adopted in this report to describe morama beans' resistance to deformation. As seen in Figure 3, the modulus of deformability of morama beans decreased with increasing microwave power and heating time, from a value of 34.3 MPa in the control sample to the lowest value of 24.2 MPa. However, there was no

Table 4. Summary of second order RSM models for texture response variables.

Parameter	p-value	Eigen values	Stationary points	
			Time	Power
Peak Force	0.0002409	0.55520413 0.02673378	201	616
Work	0.008904	0.42621557 0.08563866	138	718
Modulus of Deformability	0.01797	0.22460307 -0.09077868	63	570

**Figure 1.** Peak Force (N) as a function of microwave power (W) and heating time (s).**Figure 3.** Effects of microwave power (W) and heating time (s) on modulus of deformability (MPa) of morama beans.**Figure 2.** Dependence of work (Nmm) on microwave power (W) and heating duration (s).

significant difference ($p > 0.05$) among the data. Low values of modulus were recorded at medium microwave power levels, after which it increased at higher microwave

power levels. A similar trend was observed with heating time, leading to the saddle shape of the surface plot, which was confirmed by positive and negative eigenvalues for time and power (Table 4). This suggests that the stationary point for the modulus of deformability is neither a minimum nor a maximum (Kocabaş, 2001). The RSM plot, therefore, indicates that heating morama beans at intermediate microwave power levels with longer heating durations may be considered an optimization strategy to reduce the stiffness of morama beans.

Conclusions

Morama beans, with a mean moisture content of 8.1% on a wet basis, were heated in a domestic microwave as a potential pre-decortication heat treatment method, and the effects of microwave power and heating duration on their textural properties were determined. Compression testing revealed a significant reduction in peak force required to compress the morama beans to 20% strain ($p < 0.05$), with the lowest peak force recorded at 600 W and a 60 s heating treatment. Furthermore, response

surface modeling estimated that the optimal reduction in peak force could potentially be achieved with prolonged heating for 201 sec at 616 W microwave power settings. However, no significant effects were found on work and modulus of deformability under the test conditions reported herein. Given the potential of microwave heating to significantly weaken the mechanical strength of morama beans in a short period of time, further evaluation at higher treatment intensities and with varying moisture levels is recommended.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The morama beans used in this study were provided through Task 335 of the SASSCAL I Project. The authors gratefully recognize the support and resources made available by this initiative.

REFERENCES

- Alade EI, Koya OA, Omidiji BV (2020). Development of a modified palm-nut cracker. *Agricultural Engineering International: CIGR Journal* 22(1):202-212.
- Association of Official Analytical Chemists (AOAC) (2005). Solids (Total) and Moisture in Flour, Method 925.10. In AOAC (Ed.), *Association of Official Analytical Chemists (18th Edition)*. AOAC International, Gaithersburg.
- Bolek S, Ozdemir M (2017). Optimization of roasting conditions of microwave roasted *Pistacia terebinthus* beans. *LWT* 86:327-336.
- Bourne MC (2002). *Food Texture and Viscosity: Concept and Measurement*, (2nd Edition). Academic Press. San Diego.
- Castro S, Silveira P, Coutinho AP, Figueiredo E (2005). Systematic studies in *Tylosema* (Leguminosae). *Botanical Journal of the Linnean Society* 147(1):99-115.
- Cullis C, Chimwamurombe P, Kunert K, Vorster J (2023). Perspective on the present state and future usefulness of marama bean (*Tylosema esculentum*). *Food Energy Security* 12:e422. <https://doi.org/10.1002/fes3.422>
- Emesu P, Mabuza P (2014). Determination of some engineering properties of morama bean (*Tylosema esculentum*). *Agricultural Engineering International: CIGR Journal* 16(3):180-188.
- Goszkiewicz A, Kołodziejczyk E, Ratajczyk F (2020). Comparison of microwave and convection method of roasting sunflower seeds and its effect on sensory quality, texture and physicochemical characteristics. *Food Structure* 25:100144.
- Heldman D (2011). *Food Preservation Process Design*. Academic Press. Burlington. [https://books.google.com/books?hl=en&lr=&id=EHR9rkKq7JEC&oi=fnd&pg=PP1&dq=Heldman+D+\(2011\).+Food+Preservation+Process+Design.+Academic+Press.+Burlington&ots=Rl8j21e2DR&sig=S0nsZqw92bLA1eEMhZHlm6DjsZg](https://books.google.com/books?hl=en&lr=&id=EHR9rkKq7JEC&oi=fnd&pg=PP1&dq=Heldman+D+(2011).+Food+Preservation+Process+Design.+Academic+Press.+Burlington&ots=Rl8j21e2DR&sig=S0nsZqw92bLA1eEMhZHlm6DjsZg)
- Jackson JC, Duodu KG, Holse M, de Faria MDL, Jordaan D, Chingwaru W, Hansen A, Cencic A, Kandawa-Schultz M, Mpotokwane SM, Chimwamurombe P, de Kock HL, Minnaar A (2010). The Morama Bean (*Tylosema esculentum*). A Potential Crop for Southern Africa. *Advances in Food and Nutrition Research* 61(C):187-246.
- Jideani VA, Van Wyk J, Cruywagen MH (2009). Physical properties of *Tylosemia esculentum* and the effect of roasting on the functional properties of its flour. *African Journal of Agricultural Research* 4(11):208-219.
- Jokanović MR, Džinić NR, Cvetković BR, Grujić S, Odžaković B (2012). Changes of physical properties of coffee beans during roasting. *Acta Periodica Technologica* 43:21-31.
- Kgosikoma K, Mackenzie-Tsedi L, Kelebang B, Ranchobolo T (2020). Market prospects and willingness to pay for indigenous products: The case of Morama (*Tylosema esculentum*). *African Journal of Agricultural Research* 16(7):963-975.
- Kobue-Lekalake RI, Matenanga OK, Sekwati-Monang B, Tibe O, Bultosa G, Seifu E, Molapisi M, Bathophi MG, Gwamba J, Sonno K, Mokhawa G, Phakama T, Haki GD (2022). Indigenous and under-utilised oil seeds of Botswana: proximate composition, phytochemical screening and antioxidant activity. *International Journal of Pharmaceutical Sciences and Research* 13(10):4093.
- Kocabaş Z (2001). An Application and Interpretation of the Second Order Response Surface Model. *Tarım Bilimleri Dergisi* 7(4):121-128.
- Kouchakzadeh A (2013). Microwave thermal shocking assisted pistachios splitting mouth. *Agricultural Engineering International: CIGR Journal* 15(4):270-274.
- Kutlu N, Pandiselvam R, Saka I, Kamiloglu A, Sahni P, Kothakota A (2022). Impact of different microwave treatments on food texture. *Journal of Texture Studies* 53(6):709-736. <https://doi.org/10.1111/jtxs.12635>
- Lenth RV (2009). Response-Surface Methods in R, Using rsm. *JSS Journal of Statistical Software* 32(7):1-17.
- Maruatona GN (2008). Physicochemical, nutritional and functional properties of defatted marama bean flour [MSc Thesis]. University of Pretoria.
- Mazimba O, Majinda RRT, Modibedi C, Masesane IB, Cencić A, Chingwaru W (2011). *Tylosema esculentum* extractives and their bioactivity. *Bioorganic and Medicinal Chemistry* 19(17):5225-5230.
- Meloni E, Iervolino G, Palma V (2023). Basics of Microwave Heating and Recent Advances. In: Hu J, Reddy BM (Eds), *Advances in Microwave-assisted Heterogeneous Catalysis*, vol 45, Royal Society of Chemistry, London pp. 1-24.
- Mmonatau Y (2005). Flour from the morama bean: Composition and sensory properties in a Botswana perspective [MSc Thesis]. Stellenbosch University.
- Mohite AM, Sharma N, Mishra A (2019). Influence of different moisture content on engineering properties of tamarind seeds. *Agricultural Engineering International: CIGR Journal* 21(1):220-224.
- Mosele MM, Hansen ÅS, Hansen M, Schulz A, Martens HJ (2011). Proximate composition, histochemical analysis and microstructural localisation of nutrients in immature and mature seeds of marama bean (*Tylosema esculentum*). An underutilised food legume. *Food Chemistry* 127(4):1555-1561.
- Nguyen TT, Jittanit W, Srichamnong (2019). Production of xyloglucan component extracted from tamarind (*Tamarindus indica*) seeds using microwave treatment for seed decortication. *Journal of Food Processing and Preservation* 43:e14055.
- Nyembwe P, Minnaar A, Duodu KG, de Kock HL (2015). Sensory and physicochemical analyses of roasted marama beans [*Tylosema esculentum* (Burchell) A. Schreiber] with specific focus on compounds that may contribute to bitterness. *Food Chemistry* 178:45-51.
- Patterson L, Aggarwal P, Sixpence K, Moiphisi T, Scatolini O, Nyirenda E, Tibi S (2018). Morama Nut Project: It's a hard nut to crack [Unpublished Report]. International Development Innovation Network. Available at: <https://idin.org/resources/presentations-reports/cgui-morama-nut-sheller-report-ids-botswana>
- Pittia P, Nicoli MC, Sacchetti G (2007). Effect of moisture and water activity on textural properties of raw and roasted coffee beans. *Journal of Texture Studies* 38(1):116-134.
- R Core Team (2024). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>
- Rao VNM, Quintero X (2014). Rheological Properties of Solid Foods. In Rao MA, Rizvi SSH, Datta AK, Ahmed J (Eds.), *Engineering Properties of Foods (4th Edition)*. CRC Press.
- Sahin S, Sumnu SG (2006). *Physical Properties of Foods*. Springer Science Business Media, LLC.
- Schouteten JJ, Lemarcq V, Van De Walle D, Sioriki E, Dewettinck K

- (2023). Microwave Roasting as an Alternative to Convection Roasting: Sensory Analysis and Physical Characterization of Dark Chocolate. *Foods* 12:887.
- Shayanfar S, Kashaninejad M (2012). The Effect of Different Non-mechanical Treatments on Splitting Pistachio Nuts. *Journal of Nuts* 3(3):1-4.
- Singh RP, Heldman RD (2009). *Introduction to Food Engineering* (4th Edition). Academic Press, Amsterdam.
- Sinha A, Bhargav A (2020). Young's modulus estimation in food samples: effect of experimental parameters, *Mechanics and Industry* 21:404.
- Tjiparuro Z (2013). Challenges of designing a cracker for Morama bean - Short communication. *Research in Agricultural Engineering* 59(1):35-37.
- van der Maesen LJG (2006). *Tylosema esculentum*. *Tylosema Esculentum* (Burch.) A.Schreib. [Internet] Record from PROTA4U. In: Brink M, Belay G (Editors). PROTA (Plant Resources of Tropical Africa / Ressources Végétales de l'Afrique Tropicale), Wageningen, Netherlands.
https://prota.prota4u.org/protav8.asp?h=M26andt=Tylosema_esculentum&p=Tylosema+esculentum#MajorReferences