



**TEXTURAL AND SENSORIAL CHARACTERISTICS OF BAMBARA GROUNDNUT
SHORTCRUST AND PUFF PASTRY.**

by

SAMUKELISIWE DORCAS NKANTSU

Thesis submitted in partial fulfilment of the requirements for the degree

Master of Science: Food Science and Technology

in the Faculty of Applied Sciences

at the Cape Peninsula University of Technology

Supervisor: Prof. V.A. Jideani

Co-supervisor: Prof. O. Oguntibeju

Bellville

December 2023

CPUT copyright information

The dissertation/thesis may not be published either in part (in scholarly, scientific or technical journals), or as a whole (as a monograph), unless permission has been obtained from the University.

DECLARATION

I, Samukelisiwe Dorcas Nkantsu, declare that the contents of this thesis represent my unaided work and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my opinions, not necessarily those of the Cape Peninsula University of Technology.

Signed

Date

ABSTRACT

Gluten-intolerant patients and coeliac sufferers have increased over time and given rise to alternative gluten-free flour sources. This study investigated the effect of Bambara groundnut flour on the textural and sensorial properties of shortcrust and puff pastry products. Bambara groundnut flour was proposed to provide an alternative to the gluten-free market. It had a mix which incorporated carboxymethyl cellulose (CMC) and modified starch as gluten substitutes. The CMC and modified starch proved to be a good combination of additives to use for producing gluten-free pastry pies and CMC had a more significant effect on the optimal flour. The optimal BGN flour mix was determined to be 1% CMC and 5% modified starch. The optimal BGN flour mix can be used to make gluten-free pastry products, and the use of whole and dehulled BGN flour was able to provide a pliable dough for producing gluten-free pastries and it imparted distinct colour characteristics to the pastry products. Shortcrust (rather than 70 or 80% fat content) and 100% fat content for puff pastry (80 or 120% fat content) products were analysed for textural properties, revealing that 60% fat content for shortcrust and 100% fat content for puff pastry resulted in favourable characteristics such as firmness and structural integrity. Quantitative descriptive analysis (QDA) and consumer sensory evaluation were done to evaluate the whole BGN, dehulled BGN and wheat shortcrust and puff pastry pies. Whole BGN pastry products had unique characteristics, including larger crack size (shortcrust: 26.27 and puff pastry: 10.31), rough texture (shortcrust: 10.35 and puff pastry: 7.63), and a stronger beany taste (shortcrust: 10.03 and puff pastry: 9.26) and nutty aroma. Consumer sensory evaluation was done on appearance, crust colour, crumb colour, aroma, texture, and overall acceptability. Consumer sentiment was more positive towards wheat-based pies and had a more negative and neutral sentiment towards whole and dehulled BGN. The proximate analysis demonstrated the nutritional richness of whole and dehulled BGN pastry products. It highlighted their high protein (13.45-18.27%), mineral (1.97-2.73%), and fat content (8.62-12.68%), which may be beneficial to gluten-intolerant individuals, coeliac sufferers and health-conscious consumers. X-ray tomography revealed insights into the internal structure of pastry products, with factors like hole dimensions and roundness influencing the texture. The use of BGN flour, both whole and dehulled, contributed to distinct colour characteristics such as browning or darkening of the crumb and crust of the pastry products, diverging from those of wheat flour, with variations in L^* (34.42-79.80), a^* (1.67-14.78), and b^* (12.18-31.88) values. The Lightness of the crust and crumb of whole BGN shows that it is much darker than wheat pastry products.

ACKNOWLEDGEMENTS

I wish to thank the following people and institutions that assisted me with my research:

- Prof V. Jideani, my supervisor and lecturer at CPUT, for her wisdom and guidance throughout my research and for being meticulous with me every step of the way. She is truly one of a kind, it has been a great experience learning from her.
- Prof Oguntibeju, my co-supervisor, for advice and guidance as well as financial assistance through the NRF bursary.
- Ms. Donna Thomas, NPD lab technician at CPUT, for her assistance and guidance in the lab and for always accommodating me in the lab.
- Mr Owen Wilson, Senior Lab technician at CPUT, for Procurement and lab assistance.
- AgriFood Technology Station team, CPUT Bellville, Mr Ndumiso Mshicileli, Ms Christa van Schalkwyk, and Mrs Hybre van Blerk, For all the technical guidance and assistance with proximate analysis, sensory evaluation, colour analysis and texture analysis in the lab. Their assistance was very beneficial to my project.
- Colleagues in the Cereal, Legumes and Biopolymers research group, for assistance with lab work, research and sensory evaluation. Special Mention to Nontobeko, Oluwakemi, Zuko, Adeola, Rotondwa and Londiwe.
- My church Brothers and Sisters, for all their assistance with Sensory evaluation (Consumer sensory and QDA) and for all the support they gave me throughout my Master's project journey.

The financial assistance of the National Research Foundation towards this research is acknowledged. Opinions expressed in this thesis and the conclusions arrived at, are those of the author, and are not necessarily to be attributed to the National Research Foundation.

DEDICATION

I would like to dedicate this work to my good God who has carried and sustained me throughout this project, all the glory belongs to Him. Also, to my darling husband Sibulele Nkantsu, thank you for being so selfless and believing in me. Honey, you truly are a blessing to my life, and I truly appreciate all the support, and encouragement you gave, and the sacrifices you made for me to be able to complete this project.

TABLE OF CONTENTS

Declaration	li
Abstract	lii
Acknowledgements	iv
Dedication	V
Glossary	xiii
CHAPTER ONE: MOTIVATION AND DESIGN OF THE STUDY	1
1. Introduction	1
1.1 Statement of the problem	3
1.2 Broad Objectives	3
1.2.1 Specific Objectives	3
1.3 Hypothesis	4
1.4 Delineations of the research	4
1.5 Significance of the research	4
1.6 Thesis Overview	5
1.7 References	6
CHAPTER TWO: LITERATURE REVIEW	8
2.1 Overview of Pastry	8
2.2 Pastry ingredients	9
2.2.1 Flour	9
2.2.2 Hydrocolloids and gums	12
2.2.3 Fat	18
2.2.4 Liquid	19
2.2.5 Salt	20
2.2.6 Other ingredients	20
2.2.6.1 Eggs	20
2.2.6.2 Yeasts and other leavening agents	21
2.3 Types of pastry	21
2.3.1 Puff pastry	21
2.3.2 Shortcrust pastry	25
2.3.3 Choux pastry	26
2.3.4 Danish Pastry	27

2.3.5	Strudel pastry	28
2.3.6	Non-gluten pastry	28
2.4	Gluten and coeliac disease	29
2.5	Overview of Bambara groundnut flour	30
2.6	Quantitative descriptive analysis	32
2.7	References	32

CHAPTER THREE: EFFECT OF CARBOXYMETHYLCELLULOSE AND MODIFIED STARCH ON PASTING AND TEXTURE PROFILE OF WHOLE BAMBARA GROUNDNUT FLOUR AND DOUGH 39

3.1	Introduction	39
3.2	Materials and methods	41
3.2.1	Source of materials	41
3.2.2	Experimental design for the effect of modified starch and carboxymethylcellulose on the pasting and textural properties of whole Bambara groundnut flour mix and dough	41
3.2.3	Pasting properties of whole BGN flour mix	43
3.2.4	Texture profile analysis of whole BGN dough	43
3.2.5	Proximate analysis of whole and dehulled BGN flour	44
3.2.6	Data analysis	44
3.3	Results and Discussion	44
3.3.1	Model Adequacy	44
3.3.2	Effects of Pasting properties on whole BGN flour mix.	48
3.3.3	Effect of modified starch and carboxymethylcellulose on the texture profile of BGN dough	52
3.3.4	Whole Bambara groundnut optimal mix.	55
3.3.5	Proximate composition of whole and dehulled Bambara groundnut flour and wheat flour	56
3.4	Conclusion	57
3.5	References	57

CHAPTER FOUR: TEXTURAL CHARACTERISTICS OF BAMBARA GROUNDNUT SHORTCRUST AND PUFF PASTRY PRODUCTS 62

4.1	Introduction	63
-----	--------------	----

4.2	Materials and methods	65
4.2.1	Source of materials	65
4.2.2	Effect of fat on the textural properties of the whole BGN flour mix for shortcrust pastry dough	65
4.2.3	Effect of fat on the textural properties of the whole BGN flour mix for puff pastry dough	68
4.2.4	Puncture test for Bambara groundnut shortcrust and puff pastry	70
4.2.5	Warner–Bratzler test of Bambara groundnut shortcrust and puff pastry	70
4.2.6	Proximate analysis of whole and dehulled pastry pies	70
4.2.7	Colour analysis of shortcrust and puff dough and pastry	70
4.2.8	X–ray Computed Tomography of Bambara groundnut shortcrust and puff pastry pies	71
4.2.9	Data analysis	71
4.3.	Results and Discussion	72
4.3.1	Effect of fat on the textural properties of the shortcrust and puff pastry products	72
4.3.2	Firmness of whole and dehulled BGN and wheat pastries	75
4.3.3	Cutting properties of whole BGN shortcrust and puff pastry	77
4.3.4	Proximate composition of whole and dehulled Bambara groundnut and wheat pastry	80
4.3.5	Colour of shortcrust and puff dough and pastry	82
4.3.6	X-ray Computed Tomography and Imaging of BGN shortcrust and puff pastry baked pie samples	88
4.4	Conclusion	91
4.5	References	91

CHAPTER FIVE: QUANTITATIVE DESCRIPTIVE ANALYSIS AND CONSUMER ACCEPTABILITY OF BAMBARA GROUNDNUT SHORTCRUST AND PUFF PASTRY PRODUCTS 97

5.1	Introduction	98
5.2	Materials and methods	99
5.2.1	Production process of shortcrust and puff pastry pies for Sensory evaluation	99
5.2.2	Quantitative descriptive analysis of shortcrust and puff pastry pies.	100

5.2.3	Consumer sensory evaluation of shortcrust and puff pastry whole and dehulled Bambara groundnut pies	103
5.3	Results and Discussion	104
5.3.1	Quantitative descriptive profile of puff and shortcrust pastry pies	104
5.3.2	Consumer sensory characteristics of whole BGN and dehulled shortcrust and puff pastry pies	112
5.4	Conclusion	122
5.5	References	122

CHAPTER SIX: GENERAL SUMMARY, CONCLUSIONS AND RECOMMENDATIONS
126

LIST OF FIGURES

Figure 2.1	Threefold method for puff pastry making	23
Figure 2.2	Fourfold method for puff pastry making	24
Figure 2.3	Variety of Bambara groundnut seeds	31
Figure 3.1	Texture profile response surface plot for whole BGN dough: (a) Springiness, (b) gumminess (c) hardness	54
Figure 4.1	Flow diagram of shortcrust pastry pies production process	67
Figure 4.2	Flow diagram of puff pastry pies production process	69
Figure 4.3	Whole Bambara groundnut shortcrust pies with different fat contents (a) 60%, (b) 70% and (c) 80%	73
Figure 4.4	Whole Bambara groundnut puff pastry pies of different fat variations (a) 80%, (b) 100%, (c) 120% and (d) 100% showing distinct layering	74
Figure 4.5	Box plot for Lightness of shortcrust dough, crust and crumb	83
Figure 4.6	Box plot of red/green coordinates for shortcrust dough, crust, and crumb	84
Figure 4.7	Box plot of blue/yellow coordinates for shortcrust dough, crust and crumb	84
Figure 4.8.	Box plot of Lightness for puff dough, crust and crumb	85
Figure 4.9	Box plot of red/green coordinates for puff dough, crust and crumb	86
Figure 4.10	Box plot of blue/yellow coordinates for puff pastry	87
Figure 4.11	X – ray Computed Tomography images on whole Bambara groundnut shortcrust pastry	88
Figure 4.12	X–ray Computed Tomography images on dehulled Bambara groundnut shortcrust pastry.	88
Figure 4.13.	X–ray Computed Tomography images on whole Bambara groundnut puff pastry	89
Figure 4.14.	X–ray Computed Tomography images on dehulled Bambara groundnut puff pastry	89
Figure 4.15	PCA plot for whole BGN and dehulled BGN shortcrust and puff pastry pies	90
Figure 5.1	Basic taste test	101
Figure 5.2	Consumer acceptability consent and evaluation form with randomised marked pies	104

LIST OF TABLES

Table 2.1.	Classification of pastries according to the fat/dough rolling process and ingredients	8
Table 2.2	Properties and uses of hydrocolloids and gums used in gluten-free flours	14
Table 3.1	Levels of the flour mix additives.	42
Table 3.2	Augmented 2 ² factorial design for the effect of CMC and Modified starch on the texture profile of whole BGN flour	42
Table 3.3	Model parameters for pasting and textural properties of whole BGN flour mix	47
Table 3.4	Overall mean for pasting properties	48
Table 3.5	Pasting properties for whole BGN flour mix	50
Table 3.6	Textural properties for whole BGN flour mix.	53
Table 3.7	Proximate composition of whole Bambara groundnut, dehulled Bambara groundnut and wheat flour	56
Table 4.1	Firmness of whole BGN shortcrust and puff pastry pies	75
Table 4.2.	Comparison of firmness of pie crust for whole BGN, dehulled BGN and wheat shortcrust and puff pastry	77
Table 4.3.	Cutting properties for shortcrust and puff pastry pies	78
Table 4.4	Cutting properties for whole BGN, dehulled BGN and wheat shortcrust and puff pastry	79
Table 4.5	Proximate composition of pastry products from whole BGN, dehulled BGN and wheat	81
Table 5.1	Basic taste test solutions and dilutions	101
Table 5.2	Attributes, descriptors, and their definitions for quantitative descriptive analysis of shortcrust and puff pastry pies	102
Table 5.3	Quantitative descriptive sensory profiling of whole BGN, dehulled BGN and wheat puff pastry	106
Table 5.4	Quantitative descriptive sensory profiling of whole BGN, dehulled BGN and wheat shortcrust pastry	109
Table 5.5	Demography of panellists for consumer sensory evaluation of whole and dehulled Bambara groundnut shortcrust and puff pastry pies	113

Table 5.6	Consumer sensory characteristics for shortcrust pastry pies	114
Table 5.7	Consumer sensory panellist's comments for shortcrust pastry pies	116
Table 5.8	Consumer sensory parameters for puff pastry pies	118
Table 5.9	Consumer sensory panellist's comments on puff pastry pies	119
 APPENDICES		 129
Appendix I: Ethical Clearance		130
Appendix II: Email communique for permission to use figures from the Mustapha Bunu blog		133
Appendix III: Email communique for permission to use the pastry method from the Jeanne Sauvage blog		134
Appendix IV: Evaluation form for quantitative descriptive analysis for shortcrust and puff pastry pies made of whole Bambara groundnut, dehulled Bambara groundnut and wheat flour.		136

GLOSSARY

Terms/Acronyms/Abbreviation	Definition/Explanation
s	
CMC	Carboxymethylcellulose
BGN	Bambara groundnut
Gluten	Protein fraction from wheat
QDA	Quantitative descriptive analysis
RVA	Rapid Visco Analyser
TPA	Texture profile analysis
ANOVA	Analysis of variance
MANOVA	Multivariate analysis of variance
PCA	Principal component analysis
BGNF	Bambara groundnut flour
3D	Three dimensional

CHAPTER ONE

MOTIVATION AND DESIGN OF THE STUDY

1. Introduction

Pastry defines different kinds of baked goods obtained by mixing flour, fats (margarine, butter or shortening), water, eggs and baking powder. The pastries are mainly produced to provide a casing for the fillings and complement their flavour (Voysey & Legan, 2014:497; de Cindio & Lupi, 2011:301; Harte, 2003:4407). The basic types of pastry are shortcrust and puff pastry, with wheat flour as their main ingredient. The type of flour used plays a role in the final product (Andrews & Harte, 2003:4412). Their preparation includes mixing flour with solid fat on a ratio basis and adding liquid gradually, to obtain pasty consistency (de Cindio et al., 2011:301).

Shortcrust pastry is mostly used as a base for pies, petit fours, tarts, flans and cheesecakes (de Cindio & Lupi, 2011:302). The amount of fat that is used for shortcrust dough is normally half the ratio of flour used to make the dough (de Cindio & Lupi, 2011:302; Harte, 2003:4408).

Puff pastry dough is spread with solid fats and repeatedly rolled out. It contains alternating layers of dough separated by alternating layers of a solid-like fat that is designed to obtain the desired flaky texture. The lamination between fats and dough can be obtained by three methods: the French, English and Scottish methods (de Cindio & Lupi, 2011:303). These differ from each other by the way of layering of fat; either single-fold or three-fold (Deligny & Lucas, 2015:113). The French method includes a process of rubbing a portion of the fat into the wheat flour to lubricate the gluten. Then a portion of the water is added into the centre of the ring that is made from the flour and fat (shortening)mix; to form dough. This procedure is repeated until all the ingredients, except for the remaining fat, have been added. The remaining fat is then gradually added as the dough is folded into 6 half turns of 90°C until it is used up (Harte, 2003:4408). With the English method, the dough is rolled sheeted into a rectangular shape, and the fat is spread uniformly over two-thirds of the surface area. Three-fold puff pastry preparation is used to form three dough layers that are mainly separated by two layers of fat (Andrews and Harte, 2003:4414). The Scottish method is simple and used widely commercially. This method differs from the other two methods in that, the laminating fat is added at the dough-making stage rather than later in the process. The process is as follows; the fat is broken into lumps (approximately 5 cm) and mixed loosely within the flour. The remaining ingredients are then added to form a lumpy dough.

The rolling procedure is the same as that of the French method, with the addition of an extra half-turn (Harte, 2003:4408; Cauvain et al., 2001:126).

Wheat flour used in the making of the pastry dough naturally contains gluten, which is the main storage protein in wheat responsible for the viscoelastic properties of wheat flour dough (Masure et al., 2016:92). The fat and the wheat flour should be blended thoroughly before water is added to ensure adequate coating of the flour granules with fat to reduce the likelihood of a gluten network being entirely developed as noted by Harte, (2003:4412). The strength of the gluten network must reach a reasonable compromise; thus, the fat must have similar rheological properties with the dough when laminating (de Cindio & Lupi, 2011:303; Harte, 2003:4410). People who suffer from coeliac diseases and other gluten intolerances are unable to consume gluten-containing products leading to a growth in the production of gluten-free products. The rise within the gluten-free market is also caused by the consumption of the products by the families and friends of coeliac patients and healthy consumers who prefer gluten-free products as a lifestyle choice (Foschia et al., 2016:113)

Coeliac disease, also known as coeliac sprue or gluten enteropathy, is the most common food-induced disease caused by intolerance to wheat gluten and proteins identical to those found in barley and rye. When an intolerant or allergic individual consumes a gluten-containing product, an inflammation of the small intestine occurs (Foschia et al., 2016:114), due to an immunological reaction to gluten resulting in damage to the mucosa and malabsorption of nutrients in the intestine (Mir et al., 2016:50). Treatment for this disease is strict and permanent adherence to a gluten-free diet (Foschia *et al.*, 2016:114). This is where the need to have alternative flours arises to replace gluten-containing flours in the products. One of those flours is Bambara groundnut flour, a high-protein, gluten-free flour.

Bambara groundnut (BGN) (*Vigna subterranea*) is an African legume that has been cultivated in African countries for centuries (Atoyebi et al., 2017:820). In South Africa, it is found in Limpopo, KwaZulu-Natal and Mpumalanga provinces (Adeyi et al., 2014:26). The legume contributes to food security and nutrition since they are a source of protein (Lengwati et al., 2015:210). The high protein content of the seed gives way to interest in developing improved methods for processing and diversifying the seed for other food uses (Alakali et al., 2010:215). The flour made using BGN is suitable since it contains no gluten, making it a good alternative for people who are intolerant to gluten-based flour. However, the textural and sensory properties of the BGN flour in shortcrust and puff pastry products are unknown. Therefore, textural properties such as the characteristics of the pastry, whether flaky, crumbly or tender, should be established. The behaviour of the dough needs evaluation since there is no gluten in the seed to provide texture and structure to the product.

Determining the textural and sensory properties would be essential in developing an alternative to the use of gluten-based flour in making these pastry products for use in the industry.

1.1. Statement of the problem.

Pastry products are enjoyed by many people in different forms; however, not everyone has the privilege of indulging in pastry due to the wide use of gluten-containing flour. The gluten-based flour prevents people with coeliac disease and other gluten intolerances from consuming pastry products. This is where the need to use Bambara groundnut (BGN) flour as an alternative flour arises, as it does not contain gluten and the groundnut is known to have excellent health significance (Adeyi et al., 2014:2). Mthombeni (2017:15) reported on the functionality of Bambara groundnut flour in dehulled BGN Pastry products. The pies produced from the dehulled BGN flour required further investigation for texture and sensory properties (instrumental or analysis by panellists). In addition, the comparison of dehulled BGN flour to that of the whole BGN and wheat flour was not done. So this study will assist in comparing the textural and sensorial properties of the Bambara groundnut flour in shortcrust and puff pastry products from both whole and dehulled BGN flour to that of wheat. Therefore, determining the textural and sensory properties would be essential in developing an alternative to the use of gluten-based flour in making pastry products and increasing the variety of food choices for coeliac and gluten-intolerant individuals.

1.2. Broad objective

The broad objective of this study was to determine the textural and sensory properties of Bambara groundnut shortcrust and puff pastry products.

1.2.1 Specific objectives

The specific objectives of the study were to:

1. Characterise the texture of the dough made from whole and dehulled BGN flour.
2. Determine the texture of shortcrust and puff pastry products produced from whole and dehulled BGN dough.
3. Establish the quantitative descriptive sensory profile of whole BGN dough pastry products compared to wheat dough pastry products.
4. Establish the structure and cell size distribution of whole and dehulled BGN and wheat pastry using X-ray tomography.

1.3. Hypotheses

The following was hypothesised in this study:

1. The texture of whole and dehulled BGN dough will be characterised.
2. The texture of shortcrust and puff pastry products made from dehulled and whole BGN dough will be determined.
3. The descriptive sensory profile of whole BGN will be different to wheat,.
4. The structure and cell size distribution of whole BGN and dehulled BGN pastry will be different to that of wheat pastry.

1.4. Delineations

There are many types of pastry used for baked goods. However, only shortcrust pastry and puff pastry were used in this study and only pies were produced from whole BGN, dehulled BGN and wheat flour.

1.5. Significance of this research/Justification of study

This study developed gluten-free shortcrust and puff pastry products that are suitable for people who have coeliac disease and other gluten intolerances. The rise in the demand for gluten-free products that are innovative, healthy and nutritious gives a chance to Bambara groundnut flour-based pastry products (Foschia et al., 2016:113).

This research aligned with the bioeconomy and biotechnology strategic imperatives of research, technology, and innovation that the Cape Peninsula University of Technology (CPUT) has adopted. These strategic imperatives include those of CPUT, Western Cape Province, the South African Department of Science and Technology, the African Union and the United Nations Sustainable Development Goals (previously known as Millennium Development Goal) (Weinstein, 2012:14-18). This deals with reducing biodiversity loss, which is important for the communities cultivating the BGN seed. In the Western Cape provincial strategic imperatives, objective 9: reducing poverty and Objective 11: increasing opportunity for growth and development are aligned with the study. The South African strategic imperatives contain the Department of Science and Technology's grand challenges. The first grand challenge states that "from farmer to pharma"- value chain to strengthen the bioeconomy. The United Nations goals were adopted in 2015 to end poverty, protect the planet and ensure prosperity over the next 15 years. Goals 1 and 2 say No poverty and zero hunger, respectively. Looking at all these imperatives that are relevant to this study from the University to the United Nations, eradication of poverty, reduction of hunger and social development is common (Cape Peninsula University of Technology,

2012:14). This study will lead to a demand in supply for BGN seeds and that works in favour of the farmers and their development in having sustainable resources. Also, people who consume the seed have been using one way of consuming the product, thus the results from this research will help show that there are many uses for the seed and in that way, they can cultivate more.

1.6. Thesis overview

This thesis contains six chapters and is structured in an article format, with each chapter representing an individual manuscript. The first chapter is titled motivation and design of the study, and it gives an introduction and a brief overview including the research problem, objectives, hypothesis, delineations of the research, and significance of the study.

The second chapter is the literature review the overview of pastry, the overview of pastry, its ingredients that are commonly used, and the different types of pastry that exist, including non-gluten-based pastry products. Furthermore, gluten and coeliac disease were discussed and the overview of Bambara groundnut flour and the sensory evaluation process of quantitative descriptive analysis as a sensory evaluation tool.

The third chapter is the first research chapter, and it focuses on the effect of carboxymethyl cellulose and modified starch on the pasting and texture profile of whole Bambara groundnut flour and dough. Bambara groundnut seeds were sourced and milled to flour. An Augmented 2² factorial design with 3 centre points was used to obtain an optimal flour mix. The pasting properties of the whole BGN flour mix were determined. A texture profile analysis of the whole BGN dough was done using the Instron 3344 machine. A proximate composition of whole and dehulled BGN flour was established. The data was analysed using ANOVA and the optimum flour was modelled using DesignExpert 12.

The fourth chapter is the second research chapter, about the textural characteristics of Bambara groundnut shortcrust and puff pastry. The effect of fat on the textural properties of the whole BGN flour mix for shortcrust and puff pastry using three different levels of fat was evaluated. The puncture test and the Warner Bratzler test were done to determine the firmness and cutting properties of the BGN shortcrust and puff pastry pies. The proximate composition of the whole and dehulled pastry pies was established. A colorimeter was used to analyse the colour of the shortcrust and puff dough and pastry.

Chapter five is the third research chapter and is about the sensory evaluation of the Bambara groundnut shortcrust and puff pastry products., using quantitative descriptive analysis and consumer acceptability tests. Chapter six is the general summary of the conducted research, which includes the conclusion of the findings and recommendations.

1.7. References

- Adeyi, O., Ikhu-Omoregbe, D. & Jideani, V. 2014. *Effect of Bambara groundnut flour on the stability and rheological properties of oil-in-water emulsion. Electronic These and Dissertations, Cape Peninsula University of Technology.*
<https://etd.cput.ac.za/handle/20.500.11838/3678>
- Alakali, J.S., Irtwange, S. V & Mzer, M.T. 2010. Quality evaluation of beef patties formulated with Bambara groundnut (*Vigna subterranea* L.) seed flour. *Meat Science*, 85(2), 215–223. <https://doi.org/10.1016/j.meatsci.2009.12.027>.
- Andrews, S.L. & Harte, J.B. 2003a. Pastry Products: Types and Production. *Encyclopaedia of Food Sciences and Nutrition*. Academic Press. 4412 - 4414.
- Andrews, S.L. & Harte, J.B. 2003b. *Pastry products: Ingredient Functionality and Dough Characteristics*. Academic Press. 4407 - 4411.
- Atoyebi, J.O., Osilesi, O. & Adebawo, O. 2017. *Sensory Evaluation of Bambara Groundnut (Vigna subterranea (L.) Verdc.) Food Products in Ibadan, Nigeria. International Journal of Agriculture Innovations and Research*. 820 - 823.
- Cauvain, S. & Young, L. 2001. 8 – Laminated products. In *Baking Problems Solved*. 124–135.
- de Cindio, B. & Lupi, F.R. 2011. 15 – Saturated fat reduction in pastry. In *Reducing Saturated Fats in Foods*. 301–317. <http://dx.doi.org/10.1016/B978-1-84569-740-2.50015-4>
- Deligny, C. & Lucas, T. 2015. Effect of the number of fat layers on expansion of Danish pastry during proving and baking. *Journal of Food Engineering*, 158: 113–120.
- Foschia, M., Horstmann, S., Arendt, E.K. & Zannini, E. 2018. Nutritional therapy – Facing the gap between coeliac disease and gluten-free food. *International Journal of Food Microbiology*, 239(2016): 113–124.
- Foschia, M., Horstmann, S., Arendt, E.K. & Zannini, E. 2016. Nutritional therapy – Facing the gap between coeliac disease and gluten-free food. *International Journal of Food Microbiology*, 239: 113–124. <https://doi.org/10.1016/j.ijfoodmicro.2016.06.014>
- Harte, J.B. 2003. Pastry products: types and production, in *Encyclopaedia of Food Sciences and Nutrition* (eds B.Caballero, L.Trugo, and P.M Finglas), Academic Press, San Diego, CA. 4407–4412.
- Lengwati, M.D., Maseko, S.T., Mathews, C. & Dakora, F.D. 2015. Variation in growth and nodulation of cowpea (*Vigna unguiculata*), blackgram (*Vignamungo*), mungbean, (*Vignaradiata*, groundnut (*Arachis hypogaea*) and Bambara groundnut (*Vigna subterranea*) grown at low and high rainfall areas. *South African Journal of Botany*, 98: 210–210. <https://doi.org/10.1016/j.sajb.2015.03.154>

- Masure, H.G., Fierens, E. & Delcour, J.A. 2016. Current and forward-looking experimental approaches in gluten-free bread-making research. *Journal of Cereal Science*, 67: 92–111. <https://doi.org/10.1016/j.jcs.2015.09.009>
- Mir, S.A., Shah, M.A., Naik, H.R. & Zargar, I.A. 2016. Influence of hydrocolloids on dough handling and technological properties of gluten-free breads. *Trends in Food Science and Technology*, 51: 49–57. <http://dx.doi.org/10.1016/j.tifs.2016.03.005>.
- Voysey, P.A. & Legan, J.D. 2014. Confectionery Products – Cakes and Pastries. *Encyclopaedia of Food Microbiology*. 474 - 480. <https://doi.org/10.1006/wfm.1999.6010>.
- Cape Peninsula University of Technology. 2012. Research, Technology and Innovation 10-year blueprint, 14 - 22. https://www.cput.ac.za/storage/research/research_directorate/RTI_Blueprint.pdf

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of pastry

Pastries are types of baked goods, made from a dough or paste of flour, liquid, and fat. It may be enriched with other ingredients such as baking powder, eggs, salt, etc.; as shown in Table 2.1, and may be filled and coated with various materials depending on whether it is a savoury or sweet kind of pastry (Voysey & Legan, 2014:497; de Cindio & Lupi, 2011:301).

Table 2.1. Classification of pastries according to the fat/dough rolling process and ingredients

Pastry	Process for fat/dough rolling	Main ingredients
Danish pastry	Mixing* and sheeting/lamination	High-protein flour/pastry flour, butter/margarine/shortening, yeast, milk solids, eggs (optional), salt.
Puff pastry	Mixing* and sheeting/lamination	Fats (shortenings) high-protein flour, water, salt
Choux pastry	Mixing/extrusion	Fat, flour, water, eggs, salt
Shortcrust pastry	Mixing	Fat, flour, water and salt

*In the production process the mixing phase differs according to the method (French, English or Scottish) adapted from de Cindio and Lupi (2011:303)

When producing pastry, the dough is just a mixture of flour, water and salt before incorporating fat. The paste is the mixture of dough and laminating fat before baking; and lastly, pastry is the final baked product (Wickramarachchi et al., 2015:1066). The fat used could be butter, margarine, or shortening. Shortening is edible fat that plays a critical role in providing flavour and soft texture to pastry (Mert & Demirkesen, 2016:477). Flakiness and tenderness are two desirable characteristics of pastry products, these characteristics can occur separately or together (Andrews & Harte, 2003:4414). Different products can be obtained by changing the processing conditions involving the mixing of dough with fats (de Cindio & Lupi, 2011:301). Various kinds of pastries can be distinguished based on their ingredients, preparation method, and final use. They can be further differentiated into non-

laminated and laminated pastries. Non-laminated is the type where fat is coated with flour, this includes shortcrust pastry, choux pastry, and strudel pastry. Then laminated is where fat is folded into the dough, it includes Danish, croissants and puff pastry. For the pastries, the processes vary, and the variation involves proper fat/dough lamination methods as depicted in Table 2.1, however, the final lamination process is the same in all cases (de Cindio & Lupi, 2011:302). Further details of the several types of pastry and their ingredients are to follow.

2.2 Pastry ingredients

2.2.1 Flour

Flour is the bulk main ingredient that provides the structure for the pastry dough. This includes all-purpose flour (A blend of soft and hard white wheat flour), pastry flour (soft flour), cake flour, and whole wheat flour. Commonly, wheat flour and pastry flour are used in the making of pastry. It is very important to note that the characteristics of the pastry are influenced by the type of flour used to produce the pastry (Silow *et al.* 2016:330; Bastin, 2010:1; Andrews & Harte, 2003:4412). For instance, dough made from wheat flour is known for its ability to retain gas, which assists in the leavening ability of puff pastry (Sliwinski *et al.* 2004:231). Within the wheat flour, there are proteins (gliadins and glutenins) that yield gluten whenever the flour is dampened with water and manipulated, gluten develops and increases as the flour protein content and the amount of added water increases. Furthermore, the extent of gluten distribution throughout the dough of pastry and the amount of gluten that is developed determines whether the pastry is to be crumbly, with a tendency to be tough and compact or tender and flaky. Gluten development can be minimised by incorporating fat with flour before adding water, which insulates and limits the flour proteins from gluten development (Ooms *et al.* 2017:84; Van Der Borght *et al.* 2005:221; Andrews & Harte, 2003:4412).

Flour differs in protein content and it's important to choose a suitable one for making pastry, as protein plays a role in water absorption (Cauvain and Young, 2009:172; Sliwinski *et al.* 2004:253). The protein content of flour is also important due to its relationship with the quantity of gluten in the flour as well. Gluten quality directly affects how flour will respond when subjected to the stresses that come with processing. Gluten qualities that are considered are resistance to deformation, elasticity, extensibility and stickiness (textural characteristics) (Cauvain and Young, 2009:172; 181). The gluten assists in the formation of the structure and shape of the pastry dough, it provides body and texture to the pastry product since it is a viscoelastic material, for instance in puff pastry the gas retention during

lamination is assisted by the viscoelastic nature of gluten (Ooms et al., 2017:85; Cauvain & Young, 2009:185). When sheeting the dough of pastry, it is required that the gluten be extensible but not elastic. However, since the quantity of water added is low, the gluten tends to be more elastic. This is overcome by having a resting period during the processing to allow the gluten to become soft and less elastic. When the dough is rolled and baked, gluten is denatured by heat exposure, which contributes to toughness. High protein flours are known to yield more gluten, which results in a more cohesive dough. However, pastry flour and other low-protein flours cannot yield as much gluten and therefore often make a tender pastry which crumbles and cannot hold its structure. A mix of high-gluten flour with pastry flour can be used to achieve the desired protein concentration (Andrews and Harte, 2003:441).

Cauvain and Young (2001:21) detailed numerous techniques employed for assessing the protein quality in wheat flour. One such method is the Farinograph test, which involves blending flour and water to form a dough, under specified conditions, commonly utilized to ascertain flour-water absorption. The analysis of the mixing curve provides insights into protein quality through parameters like dough development time, dough stability, and degree of softening. Another method is the Extensograph test, where a flour-water-salt dough is prepared using the Farinograph, moulded, rested, and then stretched over pins to simulate manual dough stretching. Resistance to extension and extensibility until the point of snapping is measured, and the process may be repeated after remoulding and resting. The Alveograph or Consistograph test is yet another example, where a fixed water level is added to the flour, and the resulting dough is extruded, shaped, rested, and then inflated using air pressure. The resistance to expansion and point of rupture is recorded to generate a curve, the area of which correlates with the flour's strength (Cauvain & Young, 2001:21). These represent only a subset of the commercially available test methods for evaluating wheat flour protein quality.

The formation of dough is influenced by various properties of flour, with water absorption capacity being a significant factor. This capacity is determined by multiple flour attributes. A lower moisture content results in increased water absorption, while a higher protein content is associated with higher water absorption. Additionally, the enzymic activity in the flour can affect water absorption (Cauvain & Young, 2001:27).

Other types of flour

Wheat flour is not the only type of flour that is used to make pastry products. Many other types of flour sources do not contain gluten such as buckwheat, rice, sourdough, sorghum,

chestnut (Zhu, 2017:1173; Cai et al., 2016:1; Masure et al., 2016:93; Kaur et al., 2015:628) and others (like soya, even though some people tend to have an allergic reaction to it). Buckwheat (*Fagopyrum esculentum*) flour, derived from pseudo-cereal grains, is associated with numerous health benefits attributed to its elevated levels of phenolic compounds and antioxidant activity. These grains are almost as rich in protein (11.25%), starch (69.75%), and vitamins, as wheat (protein:11.75% and starch:74%) (Kaur et al., 2015:630). The protein in buckwheat is characterised by well-balanced amino acids with a high biological value, making it an excellent supplement for cereal grains. Moreover, the protein exhibits cholesterol-lowering and antihypertensive effects, like dietary fibre, thereby aiding in the reduction of constipation and obesity. Additionally, buckwheat contains natural antioxidants that effectively inhibit lipid peroxidation in snack foods during processing and storage (Kaur et al., 2015:628).

Rice is classified into three main groups, namely long, medium and short grain (Duodu and Taylor, 2012:754). Rice flour is a good substitute for gluten-containing wheat flour. The rice flour may be pre-gelatinised to improve its textural properties for products such as rice noodles (Cai et al., 2016:1). Chestnuts are considered fruits of *Castanea* spp., they belong to the beech family *Fagaceae*, and they have been a significant food item for centuries. They have unique eating qualities and nutritional properties, and flour can be extracted from the nut (Zhu, 2017:1173). Chestnut flour is known for high-quality proteins that have essential amino acids, dietary fibre, and low amounts of fat (1.24—3.91%), vitamin B group (0.26—3.5 mg), potassium (726—991 mg), phosphorus (137—169 mg), and magnesium (74—137 mg) (Zhu, 2017:1175; Paciulli et al., 2016:89). With the increasing prevalence of celiac disease, there has been a surge in demand for chestnut flour as a key ingredient in the production of high-quality gluten-free products including pastry products (Zhu, 2017:1173). It has been shown that when chestnut flour is used to enrich bread, there is an increase in quality from an organoleptic and nutritional point of view. Also, the bread delay in the staling process, shows that the bread is improved nutritionally and qualitatively during its shelf life (Paciulli et al., 2016:89). In the study done by Zhu,(2017:1178), a comparison of Chestnut flour and rice flour was made, what was compared was the rheological behaviour of the two-grain flours. Chestnut flour behaved opposite to rice flour in protein network breakdown, chestnut flour tends to break down quicker than rice flour due to protein composition (Zhu, 2017:1178-1179).

Some gluten-free products, if not most, tend to appear flat and lose their crumb. Sourdough is useful in that case, in improving the quality of baked goods (Campo et al., 2016:75). The sourdough is a mixture consisting of flour and water containing Lactic acid

bacteria and yeasts for the fermentation process (Foschia et al., 2016:120; Duodu & Taylor, 2012:754). The process enhances aroma quality instead of the flat aroma given by other gluten-free products without sourdough. When used in optimized proportions for baked gluten-free products, sourdough can enhance gas retention, shelf life, textural quality, nutritional value and flavour (Foschia et al., 2016:120). The products containing sourdough tend to have a prolonged shelf life due to the staling process being retarded and due to protection from mould and bacterial spoilage (Foschia et al., 2016:120; Campo et al., 2016:75; Duodu & Taylor, 2012:755). The LAB and yeast contribute to sourdough positive effects through metabolic activities such as proteolysis, lactic acid fermentation, exopolysaccharides production and synthesis of antimicrobial and volatile compounds (Foschia et al., 2016:120; Duodu & Taylor, 2012:755).

Sorghum has been considered a staple food and is gaining much interest due to its gluten-free status (Rodrigues Ferreira et al., 2016; Marston et al., 2016:637). So, it is an attractive alternative for wheat allergy sufferers, sorghum is increasingly being used in snack foods and baked products. The sorghum flour contains starch granules and non-starch components, including non-starch polysaccharides, lipids and protein (Marston et al., 2016:638).

2.2.2 Hydrocolloids and gums

Hydrocolloids are water-soluble polysaccharides that are used as functional ingredients in the food industry (Mir et al., 2016:50; Kaur et al., 2015:628; Martínez, 2015:78; Dickinson, 2003:25). These polysaccharides include extracts from plants, seaweeds and microbial sources; as well as gums obtained from plant exudates and biopolymers that are modified by chemical or enzymatic treatment of cellulose or starch (Dickinson, 2003:25). Generally, the role of hydrocolloids and gums as additives in food systems is to improve texture, provide taste and mouthfeel, moisture control, maintain shelf life and improve viscous flow properties of food (Aguilar et al., 2015:225; Kaur et al., 2015:628; Mirhosseini et al., 2015:187; Miñarro et al., 2012:476; Duodu & Taylor, 2012:755). They can slow down starch retrogradation and act as water binders, fat replacers, and gluten substitutes and they tend to affect the perceived flavour (Duodu & Taylor, 2012:755; Renard et al., 2006:430). In gluten-free flours, hydrocolloids and gums can be incorporated as improvers, and additives, to assist their rheological properties and enhance the cohesive properties of gluten-free flour dough (Masure et al., 2016:104; Mir et al., 2016:50; Duodu & Taylor, 2012:755; Ibanoglu et al., 2005:622; Dickinson, 2003:25). Overall, they improve the product stability quality by overcoming the processing, final preparation and distribution demands of gluten-free

products, they can also affect the final price of the product (Kaur et al., 2015:628; Aguilar et al., 2015:225). The most common polysaccharides used are carboxymethylcellulose, hydroxypropyl methylcellulose, guar gum (which can be combined with pectin), xanthan gum, locust bean gum, tragacanth gum, sodium alginate and carrageenan, to name a few (Masure et al., 2016:104). Table 2.2 shows the different hydrocolloids and gums with their general properties and uses in the food and baking industry. The hydrocolloids increase the viscosity of the aqueous phase of the dough and improve the dough's gas retention properties. They also assist in preventing the crumbling of baked products due to water-binding capacity (Foschia et al., 2016:120; Duodu & Taylor, 2012:756).

Table 2.2 Properties and uses of hydrocolloids and gums used in gluten-free flours.

Name	Properties and uses
Hydroxypropyl methylcellulose (HPMC)	<p>It is soluble in cold water and insoluble in hot water.</p> <p>Viscosity is dependent on the degree of polymerisation.</p> <p>When it is heated it increases viscosity and gels at 50-55°C</p> <p>Able to mimic viscoelastic properties of gluten.</p> <p>It is used in many food products including bakery products.</p> <p>Can be used as an emulsifier, film former, protective colloid and stabiliser, thickener or suspending agent.</p> <p>Acts as an oil barrier in fried foods.</p>
Carboxymethylcellulose (CMC)	<p>Its water solubility is dependent on its degree of polymerisation, the degree of substitution and the uniformity of the carboxymethyl group in its polymer.</p> <p>The higher the degree of polymerisation the greater the viscosity.</p> <p>It's known to dissolve quickly in cold water.</p> <p>Its viscosity decreases during heating, thus making it suitable to improve the volume yield during baking by encouraging gas bubble formation.</p> <p>Its ability to control viscosity allows use as a thickener, phase and emulsion stabiliser, and suspending agent.</p>

Guar gum	<p>In cakes and baked goods, it increases volume and retains moisture.</p> <p>It has an ability to hydrate rapidly in cold water to form viscous colloidal dispersions.</p> <p>The viscosity yield is dependent on time, temperature, pH, concentration and particle size of gum.</p> <p>Viscosity tends to increase at higher temperatures.</p> <p>Compatible with starch, gelatine, and other water-soluble gums.</p> <p>It increases yield and gives greater resiliency to dough and baked products.</p> <p>It's known to be an economical thickener and stabiliser.</p> <p>The solubility of it in water is known to increase with the increase in content of galactose in the gum.</p>
Xanthan gum	<p>Readily soluble in hot or cold water to form highly viscous solutions at low concentrations.</p> <p>Hydrates rapidly in cold water without forming lumps to give reliable viscosity, thus making it a good emulsifier, thickener, stabiliser, suspending agent, bodying agent or foam enhancer in foods.</p> <p>Can mimic viscoelastic properties of gluten.</p>
Locust bean gum	<p>It requires heat to dissolve and is soluble in hot water.</p>

It however has no gelling properties.

Its dispersions are very viscous.

It is compatible with proteins, carbohydrates and other plant gums.

Its solubility in water increases with increasing galactose content.

Used in the baking industry to yield softer doughs with greater resiliency and used for pie fillings.

Tragacanth gum

Considered the most viscous of all plant gums.

The viscosity is a measure of the quality and uniformity of the gum; it also determines its behaviour as a suspending agent, stabiliser or emulsifier.

It is a thickener in assorted bakery products.

Sodium alginate

Develops viscosity in water.

It is a thickener in baked products and thickens batter to give a short flow.

It thickens pastry fillings and reduces the fillings' tendency to soak into pastry.

Retains moisture in pastry due to its water binding capacity.

Carrageenan

Readily soluble in water.

Its dispersions are viscous with concentration of gum and temperature having a logarithmic effect on viscosity.

It is used for pie fillings and other milk systems as gelling agent

Adapted from Masure et al. (2016); Maphosa & Jideani (2016); Mir et al. (2016:50); Foschia et al. (2016:119); Kaur et al. (2015:628-629); (2016); Jideani (2013); Williams & Mittal, (1999:440).

2.2.3 Fat

Fat plays a crucial role in imparting tenderness, or shortness, to pastry. The fat content in dough can vary, ranging from 25 to nearly 75%, depending on the type of pastry. Its primary function is to tenderize pastry by waterproofing flour particles. As the amount of fat increases, so does the level of tenderness, demonstrating a proportional relationship (Andrews & Harte, 2003:4412). One edible fat option for pastry is shortening, commonly used in pastries like puff pastry. Shortening aids in trapping air during the creaming process, leading to aeration and serving as a leavening agent essential for the structure and geometry of the final products. It plays a critical role in achieving a softer texture and a desirable flavour by preventing the cohesion of gluten strands during mixing. Additionally, shortening imparts functional characteristics such as tenderness and moisture, thereby enhancing the shelf life of the products (Mert & Demirkesen, 2016:477). Beyond contributing to tenderness, fats also create desirable flakiness by separating the dough into distinct layers or flakes. When oils are used, they tend to coat each flour particle, limiting water contact with the flour. Consequently, minimal gluten is developed, resulting in a tender yet crumbly or even greasy pastry. While oil can be used to achieve a flaky and tender pastry, careful monitoring of the mixing process is necessary because oil readily blends with flour (Vaclavik & Christian, 2008:269; 293; Andrews & Harte, 2003:4413).

At the molecular level, the polar groups present in water exhibit an attraction to the polar groups found in both proteins and starch. Subsequently, the polar carbonyl groups and double bonds in the unsaturated fatty acid components enable fat to bond with the polar groups on the surface of flour particles. The remaining segments of the fat molecule lack an affinity for both flour and water, serving as a mechanical barrier that hinders contact with the water and protein in the flour (Andrews and Harte, 2003:4412).

The capacity of fat to disrupt gluten formation is known as its shortening power. Generally, pure fats tend to possess greater shortening power compared to butter or margarine, which contains a percentage of water. Even when the fats are pure, such as lard, hydrogenated shortenings, and oils, they exhibit distinctive characteristics in pastry products. For instance, oil is denser than lard, which, in turn, is denser than shortenings. Moreover, liquid fats have a higher spreading power and can coat flour more uniformly and comprehensively. The fat's covering power increases with a higher ratio of liquid to crystals (Andrews & Harte, 2003:4413).

Plastic fats exhibit characteristics of both liquid and crystalline fats, resulting in a pastry product that is both flakier and tender. Lard stands out as an excellent choice for pastry fat due to its notable shortening power, desirable plasticity, and effective dispersibility, all of which contribute to enhanced flakiness (Vaclavik & Christian, 2008:269; 293; Andrews & Harte,

2003:4413). The choice of an appropriate fat depends on various factors such as ambient temperature, processing method, and the desired crust for the pastry product. Optimal fats are those that are firm, plastic, and possess shortening properties, constituting approximately half the percentage of the dough weight while containing some moisture. The presence of moisture in the fat aids in generating steam, contributing to leavening effects and the desired flakiness in the pastry (Andrews and Harte, 2003:4413).

2.2.4 Liquid

Water is the most commonly used liquid in pastry making, as highlighted by Wickramarachchi et al. (2015:1066) and Andrews & Harte (2003:4413). However, other liquids such as milk and eggs, as well as fats like butter and margarine (which contain approximately 16% water), can also contribute to the liquid content in pastry (Andrews & Harte, 2003:4413). The presence of liquids is crucial for various reasons, including hydrating the flour, facilitating gluten development (especially in wheat flour where liquid promotes gluten formation), and providing cohesion to the dough. Without adequate liquid, flour particles would fail to adhere and form a cohesive dough (Wickramarachchi et al., 2015:1066; Vaclavik & Christian, 2008:368; Andrews & Harte, 2003:4413; Cauvain & Young, 2001a:18).

In gluten-free flours containing hydrocolloids, water tends to be bound and stabilized by these hydrocolloids (Mir et al., 2016:51). Cauvain and Young (2001) observed that the quantity of liquid used in the formulation significantly influences the rheological properties of the final paste. Insufficient liquid results in a non-cohesive sheet, while excess liquid yields a soft paste that is challenging to process (Cauvain & Young, 2001a:79). Inadequate liquid leads to a crumbly dough that is difficult to handle, whereas excessive liquid is undesirable in pastry dough. Nevertheless, choux pastry requires a specific soft consistency, and maintaining this texture involves gradually adding liquid, be it water or milk, to achieve the desired final paste consistency (Andrews & Harte, 2003:4413).

To achieve a flaky texture in pie dough, it is recommended to use chilled water, and if necessary, ice can be added to maintain a low water temperature (Cauvain & Young, 2009c:18; Harte, 2003:4409; Andrews & Harte, 2003:4413). This approach prevents the homogenization of ingredients during dough mixing by forming fat particles. Additionally, liquid plays a crucial role in the leavening process of pastry. During baking, the liquid in the pastry dough generates steam, which contributes to the leavening and separation of the pastry layers (Vaclavik & Christian, 2008:368; Andrews & Harte, 2003:4413). In some pastry recipes, milk is used instead of water as the liquid source. The inclusion of milk enhances crust colour through lactose, resulting in a soft

crumb, imparting flavour, and promoting Maillard browning for colour during baking. The solids present in milk contribute to reinforcing the internal cell structure, thereby preserving the flakiness of the pastry. Moreover, milk facilitates the creation of a thin and smooth crust (Vaclavik & Christian, 2008:368; Andrews & Harte, 2003:4413).

2.2.5 Salt

Salt, also known as sodium chloride (NaCl) (Silow et al., 2016:330), functions as a seasoning to the pastry product and it is not a requirement when it comes to producing a successful pastry product (Andrews & Harte, 2003:4413). Salt has been traditionally used as a baked goods ingredient since its influence on several technological, rheological and sensory parameters was identified (Silow et al., 2016:330). Salt plays a crucial role in enhancing the flavour of the product (Vaclavik & Christian, 2008:360). A crust lacking salt will result in a bland taste. However, excluding salt from the recipe does not impact the mechanical aspects of the pastry (Andrews & Harte, 2003:4413). In the production of pastry dough, salt contributes to workability. It is recognized for increasing the mixing tolerance of dough and positively affecting the strength of the gluten network, thereby enhancing the stability and flexibility of the dough (Silow et al., 2016:330). As noted by Cauvain and Young (2001:75), salt reduces the water activity of the product, leading to an extended shelf life and inhibition of microorganisms. The levels of salt in baked products vary based on the functional requirements of the product. Additionally, salt is known to reduce stickiness and water absorption in dough (Silow et al., 2016:330).

2.2.6 Other ingredients

These are the other ingredients that are added to enhance the pastry product, for instance, eggs and leavening agents. They will be discussed below in more detail.

2.2.6.1 Eggs

They find application in various pastries, including choux paste (de Cindio & Lupi, 2011:305), short paste (Mikiewicz et al., 2013:302; de Cindio & Lupi, 2011:304), strudel pastry (Harte, 2003:4409), and croissant doughs (Wickramarachchi et al., 2015:1066; Harte, 2003:4410; Andrews & Harte, 2003:4413). Eggs are optional in yeast-leavened Danish (de Cindio & Lupi, 2011:303) and puff pastry (Andrews & Harte, 2003:4413). The yolk of eggs can serve to lubricate the gluten, while the egg white contributes to the volume of the baked pastry. They also add richness, structure, and improved shelf life to the pastry product (Andrews & Harte, 2003:4413). Eggs contribute to the liquid content that aids dough formation and are recognized as effective

emulsifiers (Rodrigues Ferreira et al., 2016:150; Vaclavik & Christian, 2008:358; Andrews & Harte, 2003:4413). Being a good source of protein, especially albumin proteins, eggs facilitate dough cohesiveness when subjected to heat and provide structure to the dough (Rodrigues Ferreira et al., 2016:150; Vaclavik & Christian, 2008:358).

2.2.6.2 Yeasts and other leavening agents.

Baked goods are leavened biologically, chemically or by steam. A simple method of incorporating air whilst mixing the dough is also considered to promote the leavening of the product (Vaclavik & Christian, 2008:357). Chemically, baking powder and baking soda are added, and carbon dioxide leavens the baking product. Biologically, Yeast is used to leaven the product and it also produces Carbon dioxide (Vaclavik & Christian, 2008:357). Yeast is added or used in the dough for laminated products such as croissants and Danish pastry; this is to provide leavening through the production of carbon dioxide (Deligny et al., 2017:10; Wickramarachchi et al., 2015:1065; Cauvain, 2015:267; de Cindio & Lupi, 2011:302; Cauvain & Young, 2009:184; Cauvain & Young, 2001:135). Upon incorporating yeast into pastry dough, a fermentation period ensues, aiming to enhance the product volume before baking and achieve a favourable final result (Wickramarachchi et al., 2015:1065). The prevalent strain of yeast utilized in most baked goods is *Saccharomyces cerevisiae*, commonly known as baker's yeast (Voysey & Legan, 2014:502; Cauvain et al., 2001:135), and the temperature during the leavening or fermentation period is a critical factor (Belitz et al., 2009:723; 726). Yeast plays a vital role in aerating the paste during fermentation (proving process) and baking. However, it also poses a challenge by disrupting the dough's integrity and the layers of fat. To counter this disruption of layers, it becomes necessary to maintain the thickness of both the dough and fat layers greater than that of regular puff pastry (Cauvain et al., 2001:135). Danish pastry dough may contain a higher concentration of yeast to trigger the growth-inhibiting effects of added sugar (Andrews & Harte, 2003b). When incorporating yeast into dough containing salt, it is crucial to carefully control the amount of salt used to avoid inhibiting yeast activity (Cauvain & Young, 2009:172).

2.3 Types of pastry

2.3.1 Puff pastry

Puff pastry is laminated dough preparations, which are leavened without the use of yeast or any rising agents; and they are enjoyed all around the world by many different cultures, (Bessieris, 2015:41; Wickramarachchi et al., 2015:1065). This pastry is usually prepared with high-protein flour, water, salt and fat (shortening) (Wickramarachchi et al., 2015:1069; Harte, 2003:4408;).

Traditionally, wheat flour is usually used to produce puff pastry and the type of flour to be used is chosen based on its protein content (Silow et al., 2016:333; Wickramarachchi et al., 2015:1069). It is distinct for its multiple sandwiching of fat and dough layers when sheeting, followed by the lamination process of folding and rolling out. That makes their resulting flakiness appeal to consumers (Besseris, 2015:41). Puff pastry is renowned for its lighter, flakier, and more delicate texture compared to shortcrust pastry. It boasts a higher fat content and involves a distinctive preparation method crucial for achieving a successful puff pastry product (Silow et al., 2016:330; Wickramarachchi et al., 2015:1065; Simovic et al., 2009:1235; Harte, 2003:4408). The pastry is distinguished by its unique original alveolar structure, featuring large and irregular bubbles predominantly distributed horizontally. The flaky texture is a result of the repeated process of alternately folding and rolling out thin layers of fat and dough. This layered structure is formed through sheeting and laminating steps that precede the baking process (Deligny & Lucas, 2015:113; de Cindio & Lupi, 2011:306).

The key controlling parameters when making puff pastry are kneading time, the lamination level, the water quantity added, and the fat temperature. The combination of these controlling factors appears restrictive, but they implicate the significant rheological aspect of the wheat dough (Besseris, 2015:40). Generally, the dough and fat are folded to create multiple layers and then rolled out in a roller system. The fat used to make puff pastry should have certain key performance and structural characteristics, such as firmness (also referred to as consistency), predetermined plasticity, melting properties, and solid fat content profile (Renzetti et al., 2015:24; Wickramarachchi et al., 2015:1066-1067; Simovic et al., 2009:1242). The fat must be firm and consistent enough to withstand the folding process and to form continuous intact thin layers during sheeting. Also, it must be plastic enough to be pliable and spreadable under pressure. The melting properties of the fat determine the solid fat content, which then defines and influences the firmness and functionality of the fat. The pliability or workability is also facilitated by the melting properties of the fat during lamination and baking. In some fats, this results in palate cling of the pastry due to melting temperatures being above human body temperature. Thus, there have been puff pastry fats that have been specifically designed just for pastry production, and this results in less palate cling of the pastry (Renzetti et al., 2016:24; Wickramarachchi et al., 2015:1067).

The creation of puff pastry is acknowledged as a complex process with diverse production methods, maintaining its status as an art form to this day (Wickramarachchi et al., 2015:1065). Numerous approaches have been devised for producing puff pastry, with variations in the initial incorporation of fat layers, specifically through single-fold or three-fold methods (Deligny & Lucas, 2015:113). Subsequently, two folding methods are employed: the three-fold or half-turn and the

four-fold turn. In the former, the paste is folded into thirds, multiplying the number of fat layers by three with each turn (as depicted in Figure 2.1). In the latter, the paste is folded into quarters, resulting in a multiplication of layers by four with each turn (illustrated in Figure 2.2). Puff pastry can incorporate various fats, including butter and shortenings with different fatty acid compositions and solid fat profiles. The proportion of layering fat used in the dough may range from 26% to 75% of the flour (Bunu, 2016:7-8; Deligny & Lucas, 2015:113).

As per Wickramarachchi et al. (2015:1066) and Harte (2003:4408), three commonly employed methods for mixing and handling puff pastry dough are outlined. These methods include the French roll-in method, the English roll-in method, and the Scottish roll-all-in method. Renzetti et al. (2016:25) also discuss the Dutch method, also known as the Dutch system, which shares similarities with the Scottish method in both preparation and processing (Renzetti et al., 2016:25). In the French method, a portion of the pastry fat is rubbed into the flour to lubricate the gluten. Subsequently, a part of the water, acid, and eggs is placed into the centre of the ring formed by the mixed flour and fat (shortening).

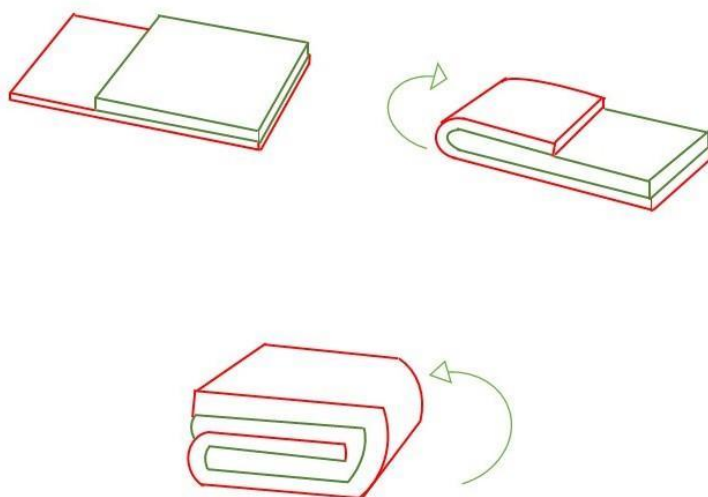


Figure 2.1. Threefold method for puff pastry making (adapted with permission from Bunu, 2016:7)

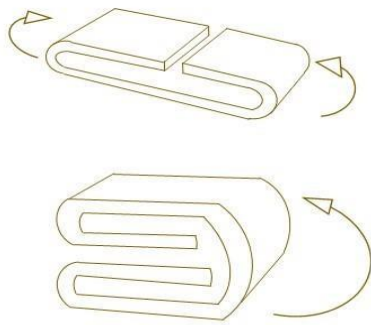


Figure 2.2. Fourfold method for puff pastry making (adapted with permission from Bunu, 2016:8)

Thorough mixing is crucial, and the process is repeated until all the ingredients, except for the remaining fat, are incorporated. The resulting dough is then rolled into a rectangle with a thickness of 125 cm, featuring a thinner outer border, and the fat is rolled to match the dimensions of the thicker dough. Following the placement of fat on the thicker dough, the thinner dough is folded over onto the thicker dough, creating a type of pocket. Subsequently, the fat and dough are rolled into a rectangle. To form a half-turn, one end of the dough is folded two-thirds of the way down the rectangle, and the opposite end is then folded to cover the initial fold. At this stage, the resulting rectangle comprises three layers of pastry fat separated by layers of dough. The dough is allowed to relax, and the rolling process is repeated after turning the dough by 90°, completing a total of six half turns. While the French method is the most widely adopted for puff pastry preparation, some individuals usually favour alternative methods due to the complexity and challenges associated with executing it in high-speed commercial manufacturing processes (de Cindio & Lupi, 2011:306; Harte, 2003:4408).

An alternative approach is the English method, where the dough is rolled into a rectangular shape, and the roll-in fat is evenly spread over two-thirds of the area. A three-fold process is employed to create three layers of dough separated by two layers of fat (de Cindio & Lupi, 2011:306; Simovic et al., 2009:1237; Harte, 2003:4408). The Scottish method, widely used in commercial settings, is simpler. All the pastry fat is divided into approximately 5 cm lumps and loosely mixed with the flour. The remaining ingredients are then added to form a lumpy dough. The rolling process mirrors that of the French method, with the addition of one extra half-turn. Following the final rolling, the dough is shaped and allowed to relax before baking.

Numerous formulations exist for puff pastry dough, with some incorporating yeasts and other additives that strengthen proteins and soften gluten. Despite the availability of additives, most studies have focused on puff pastry with fat as the sole layering agent (Besseris, 2015:41). An ideal choice is a firm, plastic fat (shortening) equivalent to 50% of the dough weight containing moisture (Andrews and Harte, 2003:4413). The fat layers function as impermeable barriers to water vapour produced during dough heating, compelling each dough layer to expand due to pressure beneath these impermeable layers. The mechanism of impermeable fat layers has been formulated based on experiments that varied the number of folds (de Cindio & Lupi, 2011:306; Baardseth et al., 1995:72).

The flakiness of puff pastry, as seen in Danish pastry, relies on the formation of thin films of gluten protein that trap water vapour and carbon dioxide for fermentation. These thin gluten films should be separated by continuous layers of fat to create a three-dimensional structure. The layered fat sheets act as a barrier, preventing adjacent dough layers from merging as they are progressively reduced in thickness through the folding and rolling process (Baardseth et al., 1995:72).

During baking the vapour that is released by either the fat or dough acts as a leavening agent in the laminated dough of puff pastry (de Cindio & Lupi, 2011:306). The gluten is taken into consideration when using wheat flour and other gluten-containing flour when making the pastry. The gluten network of the dough must be well developed to allow the expansion of gas to be supported and avoid the collapsing of the desired structure. The dough needs to be capable of producing a puff pastry product that is tender and flaky after baking. Therefore, the fat used in the dough must be solid and possess rheological properties like the dough during the laminating process. Additionally, the fat should be easily rolled out without breaking into pieces (de Cindio & Lupi, 2011:306). The purpose of the fat layers in the pastry is to serve as impermeable barriers against the water vapour generated during baking. The heat causes each impermeable layer to expand due to the pressure developed beneath it (Deligny et al., 2017:6). This type of pastry is versatile and can be used for various products such as pies, turnovers, shells filled with whipped cream, custards, fruits, and sausage rolls, among others (Harte 2003:4408).

2.3.2 Shortcrust pastry

Shortcrust pastry is a highly enriched dough consisting of fat, water, flour, and when needed, eggs and sugar (de Cindio & Lupi, 2011:304). The preparation of this pastry involves cutting solid fat into flour and salt, followed by the gradual addition of water to achieve the appropriate consistency for rolling the dough into the desired shape. This type of pastry, commonly used for

pie crusts, is straightforward and widely used (de Cindio & Lupi, 2011:304; Harte, 2003: 4407). Typically, low-protein pastry flour is employed to prevent gluten development in the dough. To further prevent gluten formation, it is important to limit the mixing step after adding water and avoid excessive reworking of the dough, as overhandling can result in a tough crust (Harte, 2003:4407). Gluten formation is not a typical requirement for shortcrust pastry. Therefore, traditional multistage dough mixing methods have been developed to minimize the potential for gluten formation by protecting the flour proteins with fat. While the degree of gluten formation needed in shortcrust pastry is less than that in bread making, some gluten development is still desirable to ensure the integrity of the pastry units or sheets during shaping and rolling. Without adequate gluten, cracks may form on the pastry surface (de Cindio & Lupi, 2011:304; Cauvain & Young, 2001:142). Excessive gluten development in shortcrust pastry can lead to issues such as shrinkage during rolling, blocking, shaping, and baking (Cauvain & Young, 2001a:142). Overworking the dough is considered risky, as it elongates the gluten strands, resulting in a chewy final product (de Cindio & Lupi, 2011:304).

The quantity of water incorporated into the formulation is a crucial factor influencing the rheological characteristics of the final paste. Insufficient water leads to a lack of cohesion in the sheet, while excessive water renders the paste overly soft for processing. The levels of fat also impact the rheology of the final paste, and to some extent, fat and water can be substituted to influence paste firmness: higher fat content results in a softer paste, which can be counterbalanced by adjusting the water content. However, concerning gluten formation, fat and water have opposite effects; fat hinders gluten formation, whereas water promotes it (Cauvain and Young, 2001:142). Achieving a firmer crust involves maintaining cooler ingredient temperatures and breaking the mixture into very small pieces. The choice of fat also influences the crust's flakiness. The dough undergoes kneading and a resting period before being rolled out and used for various products. During rolling, it is essential to begin from the centre and proceed toward the desired direction or side to achieve the desired shape and thickness (Andrews and Harte, 2003:4414). Shortcrust pastry finds its primary application in the production of biscuits, tarts, and pies, as well as the bottom and sides of fruit pies, flans, and cheesecakes (de Cindio & Lupi, 2011:304).

2.3.3 Choux pastry

Choux pastry, a versatile dough often utilized for various pastry creations, is commonly filled with creams or fashioned into decorative shapes for garnishing purposes (de Cindio & Lupi, 2011:304). A diverse range of pastry products, including cream puffs, éclairs, soup nuts, and decorative

shapes for pastry embellishments, are crafted using choux paste (Harte, 2003:4409). This particular pastry distinguishes itself by undergoing cooking before the piping or spooning process. Its composition typically includes 150-200 parts eggs, 100 parts flour, 100 parts fat, and around 200 parts water. The flour is swiftly incorporated into a mixture of liquid, seasoning, and fat, which is then heated to boiling temperatures. Complete dispersion of fat in the hot liquid is crucial for forming a proper emulsion. Stirring continues until the paste is smooth, gelatinized, and free of lumps adhering to the pan. Following this, the mixture is cooled, and eggs are gradually beaten into the choux paste, ensuring thorough mixing after each addition. Additional liquid may be introduced gradually to achieve the desired soft consistency. The resulting paste is then spooned or piped onto parchment paper-lined or greased pans, baking until crisp (de Cindio & Lupi, 2011:304-305; Harte, 2003:4409).

An alternative method for producing choux pastry involves a continuous extrusion process widely adopted in the industry. This process employs an extruder, a screw system within a tube or barrel, conveying dough toward a die. The dough undergoes compression and heating to elevated temperatures and pressures before extrusion through dies. Extrusion cooking leads to various alterations in the dough, including mixing, kneading, starch gelatinisation, protein coagulation, formation of amylose-lipid complexes, and the development of non-enzymatic browning and homogenization. All these transformations must be carefully considered to ensure a proper choux pastry production process (de Cindio & Lupi, 2011:305; Harte, 2003:4409). Choux pastry typically employs high-protein flour (12-13%), and during baking, coagulation of egg and flour proteins occurs, preventing steam and gas from escaping the pastry and setting it into the desired form (Andrews and Harte, 2003:4412)

2.3.4 Danish pastry

Danish pastry has a similar formulation in terms of the lamination process to that of puff pastry and both are characterized by a unique aerated texture and alveolar with large bubbles that are distributed horizontally (Deligny et al., 2017:6; Deligny & Lucas, 2015:113; Baardseth et al., 1995:72;). It is a rich pastry that is produced with a lamination process that includes fermented sweet dough (the difference from puff pastry). The ingredients include flour, yeast, sugar, eggs, fat, liquid and other enriching agents (Wickramarachchi et al., 2015:1065). The puffing process of the pastry is achieved by the leavening agents during baking. High-protein wheat flour is mostly used in making Danish pastries to achieve easier lamination (de Cindio & Lupi, 2011:303; 307; Harte, 2003:4409). de Cindio and Lupi (2011:307) reported on two methods that can be used for Danish pastry preparation: the conventional and the lamination method. The conventional method

includes three-folds, where all ingredients are mixed except the fat. A large amount of fat is distributed over two-thirds of the rectangular sheeted dough, the rectangle is then folded (de Cindio & Lupi, 2011:307; Harte, 2003:4409-4410).

The lamination method is mostly industrially used (de Cindio & Lupi, 2011:307). The pastry is produced by layering the fat/shortening between two pieces of dough. This can be achieved by extruding dough around the fat or high-speed pumping of the fat between two continuous dough sheets (de Cindio & Lupi, 2011:307). The number of turns determines the impervious fat layers, the amount of fat layers influences the resulting structure and texture of the product after baking as well as the fermentation process since it provides volume before baking (Deligny & Lucas, 2015:114). After baking, the pastry is composed of large, elongated cavities. These cavities are a result of thin layers of dough and fat that are formed by successive repetitions of folding and lamination steps before fermentation and baking (Deligny & Lucas, 2015:114; Bousquieres et al., 2014:359).

2.3.5 Strudel pastry

The dough used for strudel pastry can either be of puff pastry variety or created from a combination of water, seasoning, eggs, fat (shortening) or oil, and optionally high protein flour, sugar, and lemon juice. The fat is incorporated into a mixture of flour, and liquid ingredients are added gradually (Harte, 2003:4409). The resulting dough is formed into a ball, kneaded, shaped into a rectangular form, allowed to relax, and then delicately stretched to achieve an extremely thin, transparent consistency, with oil brushed onto these thin layers. Manual stretching for home preparation can be challenging, leading to the development of commercial methods for producing these thin sheets. Strudel dough has the flexibility to be frozen and can be utilized in the creation of various products, including the well-known Swiss roll (Harte, 2003:4409).

2.3.6 Non-gluten pastry products

Research that has been done on Gluten-free baked products mostly focuses on bread, since bread is seen as a staple food in many countries (like South Africa). There has not been much research specifically on gluten-free pastry. However, Zhu (2017:1178) reported on the suitability of chestnut flour in pastry making. This flour is known for its unique eating quality and quality proteins, dietary fibre, low amounts of fat and vitamin E, vitamin B group, potassium, phosphorus, and magnesium (Zhu, 2017:1174; Paciulli et al., 2016:89). Zhu (2017:1173) was studying the rheological properties of chestnut flour dough. He concluded that chestnut flour alone can be used for pastry making as during heating it exhibited similar behaviour to soft wheat flour that is suitable

for use in pastry (Zhu, 2017:1178). Shepherd (2016:2) mentioned a Cape Town Gluten-free bakery called The Allergen Baker, which was then looking to develop gluten-free frozen short crust and puff pastry items (Shepherd, 2016:2). This shows the need for the development of more gluten-free pastry products from other flour sources such as Bambara groundnut.

2.4 Gluten and coeliac disease

As per the Codex Alimentarius, gluten is described as the protein component derived from wheat, rye, barley, oats, or their hybrid varieties and their derivatives, causing intolerance in certain individuals (Palabiyik et al., 2016:633; Scherf et al., 2015:2; Codex Stan, 2008:2;). Another definition of gluten is the cohesive, viscoelastic protein material produced as a by-product during the isolation of starch from wheat flour (Vaclavik & Christian, 2008:352; Day et al., 2006:82). Gluten serves as the primary structural protein in most baked goods, contributing to the elasticity, cohesiveness, and viscosity of dough (Miñarro et al., 2012:476). Numerous studies have indicated that wheat gluten proteins are the main triggers of adverse immune responses and diseases, such as celiac/coeliac disease (Scherf et al., 2015:2).

Coeliac disease is a persistent intolerance to wheat gluten and related cereal proteins, marked by inflammation of the small intestine leading to impaired absorption of water and nutrients (including iron, folic acid, calcium, and fat-soluble vitamins). In some cases, it can result in malnutrition. Individuals affected by this intolerance must adhere to a strict, lifelong gluten-free diet, avoiding products containing gluten (Masure et al., 2016:92; Mir et al., 2016:50; Rodrigues Ferreira et al., 2016:147; Silvester et al., 2016:777-778; Tayob et al., 2016:12; Giuberti et al., 2015:43; Mirhosseini et al., 2015:184; Scherf et al., 2015:4; Badenhorst, 2014:31; Matos & Rosell, 2012:107; Miñarro et al., 2012:476; Vallons et al., 2011:1672; Cataldo & Montalto, 2007:2153; Day et al., 2006:86;). In African populations, Coeliac disease was more prevalent in North Africa than any other part of Africa with a percentage greater than 5% (Cataldo & Montalto, 2007:2154). In South Africa, it is estimated to occur in 1% of European ancestry and 0.3% of African blacks (Badenhorst, 2014:32).

Not every person can enjoy pastries made from wheat flour; people who suffer from coeliac disease and other gluten intolerances can never share that experience. This has led to a growth in the production of gluten-free products within the food industry. The rise within the gluten-free market is also caused by the consumption of the products by the families and friends of coeliac patients, and health-conscious consumers who prefer gluten-free products as a lifestyle choice (Morreale et al., 2018:154; Foschia et al., 2016:113). According to Shepherd (2016:1), the South African bakery sector has only been using conventional bakery products. Gluten-free

products were not featured as much on the retail shelves and only recently started to grow. Food industry analysts now count South Africa as one of the next five key international markets for gluten-free products, even though its domain consumers are still high-end income earners (Shepherd, 2016:1). It is imperative to note that the South African market is made up of consumers who are focused on strong health and wellness, which shows that there is space for growth. In 2016, Mintel published data that showed that around 7% of total food and drink launches in the country were gluten-free, which according to them was a 1% increase from the previous year (Shepherd, 2016:1). Mintel also noted that in two major retailers, namely Woolworths and Shoprite Holdings' Checkers, wellness had been a major factor that led them to introduce gluten-free products in their product ranges. Nowadays, you can find a shelf dedicated to gluten-free products, and some companies are also selling the products online. Awareness of health issues is assisting them in selling the products (Shepherd, 2016:2). The growth in gluten-free products has been evident for the Allergen Baker, which is a Cape Town-based firm that used to supply small shops but is now supplying Pick n Pay stores in the Western Cape and is soon to supply them nationally (Shepherd, 2016:2-3). This shows that the demand for gluten-free products is growing.

To avoid gluten-containing products, consumers can opt for flour derived from non-gluten sources, like Bambara groundnut. However, the use of gluten-free alternatives may present technological challenges for the final product, such as an undesirable mouthfeel, crumbly texture, and rapid staling (Miñarro et al., 2012:476). To address this issue, many gluten-free products now incorporate starches, proteins from animal and vegetable sources, and hydrocolloids. The objective is to emulate the properties of gluten, aiming for an enhanced structure, mouthfeel, overall acceptability, and prolonged shelf life (Miñarro et al., 2012:476).

2.5 Overview of Bambara groundnut flour

Bambara groundnut (*Vigna subterranea*) (Figure 2.3) is one of the high-protein plant seeds found in some African countries including South Africa. In Africa, the estimated production is about 330 000 metric tons. Nigeria leads with 100 000 tons followed by Burkina Faso, Ghana, Mali, Cameroon and Ivory Coast. In South Africa, it is mostly for subsistence purposes and only recently did commercialisation of the legume and its by-products increase (DAFF, 2016:4; Hillock *et al.*, 2012:6). The high protein content gives way to interest in the development of improved methods for processing and diversifying the seed for other food uses (Adeyi et al., 2014:28; Alakali et al., 2010:215). The colour of the seed varies from white to cream, yellow, brown, purple-red or black; as seen in Figure 2.3. In traditional farming systems, the seed is mostly grown by women farmers

as an intercrop with one or more species (Adeyi et al., 2014:28). It is easy to cultivate, which means it has very little or any demand on the soil and hence, it is less prone to the risk of total crop failure (Baryeh, 2001:326). The Bambara plant is highly drought tolerant, and it adapts very well to the change in climate. It was known to be under-utilized, but researchers have come up with many ways that the Bambara plant can be used in Southern Africa such as fibre as reported by Maphosa and Jideani (2016). In parts of Kwazulu-Natal and Mpumalanga this is used to feed families in the form of a staple called Isithwalaphishi which is a mixture of freshly boiled Bambara groundnut and mealie meal (Oyeyinka *et al.*, 2015:171).



Figure 2.3 Variety of Bambara groundnut seeds (Adeyi et al., 2014:28)

The matured seeds of Bambara groundnut can be processed into flour, offering a high-carbohydrate product. Research indicates a nutritional composition of 53.1% carbohydrates, 17.4% protein, 6.1% fat, 6.1% fibre, and 3.4% ash, with low levels of calcium, iron, and potassium. The primary carbohydrate in the grain is starch, comprising 35-46% on a flour basis. Starch content may vary based on the Bambara variety (white/cream or black), impacting functional properties like swelling and gelatinization. During gelatinisation, starch granules absorb water, causing amylose to leach out and increase viscosity. Notably, Bambara groundnut flour lacks

gluten, making it an ideal alternative for those intolerant to gluten-based flour. Furthermore, studies suggest that Bambara groundnut flour possesses favourable functional properties, including oil and water absorption capacities, bulk density, and emulsifying activities, enhancing its utility as a gluten-free option (Ogundele et al., 2017:655).

2.6 Quantitative descriptive analysis

Quantitative descriptive analysis (QDA) is a sensory tool that was developed in the 1970's, to measure and optimize sensory attributes of various food products during product development, process development or shelf-life studies (Puri et al., 2015:1238; Choi, 2013:114; Gillette, 1984:404). (Leighton et al., 2010:4) noted that the process of QDA is time-consuming, this is because the panellists should first be recruited from the public. Then they are trained to establish the vocabulary or scientific terms to be used, then the panel is exposed to variations of the product to acquire an accurate concept of the product (Choi, 2013:114; Leighton et al., 2010:4; Lawless et al., 2001:13). The panel leader only facilitate the discussions and provide the necessary tools (Choi, 2013:114). The trained panellists measure the products' quality attributes and develop quantitative product descriptions that can be analysed statistically. (Puri et al., 2015:1238; Choi, 2013:114; Stone et al., 2012:250; Lawless et al., 2001:13). Line scales can be used to describe the intensity of rated sensory attributes. The attributes may include qualities like appearance, colour, taste, hardness, elasticity, taste, stickiness, odour, bitterness, and overall acceptability, just to mention a few (Choi, 2013:114; Ribeiro et al., 2010:1352-1353; Gillette, 1984:403; 408). The panellists are trained to identify and score the key product attributes consistently. The resulting terms allow for precise profiling of sensory attributes and the analysis can be used to model predictions of consumer acceptability (Puri et al., 2015:1238-1239; Lawless et al., 2001:13). The results obtained can be graphically represented for perceptual mapping. The results enable the panel leader (researcher or scientist) to relate specific ingredients or process variables to specific changes in the sensory attributes of products (Puri et al., 2015:1239; Stone et al., 2012:251; 264; Lawless et al., 2001:13). Principal Component Analysis (a multivariate statistical technique), histograms and spider plots can be used in QDA to reduce attributes (dependent variables) to factors based on correlation among original variables (Lawless et al., 2001:13).

2.7 References

Adeyi, O., Ikhu-Omoregbe, D. & Jideani, V. 2014. Effect of Bambara groundnut flour on the stability and rheological properties of oil-in-water emulsion. Electronic Theses and Dissertations, Cape Peninsula University of Technology. <https://etd.cput.ac.za/handle/20.500.11838/3678>.

- Aguilar, N., Albanell, E., Na, B., Narro, M. & Capellas, M. (2015). Chickpea and tiger nut flours as alternatives to emulsifier and shortening in gluten-free bread. *Food Science and Technology*, 62(1), 225–232. <https://doi.org/10.1016/j.lwt.2014.12.045>.
- Alakali, J.S., Irtwange, S. V & Mzer, M.T. 2010. Quality evaluation of beef patties formulated with Bambara groundnut (*Vigna subterranea L.*) seed flour. *Meat Science*, 85(2), 215–223. <https://doi.org/10.1016/j.meatsci.2009.12.027>.
- Andrews, S.L. & Harte, J.B. 2003a. Pastry Products: Types and Production. *Encyclopaedia of Food Sciences and Nutrition*. Academic Press. 4412 - 4414. <https://www.scribd.com/document/691469560/2003-Pastry-Types-and-Production>
- Andrews, S.L. & Harte, J.B. 2003b. *Pastry products: Ingredient Functionality and Dough Characteristics*. Academic Press. 4407 - 4411. https://www.researchgate.net/publication/290862714_PASTRY_PRODUCTS_Ingredient_Functionality_and_Dough_Characteristics#:~:text=10.1016/B0%2D12%2D227055%2DX/00894%2D4
- Baardseth, P., Naes, T. & Vogt, G. 1995. Roll-in Shortenings Effects on Danish Pastries Sensory Properties Studied by Principal Component Analysis. *Lebensmittel-Wissenschaft & Technologie*, 28(1): 72–77. [https://doi.org/10.1016/s0023-6438\(95\)80015-8](https://doi.org/10.1016/s0023-6438(95)80015-8)
- Badenhorst, J. 2014. Coeliac disease. *South African Academy of Family Physicians*, 56(1): 31–34. <https://doi.org/10.1080/20786204.2014.10844580>.
- Baryeh, E.A. 2001. Physical properties of Bambara groundnuts. *Journal of Food Engineering*, 47(4): 321–326. [https://doi.org/10.1016/s0260-8774\(00\)00136-9](https://doi.org/10.1016/s0260-8774(00)00136-9).
- Bastin, S. 2010. Pies and Cobblers. College of Agriculture, University of Kentucky. https://fcs-hes.ca.uky.edu/sites/fcs-hes.ca.uky.edu/files/2ssc_pies_cbblerpub.pdf [02 December 2023].
- Besseris, G.J. 2015. Profiling multiple static and transient puff-pastry characteristics with a robust-and-intelligent processor. *Journal of Food Engineering*, 164, 40–54. <https://doi.org/10.1016/j.jfoodeng.2015.04.011>.
- Bousquieres, J., Deligny, C., Challos, S. & Lucas, T. 2014. Using confocal laser scanning microscopy to examine the breakdown of fat layers in laminated dough. *Food Research International*, 62, 359–365. <https://doi.org/10.1016/j.foodres.2014.02.019>.
- Bunu, M. (2016). Three Methods for Puff Pastry. <https://www.thewisebaker.com/2016/12/puff-pastry-recipe.html?showComment=1528295240109#c6548706501552037247> [11 June 2018].
- Cai, J., Hong Chiang, J., Yi Pei Tan, M., Kiat Saw, L., Xu, Y. & Na Ngan-Loong, M. 2016. Physicochemical properties of hydrothermally treated glutinous rice flour and xanthan gum mixture and its application in gluten-free noodles. 186(2016), 1-9. <https://dx.doi.org/10.1016/j.jfoodeng.2016.03.033>.

- Campo, E., Del Arco, L., Urtasun, L., Oria, R. & Ferrer-Mairal, A. 2016. Impact of sourdough on sensory properties and consumers' preference of gluten-free breads enriched with teff flour. 67(2016) 75-82. <http://dx.doi.org/10.1016/j.ics.2015.09.010>.
- Cataldo, F. & Montalto, G. 2007. Celiac disease in the developing countries: A new and challenging public health problem. *World Journal of Gastroenterology*, 13(15), 2153–2159. <http://www.wjnet.com/1007-9327/13/2153.asp>.
- Cauvain, S. 2015. Speciality Fermented Goods. *Technology of Breadmaking*. 3rd ed. Switzerland: Springer International Publishing. 253-277. https://doi.org/10.1007/978-3-319-14687-4_9
- Cauvain, S. & Young, L. 2001a. 9 – Short pastry. In: *Baking Problems Solved*. Woodhead publishing. 136–147. <http://dx.doi.org/10.1533/9781855736184.136>
- Cauvain, S. & Young, L. 2001b. Flours. *Baking Problems Solved*. Woodhead publishing. 18–37. <http://dx.doi.org/10.1533/9781855736184.18>.
- Cauvain, S., & Young, L. 2001. 8 – Laminated products. In *Baking Problems Solved*. Woodhead publishing. 124–135. <https://doi.org/10.1533/9781855736184.124>.
- Cauvain, S.P. & Young, L.S. 2009a. 2 – Flours and grains. In *More Baking Problems Solved*. Woodhead Publishing. 33–51. <http://dx.doi.org/10.1533/9781845697204.169>.
- Cauvain, S.P. & Young, L.S. 2009b. 3 – Other bakery ingredients. In *More Baking Problems Solved*. 52–82. <https://doi.org/10.1533/9781845697204.52>.
- Cauvain, S.P. & Young, L.S. 2009c. 7 – Pastries. In *More Baking Problems Solved*. Woodhead publishing. 169–185. <https://doi.org/10.1533/9781845697204.169>.
- Choi, S.E. 2013. Sensory evaluation. In Edelman, S. (ed.). *Food Science an Ecological Approach*. New York: Jones and Bartlett Learning, LLC: 84–111.
- de Cindio, B. & Lupi, F.R. 2011. 15 – Saturated fat reduction in pastry. In *Reducing Saturated Fats in Foods*. 301–317. <http://dx.doi.org/10.1016/B978-1-84569-740-2.50015-4>.
- Codex Stan, A. (2008). Codex Standard for Foods for Special Dietary Use for Persons Intolerant To Gluten. *Codex Alimentarius*, Codex Stan 118-1979 Rev. in 2008.
- Day, L., Augustin, M.A., Batey, I.L. & Wrigley, C.W. 2006. Wheat-gluten uses and industry needs. *Trends in Food Science and Technology*, 17(2): 82–90.
- Deligny, C., Collewet, G. & Lucas, T. 2017. Quantitative MRI study of layers and bubbles in Danish pastry during the proving process. *Journal of Food Engineering*, 203: 6–15.
- Deligny, C. & Lucas, T. 2015. Effect of the number of fat layers on expansion of Danish pastry during proving and baking. *Journal of Food Engineering*, 158: 113–120.
- Department of Agriculture, Forestry and Fisheries(DAFF), 2016. Bambara groundnuts (*Vigna Subterranea*).

https://www.dalrrd.gov.za/phocadownloadpap/Brochures_and_Production_Guidelines/Bambara.pdf [21 June 2024].

- Dickinson, E. 2003. Hydrocolloids at interfaces and the influence on the properties of dispersed systems. *Food Hydrocolloids*, 17(1): 25–39.
- Duodu, K.G. & Taylor, J.R.N. 2012. 30 – The quality of breads made with non-wheat flours. In *Breadmaking*. 2nd ed. Woodhead publishing. 754–782. <https://doi.org/10.1533/9780857095695.4.754>.
- Foschia, M., Horstmann, S., Arendt, E.K. & Zannini, E. 2016. Nutritional therapy – Facing the gap between coeliac disease and gluten-free food. *International Journal of Food Microbiology*, 239: 113–124.
- Gillette, M. 1984. Applications of Descriptive Analysis. *Journal of Food Protection*, 47(5): 403–409.
- Giuberti, G., Gallo, A., Cerioli, C., Fortunati, P. & Masoero, F. 2015. Cooking quality and starch digestibility of gluten-free pasta using new bean flour. *Food Chemistry*, 175: 43–49.
- Harte, J.B. 2003. Pastry products: Types and Production. In *Encyclopaedia of Food Sciences and Nutrition*. 4407–4412.
- Hillock, R.J., Bennet, C. & Mponda, O.M. (2012) BAMBARA NUT: A REVIEW OF UTILISATION, MARKET POTENTIAL AND CROP IMPROVEMENT. *African Crop Science Journal*. 20(1): 1 – 16.
- Ibanoglu, E., Van Der Borght, A., Goesaert, H., Veraverbeke, W.S., Delcour, J.A., Foster, T.J., Dickinson, E., Gabriel, E.G., Jideani, V.A. & Ikhu-Omoregbe, D.I.O. 2005. Effect of hydrocolloids on the thermal denaturation of proteins. *Journal of Cereal Science*, 7(11): 621–626.
- Jideani, V.A. (2013). *Food Hydrocolloids*. 1–62. Cape Town.
- Kaur, M., Sandhu, K.S., Arora, A. & Sharma, A. 2015. Gluten free biscuits prepared from buckwheat flour by incorporation of various gums: Physicochemical and sensory properties. *LWT - Food Science and Technology*, 62(1): 628–632.
- Lawless, H.T., Boor, K.J. & Chapman, K.W. 2001. Quantitative Descriptive Analysis and Principal Component Analysis for Sensory Characterization of Ultra pasteurized Milk. *Journal of Dairy Science*, (84): 12–20.
- Leighton, C.S., Schönfeldt, H.C. & Kruger, R. 2010. Quantitative descriptive sensory analysis of five different cultivars of sweet potato to determine sensory and textural profiles. *Journal of Sensory Studies*, 25(25): 2–18.
- Maphosa, Y. & Jideani, V.A. 2016. Physicochemical characteristics of Bambara groundnut dietary fibres extracted using wet milling. *South African Journal of Science*, 112(1–2): 1–8.

- Marston, K., Khouryieh, H. & Aramouni, F. 2016a. Effect of heat treatment of sorghum flour on the functional properties of gluten-free bread and cake. *LWT - Food Science and Technology*, **65**: 637–644.
- Martínez, M.M. 2015. Applications of the rapid visco analyser (RVA) in the food industry: a broader view. *News & Publications*. <http://www.perten.com/Publications/Articles/Applications-of-the-Rapid-Visco-Analyser-RVA-in-the-Food-Industry-a-broader-view/>. [18 January 2017]
- Masure, H.G., Fierens, E. & Delcour, J.A. 2016. Current and forward-looking experimental approaches in gluten-free bread-making research. *Journal of Cereal Science*, **67**: 92–111. <https://doi.org/10.1016/j.jcs.2015.09.009>
- Matos, María Estela & Rosell, C.M. 2012. Relationship between instrumental parameters and sensory characteristics in gluten-free breads. *European Food Research and Technology*, **235**(1): 107–117.
- Mert, B. & Demirkesen, I. 2016. Evaluation of highly unsaturated oleogels as shortening replacer in a short dough product. *LWT - Food Science and Technology*, **68**: 477–484.
- Mikiewicz, K., Nebesny, E. & Rosicka-Kaczmarek, J. (2013). Changes of polymorphism of lipid fractions of shortcrust pastries during storage Studies with the use of thermal analysis (DSC). *Journal of Thermal Analysis Calorimetry*, 301–310.
- Miñarro, B., Albanell, E., Aguilar, N., Guamis, B. & Capellas, M. 2012. Effect of legume flours on baking characteristics of gluten-free bread. *Journal of Cereal Science*, **56**(2): 476–481.
- Mir, S.A., Shah, M.A., Naik, H.R. & Zargar, I.A. 2016. Influence of hydrocolloids on dough handling and technological properties of gluten-free breads. *Trends in Food Science and Technology*, **51**: 49–57. <http://dx.doi.org/10.1016/j.tifs.2016.03.005>.
- Mirhosseini, H., Farhana Abdul Rashid, N., Tabatabaee Amid, B., Whye Cheong, K., Kazemi, M. & Zulkurnain, M. 2015. Effect of partial replacement of corn flour with durian seed flour and pumpkin flour on cooking yield, texture properties, and sensory attributes of gluten-free pasta. *LWT - Food Science and Technology*, **63**: 184–190.
- Morreale, F., Angelino, D. & Pellegrini, N. 2018. Designing a Score-Based Method for the Evaluation of the Nutritional Quality of the Gluten-Free Bakery Products and their Gluten-Containing Counterparts. *Plant Foods for Human Nutrition*, **73**: 154–159. <https://doi.org/10.1007/s11130-018-0662-5>.
- Ogundele, O.M., Minnaar, A. & Emmambux, M.N. (2017). Effects of micronisation and dehulling of pre-soaked Bambara groundnut seeds on microstructure and functionality of the resulting flours. *Food Chemistry*, **214**, 655–663.
- Ooms, N., Pareyt, B., Jansens, K.J., Reyniers, S., Brijs, K. & Delcour, J.A. 2017. The impact of redox agents on further dough development, relaxation and elastic recoil during lamination and fermentation of multi-layered pastry dough. *Journal of Cereal Science*, **75** (2017). 84-91. <http://dx.doi.org/10.1016/j.jcs.2017.03.026>.

- Oyeyinka, S.A., Singh, S., Adebola, P.O., Gerrano, A.S. & Amonsou, E.O. 2015. Physicochemical properties of starches with variable amylose contents extracted from Bambara groundnut genotypes. *Carbohydrate polymers*, 133: 171–8.
- Paciulli, M., Rinaldi, M., Cirlini, M., Scazzina, F. & Chiavaro, E. 2016a. Chestnut flour addition in commercial gluten-free bread: A shelf-life study. *LWT - Food Science and Technology*, **70**: 88–95.
- Palabiyik, I., Yildiz, O., Toker, O.S., Cavus, M., Ceylan, M.M. & Yurt, B. 2016. Investigating the addition of enzymes in gluten-free flours – The effect on pasting and textural properties. *LWT - Food Science and Technology*, **69**: 633–641.
- Puri, R., Khamrui, K., Khetra, Y., Malhotra, R. & Devraja, H.C. 2015. Quantitative descriptive analysis and principal component analysis for sensory characterization of Indian milk product cham-cham. *Journal of Food Science and Technology*, 53(2): 1238–1246.
- Renard, D., Van De Velde, F. & Visschers, R.W. 2006. The gap between food gel structure, texture and perception. *Food Hydrocolloids*, 20(4): 423–431.
- Renzetti, S., de Harder, R. & Jurgens, A. 2016. Puff pastry with low saturated fat contents: The role of fat and dough physical interactions in the development of a layered structure. *Journal of Food Engineering*, 170: 24–32.
- Ribeiro, J.S., Ferreira, M.M.C. & Salva, T.J.G. 2010. Chemometric models for the quantitative descriptive sensory analysis of Arabica coffee beverages using near infrared spectroscopy. *Talanta*, 83: 1352–1358.
- Rodrigues Ferreira, S.M., De Mello, A.P., De Caldas Rosa dos Anjos, M., Carneiro Hecke Krüger, C., Azoubel, P.M. & De Oliveira Alves, M.A. 2016. Utilization of sorghum, rice, corn flours with potato starch for the preparation of gluten-free pasta. *Food Chemistry*, 191: 147–151.
- Scherf, K.A., Koehler, P. & Wieser, H. 2015. Gluten and Wheat Sensitivities – an Overview. *Journal of Cereal Science*, 67: 2–11.
- Shepherd, J. 2016. What are the next major markets for gluten-free? South Africa's fledgling but growing market: Food Industry Analysis. *Just - food*. <https://www.just-food.com/features/what-are-the-next-major-markets-for-gluten-free-south-africas-fledgling-but-growing-market/?cf-view> [17 February 2018].
- Silow, C., Zannini, E., Axel, C., Lynch, K.M. & Arendt, E.K. 2016. Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content. *Food Research International*, 89: 330–337.
- Silow, C., Zannini, E., Axel, C., Lynch, K.M. & Arendt, E.K. 2016c. Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content. *Food Research International*, 89: 330–337.

- da Silva, P.P.M., Casemiro, R.C., Zillo, R.R., Camargo, A.C., Prospero, E.T.P. & Spoto, M.H.F. 2014. Sensory descriptive quantitative analysis of unpasteurized and pasteurized juçara pulp (*Euterpe edulis*) during long-term storage. *Food Science & Nutrition*, 2(4): 321–331.
- Silvester, J.A., Weiten, D., Graff, L.A., Walker, J.R. & Duerksen, D.R. 2016. Is it gluten-free? Relationship between self-reported gluten-free diet adherence and knowledge of gluten content of foods. *Nutrition*, 32(7): 777–783.
- Simovic, D.S., Pajin, B., Seres, Z. & Filipovic, N. 2009. Effect of low-trans margarine on physicochemical and sensory properties of puff pastry. *International Journal of Food Science and Technology*, 44(6): 1235–1244.
- Sliwinski, E., Kolster, P. & Van Vliet, T. 2004. On the relationship between large-deformation properties of wheat flour dough and baking quality. *Journal of Cereal Science*. 39 (2004): 231-245. <http://doi.org/10.1016/j.jcs.2003.10.005>
- Stone, H., Bleibaum, R.N. & Thomas, H.A. 2012. Descriptive Analysis. Stone, H., Bleibaum, R.N. & Thomas, H.A (eds).In *Sensory Evaluation Practices*. 4th ed. Elsevier. 233–289.
- Tayob, S., Pillay, K., Tlou, B. & Ganie, Y. 2016. Prevalence of positive coeliac serology in a cohort of South African children with type 1 diabetes mellitus. *SAJCH* , 10(1): 12–15.
- Vaclavik, V.A. & Christian, E.W. 2008. Baked Products: Batters and Dough. In Dennis R. Heldman, ed. *Essentials of Food Science*. Dallas: Springer: 299–319.
- Vallons, K.J.R., Ryan, L.A.M. & Arendt, E.K. 2011. Promoting structure formation by high pressure in gluten-free flours. *LWT - Food Science and Technology*, 44: 1672–1680.
- Van Der Borght, A., Goesaert, H., Veraveboeke, W., & Delcour, J.A. 2005. Fractionation of wheat and wheat flour into starch and gluten: overview of the main processes and the factors involved. *Journal of Cereal science*. 41(3): 221 - 237. <http://doi.org/10.1016/j.jcs.2004.09.008>
- Voysey, P.A. & Legan, J.D. 2014. Confectionery Products – Cakes and Pastries. In *Encyclopaedia of Food Microbiology*. 497–503. <http://dx.doi.org/10.1016/B978-0-12-384730-0.00075-6>
- Wickramarachchi, K.S., Sissons, M.J. & Cauvain, S.P. 2015. Puff pastry and trends in fat reduction: An update. *International Journal of Food Science and Technology* 50, 1065–1075. <https://doi.org/10.1111/ijfs.12754>.
- Williams, R. & Mittal, G. (1999). Water and Fat Transfer Properties of Polysaccharide Films on Fried Pastry Mix. *LWT - Food Science and Technology*, 32, 440–445.
- Zhu, F. (2017). Properties and Food Uses of Chestnut Flour and Starch. *Food Bioprocess Technology*, 1173–1191.

CHAPTER THREE

EFFECT OF CARBOXYMETHYLCELLULOSE AND MODIFIED STARCH ON PASTING AND TEXTURE PROFILE OF WHOLE BAMBARA GROUNDNUT FLOUR AND DOUGH.

Abstract

There is a rise in demand for non-gluten baked products due to gluten-intolerant consumers, celiac sufferers, and health-conscious consumers who prefer to eat non-gluten products for health reasons. This study investigated the effect of carboxymethylcellulose (CMC) and modified starch on whole Bambara groundnut dough's pasting and texture profile to provide a gluten-free flour alternative for baked products. A whole BGNF mix was developed with modified starch and CMC following an augmented factorial design. The pasting properties of the flour mixes were determined, followed by dough formation from each flour mix, and their textural properties such as hardness, gumminess, and springiness were subsequently determined. Multivariate analysis of variance (MANOVA) was used to analyse data and to test significant differences ($p \leq 0.05$) between treatments. Duncan's multiple range test was also used to separate means where differences exist (IBM SPSS version 27 (2021)). The data was subjected to a two-factor interaction model using Design Expert 12. modified starch and CMC did not significantly affect peak viscosity, trough viscosity, breakdown viscosity, final viscosity, and setback viscosity. However, CMC had a significant effect ($p < 0.05$) on the dough's springiness, gumminess, and hardness. The interaction between modified starch and CMC was not significant. Notably, increasing CMC concentration significantly increased the springiness, gumminess, and hardness of the whole Bambara groundnut dough. The optimal mix was 1% CMC and 5% modified starch. Hence, CMC and modified starch can be utilised to produce gluten-free flour and dough whole Bambara groundnut mixes, catering to the needs of gluten-intolerant and health-conscious consumers.

3.1 Introduction

Bambara groundnut (BGN) is known as an underutilised climate smart legume, however, in recent years, there has been an increasing exploration of the Bambara groundnut to create a diverse range of products, including milk, yoghurt and other related products (Maphosa et al., 2022:1; Murevanhema & Jideani, 2015:1485; Adeyi et al., 2014:28; Mpotokwane et al., 2008:93). BGN is

naturally gluten-free and high in protein and fibre, making it a good source and alternative for consumers who cannot consume gluten-containing flour sources like wheat, and this then gives way for the legume to be explored as a source of flour for baked goods. The fact that it does not contain gluten makes it a challenge to develop a dough as gluten is crucial in developing and manipulating dough to get a good final product. Additives such as hydrocolloids and starches become essential in overcoming the hurdle of dough development and harnessing viscoelastic properties that are important for dough formation (Mir et al., 2016:50).

Oliveira et al. (2019:2) defined hydrocolloids as a group of polymers that are readily dispersed and partially or fully soluble in water. Hydrocolloids have valuable functional properties in the food industry, such as controlling crystallisation, inhibition of syneresis, enhancing viscosity, foaming structures, formation of films, texture improvement, and stabilisation (Oliveira et al., 2019:2; Mir et al., 2016:50). In dough formation, they are known to improve dough development and the retention of gas (essential for baked goods that require a lift within dough layers) from increased viscosity. They also mimic the viscoelastic characteristics of gluten. Examples of hydrocolloids that have been used in gluten-free baked goods are xanthan gum, locust bean, guar gum, hydroxypropylmethylcellulose (HPMC), and carboxymethylcellulose (CMC). According to the literature, a significant amount of research has focused on the use of hydrocolloids in gluten-free bread to improve the viscoelastic properties, increase elasticity, provide water binding capacity, improve stability, and breadmaking performance such as reduction in the diffusion and loss of water from bread crumb (Zhu, 2017:1178; Foschia et al., 2016:119; Jeradechachai, 2012:20-21; Pruska-Kędzior et al., 2008:1524). Hydrocolloids can also limit the interactions between proteins and starch, leading to slower staling during storage and a softer crumb (Foschia et al., 2016:119). In a study by Gull et al. (2018:152), adding CMC increased the stability and quality of their pasta, as well as better cooking quality attributes (cooked weight, water absorption and swelling index). Mir et al. (2016:54) and Jeradechachai (2012:20) noted the significant contribution of CMC as a better gluten replacer in gluten-free bread, as combinations containing CMC gave higher quality properties than other hydrocolloids such as xanthan gum. However, not much has been reported on the effect of CMC on BGN flour; hence, there is a need to study it further, as well as its interaction with other additives such as modified starch.

Starch is a plant polysaccharide with many applications in the food industry because of its thickening, gelling, and stabilising capacities for food systems. Native starches have been widely used; however, use is limited because of inherent undesirable attributes like instability in processing conditions such as collapsing under high shear and temperature. The need arises to chemically modify the starches to meet the product requirement in a way native starches cannot

(Maphosa et al., 2022:1; Waterschoot et al., 2016:69). Not a lot of studies have been done on the effect of modified starch on pastry baked goods. Also, Modified starch has not been extensively studied on BGN flour thus the need to study it further.

Mthombeni-Nkantsu (2017:15) previously studied dehulled BGN flour mix for its texture and sensory properties as a gluten-free flour mix containing Xanthan gum, CMC and modified starch. What was found in that study is that for the best mix only CMC and modified starch gave a significant result, Xanthan gum did not have a significant effect on the pasting and the textural properties of dehulled BGN flour and dough. Further investigation was then required to study the interaction of CMC and modified starch on the whole BGN flour mix. Thus, for this study, only CMC and modified starch will be studied. However, the texture and sensory properties concerning whole BGN flour are unknown. This study aims to investigate the effect of carboxymethylcellulose and modified starch on the pasting and texture characteristics of whole BGN flour and dough to obtain an optimal gluten-free whole and dehulled BGN flour mix.

3.2 Materials and methods

3.2.1 Source of materials

The Bambara groundnut (BGN) was purchased from Triotrade CC in Gauteng, South Africa. All major equipment and whole and dehulled BGN flour were obtained from the Department of Food Science and Technology at the Cape Peninsula University of Technology, Bellville campus. These include INSTRON 3344 (Blue Hill software), Rapid Visco Analyser machine (Perten RVA 4500 instruments – Thermocline for Windows (TCW) software), and a cabinet dryer. Food-grade additives were obtained from a local supplier. Sasko wheat flour was obtained from a local supermarket.

3.2.2 Experimental design for the effect of modified starch and carboxymethylcellulose on the pasting and textural properties of whole Bambara groundnut flour mix and dough.

The effect of the modified starch [1 & 5%] and CMC [1 & 4%] each at two levels (Table 3.1) on the textural profile of the whole BGN flour mix and dough was studied following an augmented 2² factorial design, each point in triplicate and three centre points, making a total of 15 runs (Table 3.2). The numerical optimisation tool Design Expert 12 was used to establish the optimum flour mix using a 2-factor interaction model.

Table 3.1 Levels of the flour mix additives.

Additive	Coded (x_i)	
	-1	+1
Carboxymethylcellulose (X_1)	1	4
Modified starch (X_2)	1	5

Transformation between coded and uncoded variables is given by $X_1 = 1.5 X_1 + 2.5$; $X_2 = 2 X_2 + 3$

The whole BGN flour mix was prepared by mixing the whole BGN flour with various amounts of modified starch and carboxymethylcellulose (CMC) following Table 3.2 in randomised order. The combinations of the flour mix were homogenised with a mixing spoon to ensure that the components were adequately dispersed. Each flour mix was analysed for pasting properties, proximate composition and the resulting dough for texture profile.

Table 3.2 Augmented 2^2 factorial design for the effect of CMC and Modified starch on the texture profile of whole BGN flour

Run number	Carboxyl methylcellulose (g)	Modified starch (g)
1	1	1
2	1	5
3	4	5
4	4	1
5	2.5	3
6	1	1
7	4	5
8	4	5
9	2.5	3
10	4	1
11	1	1
12	4	1
13	2.5	3
14	1	5
15	1	5

The information was modelled using the two-factor interaction model to identify the main effects of interaction between CMC and modified starch. To assess the statistical significance of the independent variables (modified starch and CMC) on flour mix and dough development, analysis of variance (ANOVA) was employed. The goodness of fit was determined through factors such as lack of fit, F-value, and the adequate precision ratio using DesignExpert version 12.

For achieving optimal results, numerical optimisation was carried out using DesignExpert version 12 to determine the best combination of independent variables. The goal was to maximise springiness while simultaneously minimising the hardness and gumminess of the dough.

3.2.3 Pasting properties of whole BGN flour mix.

The methods reported by Cai et al. (2016:2); Palabiyik et al. (2016:634); and Waterschoot et al. (2016:71) were used to investigate the pasting properties of whole BGN flour. The moisture content of the whole BGN flour mix was checked and recorded. Fifteen flour combinations were used for this experiment. The pasting properties of the 15 combinations of whole BGN flour mix were determined using a Rapid Visco Analyser (RVA 4500, Perten Instruments, Australia). The amount of 3 g of the whole BGN flour mix was transferred into an aluminium canister and 25 ml of distilled water was added to the canister. A plastic paddle was placed in the canister and agitated up and down to rid the mixture of any lumps. The canister and paddle were inserted into the RVA instrument. The mixture was equilibrated for a minute at 50°C, then heated to 95°C and held for 10 mins. The stirring speed was 160 rpm. The mixture was then cooled to 50°C for another minute and removed once the cycle had completely stopped. The precaution was exercised when handling the hot canister after it came out of the RVA machine to avoid harm or injuries. The peak viscosity, breakdown viscosity, setback viscosity and final viscosity were measured in triplicate using the Perten instruments ThermoLine for Windows (TCW) software.

3.2.4 Texture profile analysis of whole BGN dough.

The Texture profile analysis (TPA) technique used was adapted from Rashidi et al. (2016:10-11); Al-Rawahi et al. (2006:366) and Meullenet et al. (1998:81). The compression load cell was interfaced with Blue Hill software on INSTRON 3344. The whole BGN dough samples (20 x 20 mm in height and width) were loaded on the INSTRON instrument, and the compression load cell moved at a speed of 1 mm per second, up to 50% of the dough height was compressed initially, and then it moved back up at the same speed. Thereafter it compressed 80% of the dough

sample. The test was done in triplicate for each of the 5 samples of whole BGN flour mix dough. The “two-bite test” produced curves that allowed the gumminess, cohesiveness, springiness, chewiness, and maximum force to be recorded using Blue Hill software.

3.2.5 Proximate analysis of whole and dehulled BGN flour.

Proximate analysis was performed according to the following AACC and AOAC standard methods; protein (AOAC 990.03), fat (AOAC 920.39), moisture (AACC 44-15A), ash (AOAC 942.05), and carbohydrates and fibre were calculated by difference (AACC, 2000:1-4; AOAC, 2005:15; Marston et al., 2016:638)

3.2.6 Data analysis.

Results were reported as the mean \pm standard deviation of triplicate measurements. Multivariate analysis of variance (MANOVA) was performed to test significant differences ($p \leq 0.05$) between treatments. Duncan’s multiple range test was used to separate means where differences exist (IBM SPSS version 27 (2021)).

3.3 Results and Discussion

3.3.1 Model adequacy

The summary of linear model parameters, depicted in Table 3.3, outlines the influence of independent variables on both pasting (peak viscosity, trough viscosity, breakdown viscosity, final viscosity, and setback viscosity) and textural (springiness, gumminess, and hardness) properties of the entire BGN flour mix. For all pasting properties, the linear model did not demonstrate significance in capturing the effect of independent variables (CMC and modified starch) on the BGN flour mix. Consequently, the overall mean may better describe the response for peak viscosity, as suggested by the negative predicted R-squared values. The model F-value of 0.27 indicates insignificance relative to noise, with an 84.67% chance that this F-value is due to noise. The lack-of-fit value of 0.77, non-significant in relation to pure error, and a 40.16% chance that it could be due to noise are positive indicators for model fitness. An adequate precision ratio of 1.309 suggests an adequate signal-to-noise ratio, implying caution in using this model for navigating the design space.

Examining trough viscosity, the model F-value of 0.27 again suggests insignificance relative to noise, with an 84.60% chance of this F-value occurring due to noise. A lack-of-fit F-value of 9.7 indicates non-significance relative to pure error, with a 34.85% chance that a lack-of-fit this large is due to noise, pointing to an acceptable goodness of fit. Negative predicted R-

squared values reinforce that the overall mean might be a better predictor. An inadequate signal is indicated by an adequate precision of 1.300, advising against using the model for design space navigation.

For breakdown viscosity, the model F-value of 0.69 and a 57.90% chance of insignificance due to noise are noted. Negative predicted R-squared values and a non-significant lack-of-fit F-value of 0.03 suggest an adequate goodness of fit. However, an inadequate signal is indicated by an adequate precision ratio of 2.218, discouraging the use of the model for design space navigation.

The model F-value for final viscosity is 0.72, indicating insignificance relative to noise, with a 55.89% chance of this being due to noise. The non-significant lack-of-fit value of 1.25 suggests a good fit, supported by an adequate precision ratio of 2.229, indicating an inadequate signal for navigating the design space. Negative predicted R-squared values reinforce the potential superiority of the overall mean as a predictor.

In the case of setback viscosity, the model F-value of 3.41 implies a 5.68% chance of this large F-value occurring due to noise. The Lack of Fit value of 0.90 for the model suggests its non-significance, indicating an adequate goodness of fit. However, the predicted R-squared value of 0.0673, while not in close agreement with the adjusted R-squared of 0.3404, may hint at a substantial block effect within the model. The Adequacy Precision Ratio of 4.951, surpassing the desirable threshold of 4, indicates an adequate signal, allowing the model's use for navigating the design space. The models for pasting measurements exhibit varying significance and fit. Model F-values generally lack significance due to noise, yet Lack of Fit F-values indicate a good fit. Adequate Precision Ratios vary, implying differing signal strengths. Some models are better suited for prediction than for design navigation.

The effect of independent variables on textural properties is effectively explained by the linear model, as evidenced in Table 3.3, where the model proves significant. Specifically, the linear model for springiness shows significance ($p = 0.0001$) in describing the effect of independent variables on the entire BGN flour. The model's F-value of 27.41 signifies significance, with only a 0.01% chance of such a large F-value occurring due to noise. The Lack of Fit F-value of 0.25 indicates insignificance, with a 63.04% chance that this is due to noise—a favourable outcome. The predicted R-squared value of 0.7643 reasonably aligns with the adjusted R-squared of 0.8498. The Adequate Precision Ratio of 11.800 indicates a strong signal, allowing the models use for navigating the design space.

Similarly, the linear model for gumminess yields a significant result ($p = 0.0069$) concerning the effect of independent variables on the entire BGN flour, as per Table 3.3. The model's F-value of

6.94 signifies significance, with only a 0.69% chance of this occurring due to noise. The Lack of Fit F-value of 2.02 implies insignificance, with an 18.54% chance that this is due to noise, which is considered favourable. Although the predicted R-squared of 0.3106 deviates from the adjusted R-squared of 0.5602, indicating a possible block effect, the Adequate Precision Ratio of 6.339 suggests a sufficient signal for navigating the design space.

The effect of the linear model for hardness also exhibits significance ($p = 0.0025$) concerning the effect of independent variables on the entire BGN flour, as shown in Table 3.3. The model's F-value of 9.14 denotes significance, with only a 0.25% chance of this occurring due to noise. The Lack of Fit F-value of 1.80 implies insignificance, indicating a model with an acceptable goodness of fit. Although the predicted R-squared of 0.4241 deviates from the adjusted R-squared of 0.6357, suggesting a possible block effect, the Adequate Precision Ratio of 7.337 signals sufficient strength for navigating the design space.

Table 3.3 Model parameters for pasting and textural properties of whole BGN flour mix

Model Parameter	Pasting Properties					Texture Properties		
	Peak Viscosity	Trough Viscosity	Breakdown Viscosity	Final Viscosity	Setback Viscosity	Springiness	Gummine ss	Hardness
p-value	0.8467	0.8460	0.5790	0.5589	0.0568	0.0001*	0.0069*	0.0025*
F-value	0.27	0.27	0.69	0.72	3.41	27.41	6.94	9.14
R²	0.683	0.0685	0.1576	0.1648	0.4818	0.8820	0.6545	0.7137
Predicted R²	-0.8928	-0.8580	-0.7964	-0.5879	0.0673	0.7643	0.3106	0.4241
Adeq precision	1.309	1.300	2.218	2.229	4.951	11.800	6.339	7.337

*Significant, $p \leq 0.0$

The linear models used to explore the effect of independent variables on textural properties yielded significant results for springiness, gumminess, and hardness. These models effectively captured the relationships between variables, with high F-values indicating low chances of noise interference. Although slight deviations were observed in predicted and adjusted R-squared values, the adequate precision ratios validated the models' suitability for guiding design space exploration. This underscores the successful application of linear modeling in uncovering the intricate connections between independent variables and textural properties.

In conclusion, the assessment of pasting measurement models highlights their significance and fit, with a Lack of Fit F-values that indicate strong suitability. The linear models were proven effective in revealing the effect of independent variables on textural properties, resisting noise interference, and providing valuable insights for design exploration.

3.3.2 Effects of pasting properties on whole BGN flour mix.

The moisture content for the whole BGN flour mix ranged from 7.79 – 8.85% as detailed in Table 3.5. This was a necessary step before analysing the pasting properties of the whole BGN flour mix samples. The linear model could not be used to predict the best pasting properties for CMC and modified starch due to noise interference, thus the overall mean (Table 3.4) was the better predictor for the response than the model.

Table 3.4 Overall mean for pasting properties

Pasting properties	Mean ± standard deviation (cP)
Peak viscosity	780.33 ± 409.77
Trough viscosity	715.07 ± 356.61
Breakdown viscosity	65.27 ± 62.87
Final viscosity	1114.40 ± 435.76
Setback viscosity	399.33 ± 135.98

The resultant pasting properties of the whole BGN flour mix are detailed below in Table 3.5. Peak viscosity, known as the maximum viscosity, obtained during cooking or immediately after cooking, indicates the strength of pastes formed when the sample gelatinises during the pasting process. The increase in viscosity during the pasting process from 25-95°C, displayed the ability of the flour to absorb water and swell up as the viscous slurry is heated. An increase in peak viscosity

is attributed to increased starch granule swelling rate and the water absorption rate (Wani & Kumar, 2019:6-7; Gull et al. 2018:150; 152; Awolu, 2017:10-11). The peak viscosity had a lower limit of 241 cP, a higher limit of 1761 cP, and an overall mean of 780.33 cP (as per Table 3.4 and Table 3.5). The model terms were not significant; hence the overall mean was used to better describe the model as shown in Table 3.4

Whole BGN flour mix had a higher peak viscosity range than other gluten-free flour types. In a study by Iwe and Agiriga (2015:4) on different genotypes of banana flour, they reported a peak viscosity ranging from 310 - 671 cP, which was found to be lower compared to the peak viscosity of the WBGNF. Also, in a study of whole black bean flour, the peak viscosity ranged from 124.2–208.8 cP, which is lower than that of whole BGN flour. Wheat flour, on the other hand, has a very high peak viscosity, which was reported at 1616 cP (Ferreira et al., 2018:476-477; Iwe & Agiriga, 2015:4). The wheat flour's high peak viscosity is closer to the optimum flour mix, 1% CMC and 5% modified starch (1761 cP).

Trough viscosity measures the ability of the paste to resist or withstand breakdown during the cooling of the paste (Awolu, 2017:11). The trough viscosity ranged from 229–1489 cP as seen in Table 3.5. The overall mean was 715.07, this shows that the ability of the paste to resist breakdown when cooling varied between the different samples. The values obtained in the work done by Iwe and Agiriga (2015:4) ranged from 214.88 – 610 cP, lower than the range of the whole BGN flour mix. This depicts a higher ability for the whole BGN flour mix paste to resist breakdown, which could be due to strong associative forces within the modified starch granules. This would result in a higher holding strength of the modified starch which remains undisrupted when the BGN flour mix paste is exposed to high and constant temperature for a long period during the pasting process (Iwe & Agiriga, 2015:4; Jimoh *et al.*, 2009:2326).

The breakdown viscosity reflects the stability of the peak viscosity during the pasting process. It is also known as a measure of the degree of disintegration of granules or paste stability (Awolu, 2017:11). The breakdown viscosity ranged from 12 to 272 cP, as seen in Table 3.4 and Table 3.5. A low breakdown value usually implies that the starch granules are more stable under hot conditions, or they possess a high capacity to withstand shearing and heating during cooking or baking (Awolu, 2017:11; Iwe & Agiriga, 2015:4). A value of 272 cP could be an outlier or it could be a result of the technicalities of the process e.g, the paddle not stirring all the contents properly, also, the value is still considered a low value and will still give good stability during the heating process.

Table 3.5 Pasting properties for whole BGN flour mix

Runs	Additives			Pasting properties				
	CMC (%)	Modified starch (%)	Moisture content (%)	Peak viscosity (cP)	Trough viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)
1	1	1	8.50	859	825	34	1331	506
2	1	5	8.37	1761	1489	272	1629	140
3	4	5	8.64	687	634	53	1062	428
4	4	1	8.57	586	536	50	899	363
5	2.5	3	8.64	343	271	72	411	140
6	1	1	8.85	680	650	30	1066	416
7	4	5	7.79	634	585	49	979	394
8	4	5	8.62	951	881	70	1416	535
9	2.5	3	8.49	665	617	48	1023	406
10	4	1	8.26	1102	1032	70	1620	588
11	1	1	8.03	578	542	36	903	361
12	4	1	8.34	1260	1167	93	1914	747
13	2.5	3	8.50	771	713	58	1164	451
14	1	5	8.31	241	229	12	375	146
15	1	5	8.42	587	555	32	924	369

Other kinds of gluten-free flours reported by Awolu (2017:11) and Iwe and Agiriga (2015:4) have a higher result than that of whole BGN flour which suggests that whole BGN flour should be more stable during the pasting process than other gluten-free flours.

The quality of starch and stability of cooked paste in the process is known as final viscosity. It can also be defined as the ability of starch to form a gel or paste after cooling. The final viscosity ranged from 375 to 1914 cP (Table 3.5) and the overall mean was 1114.40 (Table 3.4). There was no significant effect ($p > 0.05$) on the interaction of CMC and modified starch, this is evident in Figure 3.1(d). The final viscosity range depended on the amount of CMC to modified starch used in each run. Iwe and Agiriga (2015:6) stated that a high final viscosity is suitable in products that need high viscosity and a strong gel or paste that will not break. Furthermore, low final viscosity is favourable where a low viscosity and good film-forming capacity are preferred. In this study, the final viscosity was higher than the work done by Iwe and Agiriga (2015:6) on the different banana flour genotypes and higher than what was determined by Awolu (2017:11) on pearl millet-based composite flours. This implies that the paste from the whole BGN flour mix could form a strong paste that will be good for the end product.

Setback viscosity is the retrogradation and reordering of starch molecules resulting from decreased temperature (cooling) of the pasting process (Gull et al., 2018:152; Awolu, 2017:13). CMC was the only one to have had a significant effect on the setback viscosity. The setback viscosity had a range of 140 to 747 cP, Iwe and Agiriga (2015:6-7) in the study of banana flour, noted that a lower setback viscosity indicates higher resistance to retrogradation and, therefore, possesses high stability. A high setback value limits the flour's food application because it is associated with a cohesive paste. Most of the flours studied were suitable for use in food applications due to the low setback. Although the range of the WBGNF tends to be higher than that of banana flour and black bean flour, it still exhibits values that make it suitable for use in pastry.

CMC was more effective throughout the pasting process than modified starch, indicating that CMC improved the viscosity of the whole BGNF, thus allowing a pliable dough to form. This shows that a flour mix combination with a small amount of CMC would have an effect on the flour, and a higher amount of modified starch will be required to aid in the flour's pasting ability. Gull et al. (2018:152) observed that the addition of CMC impacted the increase of peak viscosity and breakdown viscosity, resulting in a lower setback viscosity in pasta flours. They further reported that the addition of CMC assists in the swelling of starch, thus the combination of CMC and modified starch is an effective formula for whole BGN flour mix.

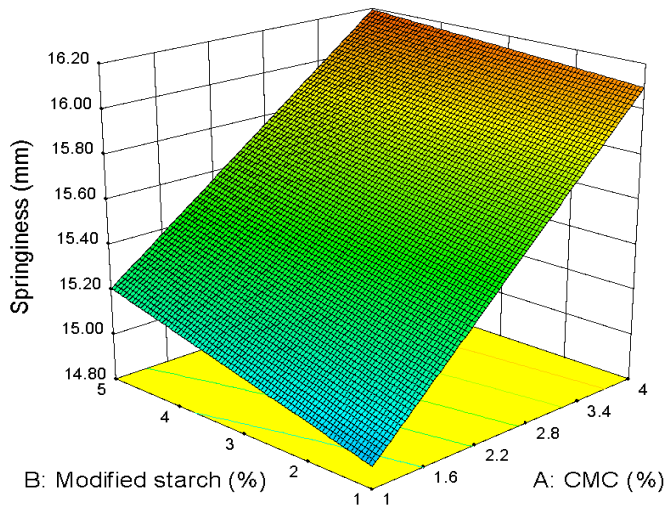
3.3.3 Effect of modified starch and carboxymethylcellulose on the texture profile of BGN dough.

The texture profile analysis measured texture parameters namely: springiness, gumminess and hardness (Trinh & Glasgow, 2012:1). The ANOVA depicted that the model terms had a significant effect on the texture profile of the whole BGN dough as shown in Table 3.6. The linear model could predict the best textural properties for CMC and modified starch.

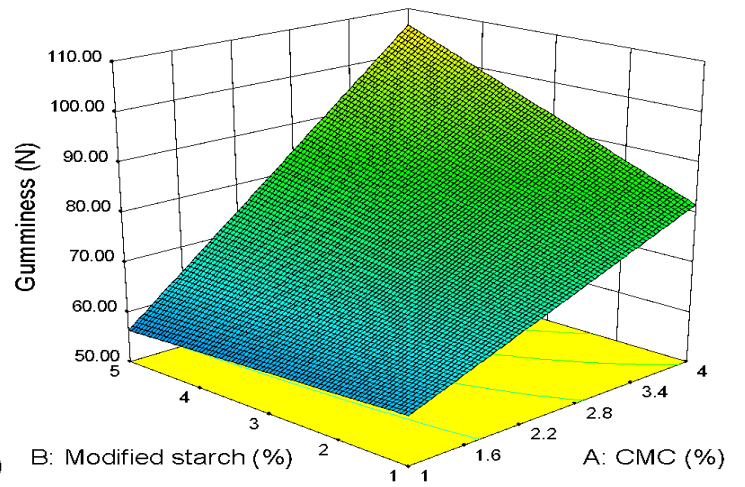
The hardness is a measure of texture at first compression and corresponds to the applied force to cause deformation of the sample (Dias et al., 2011:272; Bourne, 2002:17). The hardness ranged from 14.59 – 46.04 N, and CMC and modified starch had a significant impact on hardness. Thus if the hardness value is greater than 46.04 N, it implies a firm texture and a final product. Manipulation of the formulation (CMC and modified starch combination) may be required to achieve a suitable end product which will satisfy the consumer. The springiness is the rate at which a deformed sample returns to its original shape and size, so how well the product springs back to its original shape (Trinh et al., 2012:3; 4; Bourne, 2002:184; Meullenet et al., 1998:81). The CMC and modified starch had a significant effect ($p < 0.05$) on the springiness (Figure 3.1a) which ranged from 14.55 to 16.35 N. Specifically, an increase in CMC and modified starch resulted in a significant increase in the springiness of the dough. However, the interaction of the two additives had no significant effect on the springiness. Trinh et al. (2012) noted that the more a sample is destroyed, the less springiness it exhibits; this is also dependent on the type of probe used. In this study, the probe used did not destroy the sample.

Table 3.6 Textural properties for whole BGN flour mix.

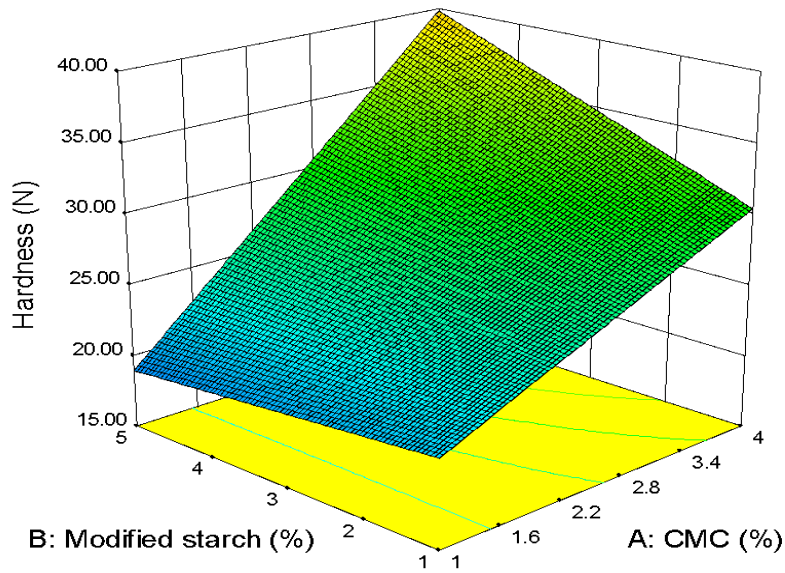
Runs	Additives			Textural properties		
	CMC (%)	Modified starch (%)	Weight (g)	Springiness (mm)	Gumminess (N)	Hardness (N)
1	1	1	95.66	14.55	44.07	>14.59
2	1	5	88.87	15.26	74.45	>24.54
3	4	5	103	16.35	110.68	>39.91
4	4	1	99.09	16.17	85.31	>32.55
5	2.5	3	99.31	15.75	63.47	>24.07
6	1	1	95.93	14.88	89.12	>32.96
7	4	5	102.92	16.29	93.21	>36.27
8	4	5	99.91	15.90	123.97	>46.04
9	2.5	3	99.93	15.46	70.27	>25.19
10	4	1	99.02	16.24	78.57	>30.02
11	1	1	95.31	15.21	53.82	>18.52
12	4	1	98.86	15.86	91.20	>32.25
13	2.5	3	99.35	15.79	62.99	>22.84
14	1	5	99.76	15.14	45.53	>16.13
15	1	5	99.79	15.22	57.92	>19.44



(a)



(b)



(c)

Figure 3.1 Texture profile response surface plot for whole BGN dough: (a) Springiness, (b) gumminess (c) hardness

Gumminess applies to semisolid samples (hardness x cohesiveness) and can be defined as the energy required to disintegrate (Trinh et al., 2012:2; 4; Bourne, 2002:184). The results for it ranged from 44.0744 to 123.966 N. Both CMC and modified starch significantly impacted gumminess, as shown in Figure 3.1(b). Also, their interaction had a significant effect on the gumminess of the dough.

Therefore, increasing CMC concentration significantly increased the springiness, gumminess, and hardness of BGN dough. The response surface models show that adding the hydrocolloid (CMC) and the modified starch will assist in providing the desired texture to the pastry product. Both CMC and modified starch significantly influenced springiness and gumminess, with their interaction also impacting gumminess. These findings provide insights for optimizing formulations and enhancing consumer experiences in food product development.

3.3.4 Whole Bambara groundnut optimal mix

In the pursuit of the optimal mix for the whole BGN flour mix, this study has brought to light a compelling comparison with the earlier investigation into the dehulled BGN flour mix. The achieved optimal blend of 1% CMC and 5% modified starch mirrors the proportions determined in the prior research, showcasing the significance of these components across both flour types. The dehulled BGN flour study used a fractional factorial design to study the effects of CMC, modified starch and xanthan gum on the dehulled BGN flour. Notably, the exclusion of Xanthan gum due to its negligible effect in the previous study aligns with the present findings. Utilising an augmented factorial design for the whole BGN flour mix analysis, this study offers a fresh perspective on the role of CMC and modified starch, compensating for the absence of gluten in both flour formulations.

When studying the pasting and textural properties of the dehulled BGN flour there was no significant effect on the dehulled BGN flour mix. However, on the textural properties for the study on dehulled BGN flour mix, CMC had no significant effect on springiness and modified starch had a significant effect. With this study for whole BGN flour mix CMC had a significant effect on springiness, which was a notable difference from the previous study. The optimal mix was then used to incorporate different fat variations to find the best fat amount which will give a good shortcrust pastry and puff pastry alternative for gluten-free consumers.

3.3.5 Proximate composition of whole and dehulled Bambara groundnut flour and wheat flour.

The proximate composition of whole BGN, dehulled BGN and wheat flours are detailed in Table 3.7. Protein contents were 17.89, 21.46 and 12.04% for whole BGN, dehulled and wheat flour, respectively.

Table 3.7 Proximate composition of whole Bambara groundnut, dehulled Bambara groundnut and wheat flour¹

Flour	Protein (%)	Moisture (%)	Ash (%)	Fat (%)	Carbohydrates (%)
Whole BGN	17.89 ± 1.26 ^a	7.80 ± 0.17 ^a	2.90 ± 0.03 ^a	4.11 ± 0.13 ^a	67.3
Dehulled BGN	21.46 ± 1.07 ^a	9.33 ± 0.18 ^b	2.39 ± 0.16 ^b	3.60 ± 0.13 ^b	63.22
Wheat	12.04 ± 5.39 ^a	11.51 ± 0.40 ^c	0.81 ± 0.01 ^a	0.70 ± 0 ^a	74.94

1.¹Values are means ± standard deviation of how many replicates? Values with different superscripts in the same column are significantly different (p < 0.05)

2. BGN–Bambara groundnut

3. Carbohydrates determined by difference

There was no significant difference in the protein content of the different flours. In comparison to a study done by Bolarinwa and Oyesiji (2021:3) protein content of gluten-free flour such as rice flour has a range of 8–12% when fortified with soybean flour. It increases to 5–15%. Even when fortified, it is still lower than that of both whole BGN and dehulled BGN flour. This, therefore, means that consuming a product made of whole and dehulled Bambara ground nut flour will result in an increase in the intake of protein in comparison to wheat flour as well. David Wesley et al. (2021:4) reported gluten-free bean flour with a protein content of 10.7%, which is lower than the BGN flours.

The moisture content for whole BGN, dehulled BGN and wheat flour were 7.8%, 9.33%, and 11.51% respectively. They differed significantly (p = 0.002) in terms of moisture. Wheat flour had a higher moisture content than BGN flour, which means that BGN flour would be much more stable during storage (Bolarinwa et al. 2021:3). The content of ash was 2.90% for whole BGN flour, 2.39% for dehulled BGN flour and 0.81% for wheat. A significant difference was observed between the flour’s ash contents. Ash, according to Bolarinwa et al. (2021:3) is the “measure of

nutritive mineral elements”, and so essential for the body. BGN flour has a higher ash content than wheat flour hence consuming products made of BGN flour will provide higher nutritive mineral content than consuming products made from wheat. The fat content was 4.11, 3.60, and 0.70% for whole BGN, dehulled BGN, and wheat flour, respectively. There was a significant ($p = 0.000$) difference in the flour's fat content. The bulk of the remaining content of the flour is carbohydrates as seen in Table 3.7 (Murevanhema et al.,2012:152).

The proximate composition of whole Bambara ground nut (BGN), dehulled BGN, and wheat flours revealed differences in protein, moisture, ash, and fat content. Both whole and dehulled BGN flours have higher protein and ash levels than wheat flour, enhancing their nutritional value. BGN flours had lower moisture content, making them more stable during storage. The higher ash content of whole and dehulled BGN flours provides better nutritive minerals. Their higher protein could contribute to increased nutritional value (Wahlgren, 2015:54). Overall, both whole and dehulled BGN flour offer potential health benefits over wheat flour.

3.4 Conclusion

The objective of producing an optimal whole BGN flour mix was achieved with a combination of 1% CMC and 5% modified starch, forming a desirable dough for a pastry product. Although independent variables had a limited effect on most pasting properties, the addition of CMC notably improved dough texture. Higher CMC concentration notably increased springiness, hardness, and gumminess in whole and dehulled BGN dough. The protein content of BGN flour confirm BGN's suitability for dough development. Lower moisture content suggests enhanced storage stability. Moisture content was lower in BGN flour than in wheat, suggesting better stability during storage. BGN flours had higher ash and fat content, providing higher nutritive mineral content and potential benefits for gluten-free consumers. The bulk of the remaining content in the flour consisted of fibre and carbohydrates. Overall, BGN flour offers a promising option with enriched nutritional value. Nevertheless, additional efforts could be made to enhance the interaction between CMC and modified starch to improve the texture, specifically the pliability, for a more desirable dough and pastry product.

3.5 References

AACC. 2000. Approved methods of the American Association of Cereal Chemists. *American Association of Cereal Chemists*.

- Adebowale, K.O., Afolabi, T.A. & Lawal, O.S. 2002. Isolation, chemical modification and physicochemical characterisation of Bambara groundnut (*Voandzeia subterranean*) starch and flour. *Food Chemistry*, 78: 305–311.
- Adeyi, O., Ikhu-Omoregbe, D. & Jideani, V. 2014. Effect of Bambara groundnut flour on the stability and rheological properties of oil-in-water emulsion. Electronic Theses and Dissertations, Cape Peninsula University of Technology. <https://etd.cput.ac.za/handle/20.500.11838/3678>.
- Al-Rawahi, A., Kasapis, S., Al-Maamari, S. & Al-Saadi, A. 2006. Development of a date confectionery: Part 2. Relating instrumental texture to sensory evaluation. *International Journal of Food Properties*, 9(3): 365–375.
- Andrews, S.L. & Harte, J.B. 2003a. Pastry Products: Types and Production. Encyclopaedia of Food Sciences and Nutrition. Academic Press. 4412 - 4414. <https://www.scribd.com/document/691469560/2003-Pastry-Types-and-Production>
- Andrews, S., & Harte, J. 2003b. PASTRY PRODUCTS | Ingredient functionality and dough Characteristics. In Elsevier eBooks (pp. 4412–4415). <https://doi.org/10.1016/b0-12-227055-x/00894-4>
- AOAC. 2005. Official methods of analysis of the Association of Official Analytical Chemists.
- Awolu, O.O. 2017. Optimization of the functional characteristics, pasting and rheological properties of pearl millet-based composite flour. *Heliyon*, 3(2).
- Bolarinwa, I.F. & Oyesiji, O.O. 2021. Gluten-free rice-soy pasta: proximate composition, textural properties and sensory attributes. *Heliyon*, 7(1): e06052.
- Bourne, Malcolm C. 2002. Food Texture and Viscosity: Concept and Measurement. 2nd ed. M. C. Bourne, ed. New York: Academic Press. https://www.academia.edu/38698369/Food_Texture_and_Viscosity_Concept_and_Measurement [01 August 2023].
- Cai, J., Hong Chiang, J., Yi Pei Tan, M., Kiat Saw, L., Xu, Y. & Na Ngan-Loong, M. 2016. Physicochemical properties of hydrothermally treated glutinous rice flour and xanthan gum mixture and its application in gluten-free noodles. 186(2016), 1-9. <https://dx.doi.org/10.1016/j.jfoodeng.2016.03.033>.

- David Wesley, S., André, B.H.M. & Clerici, M.T.P.S. 2021. Gluten-free rice & bean biscuit: characterization of a new food product. *Heliyon*, 7(1): 1–14. <https://doi.org/10.1016/j.heliyon.2021.e05956>.
- Dias, A.R.G., Zavareze, E.D.R., Elias, M.C., Helbig, E., Da Silva, D.O. & Ciacco, C.F. 2011. Pasting, expansion and textural properties of fermented cassava starch oxidised with sodium hypochlorite. *Carbohydrate Polymers*, 84(1): 268–275.
- Ferreira, C.D., Ziegler, V., Lindemann, I. da S., Hoffmann, J.F., Vanier, N.L. & Oliveira, M. de. 2018. Quality of black beans as a function of long-term storage and mouldy development: Chemical and functional properties of flour and isolated protein. *Food Chemistry*, 246: 473–480.
- Foschia, M., Horstmann, S., Arendt, E.K. & Zannini, E. 2016. Nutritional therapy – Facing the gap between coeliac disease and gluten-free food. *International Journal of Food Microbiology*, 239: 113–124.
- Gull, A., Prasad, K. & Kumar, P. 2018. Nutritional, antioxidant, microstructural and pasting properties of functional pasta. *Journal of the Saudi Society of Agricultural Sciences*, 17(2): 147–153.
- Iwe, M. & Agiriga, A. 2015. Effect of Different Harvesting Regimes on the Pasting Properties of Selected Varieties of Banana – A Response Surface Study. *Agrotechnology*, 04(01).
- Jeradechachai, T. 2012. *Application of Response Surface Methodology in the Development of Gluten-free Bread with Yellow Pea Flour Addition*. Fargo, North Dakota: North Dakota State University of Agriculture and Applied Science. <https://hdl.handle.net/10365/26829> [01 August 2023].
- Jimoh, K. O., Olurin, T. O. & Aina, J.O. 2009. Effect of drying methods on the rheological characteristics and colour of yam flours. *African Journal of Biotechnology*. 8. 2325-2328.
- Maphosa, Y., Jideani, V. A., & Ikhu-Omoregbe, D. 2022. Vigna subterranea (L.) Verdc Starch-Soluble Dietary Fibre Potential Nanocomposite: Thermal Behaviour, Morphology and Crystallinity. *Processes*, 10(2), 299. <https://doi.org/10.3390/pr10020299>

- Maphosa, Y., Jideani, V.A. & Ikhu-Omoregbe, D.I. 2022. *Vigna subterranea* (L.) Verdc Starch-Soluble Dietary Fibre Potential Nanocomposite: Thermal Behaviour, Morphology and Crystallinity. *Processes*, 10(2).
- Marston, K., Khouryieh, H. & Aramouni, F. 2016a. Effect of heat treatment of sorghum flour on the functional properties of gluten-free bread and cake. *LWT - Food Science and Technology*, 65: 637–644.
- Mir, S.A., Shah, M.A., Naik, H.R. & Zargar, I.A. 2016. Influence of hydrocolloids on dough handling and technological properties of gluten-free breads. *Trends in Food Science and Technology*, 51: 49–57. <http://dx.doi.org/10.1016/j.tifs.2016.03.005>.
- Mirhosseini, H., Farhana Abdul Rashid, N., Tabatabaee Amid, B., Whye Cheong, K., Kazemi, M. & Zulkurnain, M. 2015. Effect of partial replacement of corn flour with durian seed flour and pumpkin flour on cooking yield, texture properties, and sensory attributes of gluten-free pasta. *LWT - Food Science and Technology*, 63: 184–190.
- Mpotokwane, S.M., Gaditlhatlhelwe, E., Sebaka, A. & Jideani, V.A. 2008. Physical properties of Bambara groundnuts from Botswana. *Journal of Food Engineering*, 89(1): 93–98.
- Mthombeni, S.D. 2017. *Functionality of Bambara groundnut flour in pastry products*. Unpublished thesis, Cape Peninsula University of Technology, Bellville.
- Murevanhema, Y.Y. 2012. *Evaluation of Bambara groundnuts (Vigna subterranea (L.) Verdc.) milk fermented with lactic acid bacteria as a probiotic beverage Master of Technology (Food Technology)*. Cape Peninsula University of Technology.
- Murevanhema, Y.Y. and Jideani, V.A. 2015. Production and Characterization of Milk Produced from Bambara Groundnut (*Vigna subterranea*) Varieties. *Journal of Food Processing and Preservation*, 39(6), pp. 1485–1498. <https://doi.org/10.1111/jfpp.12368>.
- Oliveira, S., Fradinho, P., Mata, P., Moreira-Leite, B., & Raymundo, A. 2019. Exploring innovation in a traditional sweet pastry: Pastel de Nata. *International Journal of Gastronomy and Food Science*, 17, 100160. <https://doi.org/10.1016/j.ijgfs.2019.100160>
- Palabiyik, I., Yildiz, O., Toker, O.S., Cavus, M., Ceylan, M.M. & Yurt, B. 2016. Investigating the addition of enzymes in gluten-free flours – The effect on pasting and textural properties. *LWT - Food Science and Technology*, 69: 633–641.

- Pruska-Kędzior, A., Kędzior, Z., Gorący, M., Pietrowska, K., Przybylska, A. & Spsychalska, K. 2008. Comparison of rheological, fermentative and baking properties of gluten-free dough formulations. *European Food Research and Technology*, 227(5): 1523–1536.
- Rashidi, A., HadiNezhad, M., Rajabzadeh, N., Yarmand, M.S. & Nemati, S. 2016. Frozen baguette bread dough II. Textural and sensory characteristics of baked product. *Journal of Cereal Science*, 70: 9–15
- Trinh, L., Lowe, T., Campbell, G. M., Withers, P. J., & Martin, P. J. (2013). *X-ray computerised tomography investigation of bread dough: Changes in the structure and cell volume distribution during proving*. https://personalpages.manchester.ac.uk/staff/p.martin/publications/X-ray_computerised_tomography_investigation_of_bread_dough.pdf [01 August 2023].
- Wahlgren, M.B. 2015. *Oral processing and satiety perception of bread Understanding the role of texture and oral processing in consumers' perception of satiety*. Norwegian University of Life Sciences <http://hdl.handle.net/11250/294305> [02 June 2023].
- Waterschoot, J., Gomand, S. V & Delcour, J.A. 2016. Impact of swelling power and granule size on pasting of blends of potato, waxy rice and maize starches. *Food hydrocolloids*, 52: 69–77.
- Zhu, F. 2017. Properties and Food Uses of Chestnut Flour and Starch. *Food Bioprocess Technology*, (10): 1173–1191.

CHAPTER FOUR

TEXTURAL CHARACTERISTICS OF BAMBARA GROUNDNUT SHORTCRUST AND PUFF PASTRY PRODUCTS.

Abstract

Pastry has been enjoyed occasionally by many people around the world. Several pastries are made using different methods, e.g., shortcrust and puff pastry. This study analysed the textural properties and assessed the structure and cell size distribution of whole and dehulled Bambara groundnut (BGN) shortcrust and puff pastry products. BGN is a highly nutritious (gluten-free) legume that can potentially enhance pastry products' nutritional value for gluten-intolerant and coeliac sufferers. To explore this potential, the research investigated the effect of different fat contents on the texture, firmness, cutting properties, proximate composition, and colour of these pastry products. In the context of shortcrust pastry, whole BGN pies were baked with three distinct fat contents: 60%, 70%, and 80%. The findings reveal that higher fat content in the pie crust increases crumbliness, resulting in easier breakage. Shortcrust pastry with 60% fat content was determined to exhibit the most desirable attributes, including firmness and structural integrity. For puff pastry prepared with whole BGN flour, different fat content levels (80%, 100%, and 120%) were explored. The study demonstrated that 100% fat content resulted in optimal layering and pastry lift, producing distinct layers and increased volume. There was no significant difference in firmness between shortcrust pastry (6.16—29.17 N) samples with 60% and 70% fat content. Fat content had a significant influence on the firmness of puff pastry (7.71—19.07 N), with 100% fat content yielding higher maximum load and extension at maximum load compared to 80% and 120% fat contents. Proximate composition analysis unveiled the nutritional richness of both whole and dehulled BGN pastry products, highlighting their high protein (13.41—18.27%), mineral (1.97—2.73%), and fat content (8.62—12.68%), which caters to the needs of individuals with specific nutritional requirements. The colour attributes of the pastry products revealed noteworthy differences in lightness (L^*), redness/greenness (a^*), and blue/yellowness (b^*) among varying fat contents. The use of BGN flour, whether whole or dehulled, imparted distinct colour characteristics to the pastry products such as browning on the crumb and crust of the pastry products, diverging from those of wheat flour, with variations in L^* (34.42—79.80), a^* (1.67—14.78), and b^* (12.18—31.88) values. The whole BGN shortcrust and puff pastry were a darker brown than the lighter Dehulled BGN and wheat puff and shortcrust pastry. The darker colour of the whole BGN pies was impacted by the hulls included in the flour. X-ray computed tomography was used to gain

insights into the internal structure of the pastry samples, regarding the distribution of air pockets, and holes within the pastries. Principal component analysis (PCA) was applied to assess the influence of various parameters on the structural attributes of the pastry products. The image analysis indicated that hole linear dimensions played a significant role in whole and dehulled BGN puff pastry, while roundness predominantly impacted puff pastry samples. Solidity influenced puff pastry, while circularity was a significant factor affecting whole BGN shortcrust samples. The study emphasised the role of fat content in shaping the textural characteristics of shortcrust and puff pastry products crafted with whole and dehulled BGN flour. The findings provide valuable insights for optimizing fat content to achieve these pastry products' desired texture and appearance. Ultimately, this study contributed to developing pastry items that offer improved quality and nutritional value, catering to diverse dietary preferences and requirements. Whole BGN and dehulled flour were able to produce suitable pastry products.

4.1 Introduction

Pastry has been a delicacy enjoyed by many people worldwide for ages. Several types of pastries are made differently depending on the ingredients and methods used. In this study, only shortcrust and puff pastry were studied. Shortcrust pastry is a rich pastry used as a base for pies and tarts made up of water, wheat flour, and fat, following a half-fat-to-flour ratio. The flour, fat, and salt are blended thoroughly, and water is gradually added to the mix and rolled to form a dough (de Cindio and Lupi, 2011:301; Harte, 2003:4407). The fat granules should adequately coat flour before the liquid is added, ensuring the gluten network is not completely developed (de Cindio and Lupi, 2011:303; Harte, 2003:4407). The fat that does not coat the flour is melted during baking, creating voids that give texture to the end product (de Cindio and Lupi, 2011:312). Low-protein wheat flour is preferred in conventional shortcrust pastry products because it prevents gluten development in the dough, resulting in a suitably tough crust (Harte, 2003:4407).

Puff pastry is a non-yeasted laminated dough that is well known for its light and flaky texture (Deligny et al., 2017:6; Silow et al., 2016:330; Wickramarachchi et al., 2015:1065; Simovic et al., 2009:1236; Harte, 2003:4408). The pastry can be used for various products, such as turnovers, shells filled with cream, sausage rolls, etc. and is considered a commercial bakeries' staple (Harte, 2003:4408). It consists of a basic dough (high protein wheat flour, water, salt) and a fat phase (Harte, 2003:4408). The alternating dough and fat layers are obtained through a series of folding and sheeting to create multiple layers (Renzetti et al., 2016:24-25; Silow et al., 2016:331; Deligny and Lucas, 2015:113; Bousquieres et al., 2014:359; de Cindio and Lupi, 2011:306). The optimal number of layers in puff pastry has been evaluated to range from 81 to 250 (Bousquieres

et al., 2014:360). The fat in puff pastry is significant for the layering effect, flavour and highly desirable sensory enhancement, flaky structure, texture, appearance, volume and lift (Renzetti et al., 2016:25; Silow et al., 2016:330; Simovic et al., 2009:1235). The salt in puff pastry is known to assist the workability of the puff pastry dough. Enhancing the gluten network, and boosting dough stability, and flexibility are positive outcomes attributed to salt (Silow et al., 2016:330). Puff pastry dough is commonly processed using three techniques: French, English, and Scottish, each distinguished by variations in fat layering and folding procedures. In the French and English methods, fat is rolled into the flour dough, whereas in the Scottish method, fat is fragmented into lumps and loosely mixed with flour (Deligny & Lucas, 2015:115; de Cindio & Lupi, 2011:306; Harte, 2003:4408; Cauvain et al., 2001:126).

For generations, conventional wheat dough has been employed in the creation of puff pastry (Silow et al., 2016:330). Throughout the rolling and sheeting process, wheat flour dough undergoes uniaxial extension and shear at elevated deformation rates, influencing the rheological characteristics of the dough at each stage (Renzetti et al., 2016:25). This procedure not only defines the dough's quality before baking but also correlates with the behaviour of the gluten network (Renzetti et al., 2016:25; Sliwinski et al., 2004:232).

Gluten, a protein inherent in wheat, is pivotal for dough formation and imparts viscoelastic properties to the dough (Masure et al., 2016:92; Scherf et al., 2015:2; Codex Stan, 2008:2; Day et al., 2006:82). It dictates the rheological features and functionalities essential for crafting pastry products from wheat flour (Day et al., 2006:85). However, individuals with coeliac disease (an intolerance to wheat storage proteins) and other non-coeliac gluten sensitivities must strictly adhere to gluten-free products and alternative flour sources (Masure et al., 2016:92; Scherf et al., 2015:2; Aziz & Sanders, 2014:1080). One such alternative is Bambara groundnut (BGN), which can be utilized to produce pastry products.

Bambara groundnut (*Vigna subterranea*) is rich in protein (up to 25.5%) and carbohydrates (up to 61.7%) (Kaptso et al., 2015: 4915-4916; Oyeyinka et al., 2015:171; Alakali et al., 2010:215; Barimalaa et al., 2005:413; Baryeh, 2001:321). Mature BGN can be dried and ground into flour (Oyeyinka et al., 2015:171; Alozie et al., 2009:111; Adebawale et al., 2002:305). Bambara groundnut flour (BGNF) exhibits favourable functional properties, including foaming capacity and stability, oil and water absorption capacity, bulk density, gelation capacity, and emulsifying activity (Ogundele et al., 2017:655; Adeyi et al., 2014:4995). Viscoelasticity, encompassing the viscous and elastic attributes of materials like dough, is crucial for sensory perceptions when stretching and releasing the dough. Gluten-free flours lack these viscoelastic properties, but starches, hydrocolloids, and gums can enhance the viscoelasticity of gluten-free products, as improvers and

by enhancing their cohesive properties (Masure et al., 2016:104; Mir et al., 2016:49-50; Miranda et al., 2014:184).

In a preliminary study Mthombeni, (2017:15) reported on the effect of additives (CMC, modified starch and xanthan gum) used to produce shortcrust and puff pastry dough made from dehulled Bambara groundnut flour (BGNF). Xanthan gum demonstrated negligible effects on the flour mixture. Consequently, this study only focused on investigating CMC and modified starch for the optimal mix that will be suitable for producing pastry products. However, there are no publications regarding the performance of whole BGN flour in shortcrust and pastry formulations. This study aims to analyse the textural characteristics of Bambara groundnut shortcrust and puff pastry products.

4.2 Materials and methods

4.2.1 Source of materials

All major equipment and standard whole and dehulled BGN flours were obtained from the Department of Food Science and Technology at the Cape Peninsula University of Technology, Bellville campus. These include Kenwood MAJOR Titanium (KMM20 series) dough mixer, INSTRON 3344 (Blue Hill software), Rapid Visco Analyser machine (Perten RVA 4500 instruments Australia), cabinet dryer, roller mill and Baking Oven (Defy). All Baking ingredients were purchased at the local supermarket and a baking supplier.

4.2.2. Effect of fat on the textural properties of the whole BGN flour mix for shortcrust pastry dough

The method reported by Mthombeni (2017:20) for making shortcrust pastry was used, as shown in Figure 4.1. Two approaches to baking the pastry were used. Firstly, the pastry was baked blind, without filling. Then, the other was filled with cooked mince.

Whole BGN flour mix (100 g) and 0.1 g of salt (for taste) were mixed with various levels of fat (50%, 60% and 70%) in the Kenwood MAJOR Titanium mixer for 5 min at medium speed. Then, 80 ml of water was added to create dough at medium speed for 5 min. The dough was rested for 30 minutes in the fridge. Whilst the dough was resting, mince was cooked in a stainless-steel pot. Onion clove, green pepper and two carrots were chopped and sautéed in 15 ml vegetable oil with 2 g of spices for 5 min and occasionally stirred with a big spoon. Mince was added and cooked for about 10–15 minutes at medium heat (150°C), stirring occasionally until cooked and brown. A scoop of 20g of Knorr instant soup was added to make the mince filling more

viscous, stirred and brought to a boil. The heat was reduced to 95°C, and the pot was allowed to simmer for 5 min. The pot was set aside to cool down.

The dough was rolled top-to-bottom and sideways to ensure uniformity with a plastic rolling pin. Using a pastry cutter, the dough was cut and shaped. A scoop of 15 g of mince was filled into the shaped dough and closed using the pastry cutter. The pastry to be baked blind was just cut, shaped, and closed with a cutter. They were glazed with eggs, baked in a preheated oven at 180°C for 20 minutes, and cooled.

Dehulled Bambara groundnut shortcrust and wheat shortcrust pies were also baked for comparison with the whole BGN shortcrust pies. The pies were analysed further by puncture test, Warner-Bratzler test, proximate composition, colour analysis, and image analysis.

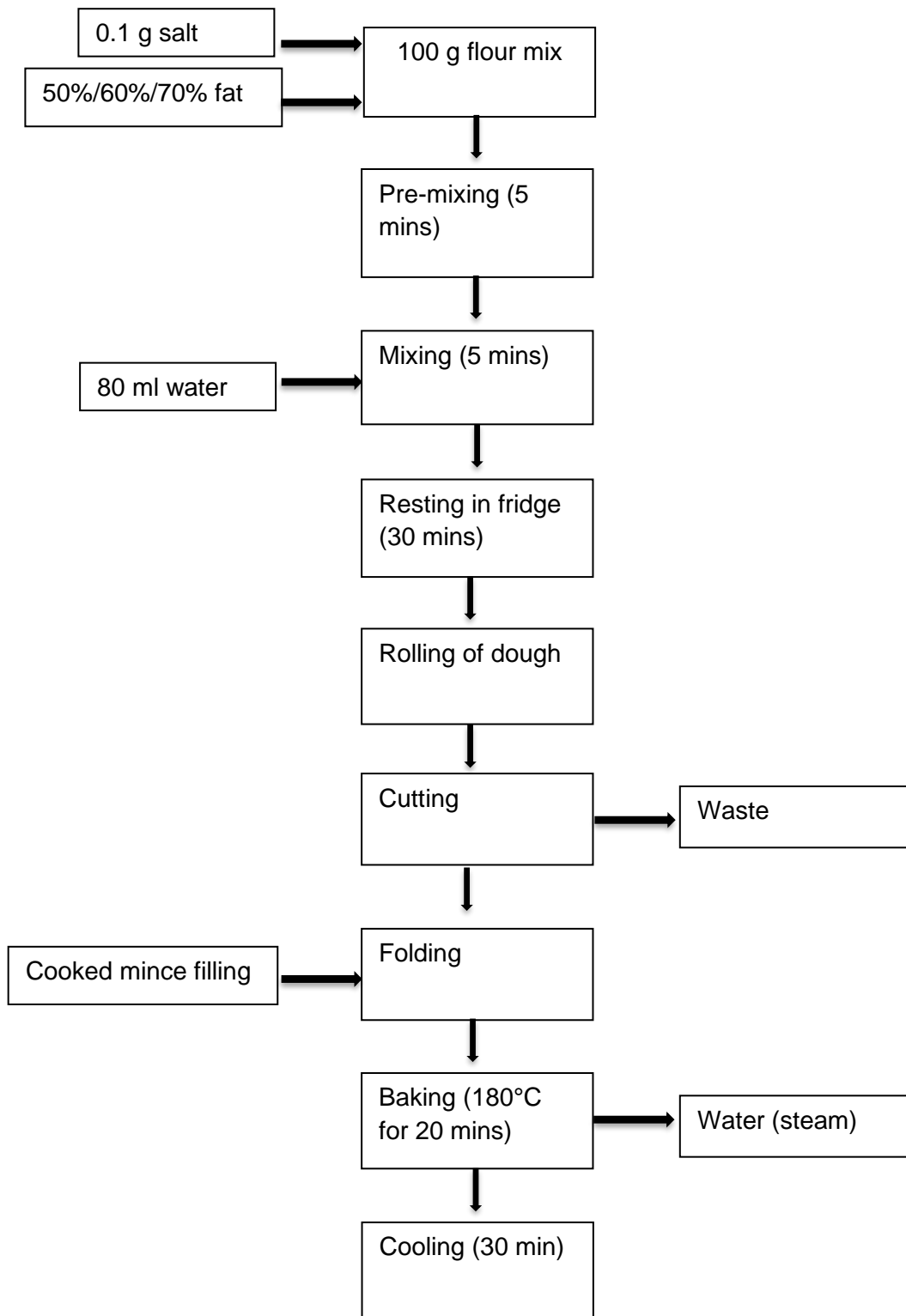


Figure 4.1. Flow diagram of shortcrust pastry pies production process.

4.2.3 Effect of fat on the textural properties of the whole BGN flour mix for puff pastry dough

The method for making puff pastry was adapted from Mthombeni-Nkantsu (2017:22) and illustrated in Figure 4.2. A whole BGN flour mix of 100 g with different added fat levels (80%, 100% and 120%) and 0.1 g salt were added into the mixer (Kenwood MAJOR Titanium). Initially, only one-quarter of the fat was added to the mixer at medium speed for 5 minutes; then 80 ml of water was added and mixed for another 5 minutes to form a dough. The dough was rolled out in a rectangular shape on a floured surface, and another quarter of the fat was placed on one end of the dough. The dough was folded into a book fold, half turned and rolled out into a rectangular book shape, another quarter of fat was added, and the same procedure was repeated until all fat was used. The dough was rested in the fridge for an hour; whilst the dough rested, minced meat was cooked as detailed previously in section 4.2.2. Thereafter, the dough was removed and rolled with a plastic rolling pin in a top-to-bottom and sideways style to ensure uniformity. The dough was cut into seven circles (14 cm in diameter) using a pastry cutter and shaped. Five of the cut pastries were filled with mince, closed using the cutter and set aside. The two other remaining were baked blind. Both were glazed with egg and put into the oven. The pies were baked in a preheated oven at 180°C for 18 minutes, removed and cooled for 30 min. Dehulled Bambara groundnut puff pastry pie and wheat puff pastry pie were also baked using the same method, for comparison with the whole BGN puff pastry pie. The pies were analysed by puncture test, Warner-Bratzler test, proximate composition, colour analysis and image analysis.

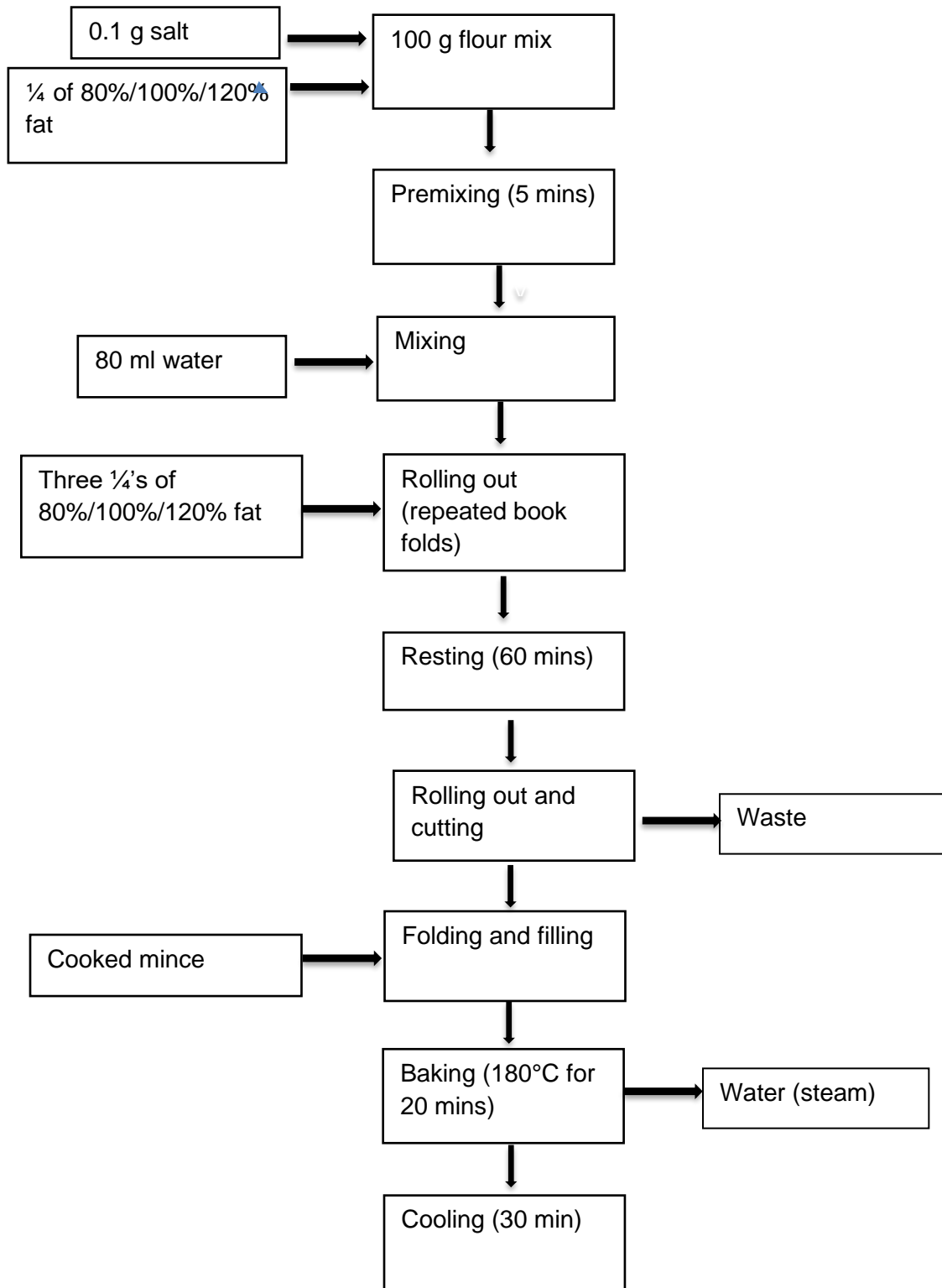


Figure 4.2 Flow diagram of puff pastry pies production process.

4.2.4 Puncture test for Bambara groundnut shortcrust and puff pastry

To determine the firmness of the blind-baked shortcrust and puff pastry, a puncture test was done using the INSTRON 3344 machine (Blue Hill software). The method was adapted from Manzocco et al., (2012:176). Pie samples of different fat variations, 60 and 70% for shortcrust and 80,100 and 120% for puff pastry (whole and dehulled Bambara groundnut and wheat shortcrust and puff pastry), were punctured in triplicate with a 3 mm cylindrical probe (Renzetti et al., 2016:26). The maximum force-distance curves were obtained by INSTRON software, and firmness was measured as the force (N) needed to puncture the shortcrust and puff pastry at approximately 0.5 cm.

4.2.5 Warner–Bratzler test of Bambara groundnut shortcrust and puff pastry

The Warner–Bratzler test is known for measuring maximum shear force as a function of how a knife would cut through a product (Schreuders et al., 2021:2). The method used in this study was adapted from Paula and Conti-Silva (2014:11), and Lyon and Lyon (1998:1587). A Warner–Bratzler shear blade with a V-shaped triangular hole was used. Whole and dehulled BGN and wheat pastries, were placed individually within the triangular hole. The blade cut the sample in the middle with a test speed of approximately 1 mm/s until completely broken. The force measured a combination of compression, tensile stress, and shearing. The peak shear force (N) was obtained for each sample (Schreuders et al., 2021:2; Lyon & Lyon, 1998:1587).

4.2.6 Proximate analysis of whole and dehulled pastry pies

Proximate analysis was performed according to the AACC and AOAC standard methods; protein (AOAC 990.03), fat (AOAC 920.39), moisture (AACC 44-15A), ash (AOAC 942.05) and carbohydrates were calculated by difference (Marston et al., 2016:638; AOAC, 2005:15; AACC, 2000:1-4).

4.2.7 Colour analysis of shortcrust and puff dough and pastry

The colour of the dough, crumb, and crust of whole Bambara groundnut, dehulled Bambara groundnut and wheat shortcrust and puff pastry were measured using a Hunter Lab ColorFlex colourimeter, Model 45/0 (Hunter Lab Reston, VA). The method adapted from Bolarinwa and Oyesiji, (2021:4); Jan et al. (2021:124); Xing-li et al. (2016:2668) Oyeyinka et al. (2015:172)); Baardseth Naes (1995:73) was used. The colour analysis was performed for two aspects. First, to compare fat contents, which were 60% and 70%. Their dough, crust and crumb were analysed and compared to find the most suitable dough for the end pastry products. Secondly, to compare

the shortcrust and puff pastry samples of different flour products. So, whole Bambara groundnut (WBGN) dough and pastry were compared to dehulled Bambara groundnut (DBGN) and wheat dough and pastry products. The values were expressed as CIELAB, where L* denoted lightness or darkness (+ = lighter, – = darker), a* redness or greenness (+ = redder, – = greener) and b* yellowness or blueness (+ = yellower, – = bluer) values. Triplicate measurements were taken for shortcrust and puff pastry samples, including dough of 60 g, crumb of 40 g, and crust of 40 g. These measurements were conducted using a sample holder, and readings were collected from three distinct positions or orientations.

4.2.8 X-ray computed tomography of Bambara groundnut shortcrust and puff pastry pies.

The x-ray computed tomography method was adapted from Hughes et al. (2017:3); Vidhya et al. (2017:1-2) and Einarsdottir et al. (2016:16-17). The shortcrust, puff pastry, whole and dehulled BGN pie samples were mounted onto the X-ray tomography scanner. Images of the pie samples were taken by X-ray imaging. This was done in different viewing directions. Then an internal three-dimensional (3D) image was constructed from the images obtained. The 3D image was then reconstructed mathematically from the images. Cell size distribution and other properties (i.e., fat distribution, size of air pockets) of the pie samples were determined from the images. This technique was useful because it is known as a non-destructive method for the internal evaluation of quality and characterization of food products (Germishuys, 2021:23; Schreuders et al., 2021:6; Vidhya et al., 2017:1-2;).

The technique included a process that permitted visualization of the interior of pies via the generation of cross-sectional data. This was done by an X-ray beam that was focused on the pie samples and a shadow image that reflected X-ray attenuation along the beam path was recorded (Schreuders et al., 2021:6; Vidhya et al., 2017:1-2). The scales of all the images were set (Pixel size 8.5 and 10 mm). The rotation of the samples generated successive images that were then stored and further analysed. The images were smoothed, sharpened, and processed with a median filter. The filtered image was converted to an 8-bit binary image. The threshold was performed using Huang's algorithm on a white background. The particles were analysed for area, perimeter, circulatory, aspect ratio, round, and solidity. The diameters were estimated from the area. The histogram plots of the particle distribution and the quartiles were estimated.

4.2.9. Data analysis

Results were reported as the mean \pm standard deviation of triplicate measurements. Data was modelled using Multivariate analysis of variance (MANOVA) to establish the difference between

treatments. Duncan's multiple range test was used to separate means where differences existed (IBM SPSS version 27 (2021)).

4.3 Results and discussion

4.3.1 Effect of fat on the textural properties of the shortcrust and puff pastry products.

Whole BGN shortcrust pastry pies were baked using three different amounts of fat, 60%, 70% and 80%. From Figure 4.3, the texture and appearance of the crumb and the pie were different for the different fat contents. The higher the fat content in the pie crust, the crumblier it was (Figure 4.3b and c) (Greedyscholars, 2017:1). This also stems from how the flour coated the fat globules of the shortening, which either resulted in a good or bad crumb. Hence, the most suitable of the three fat contents was 60% fat with desirable and much firmer pie crust compared to 70% and 80%.

Whole BGN puff pastry pies were also baked using three amounts of fat: 80%, 100% and 120%. During baking, the dough and fat layers were crucial as they trapped water vapour and separated as the pastry increased in lift and volume. So, the fat had a great role in structuring the baked puff pastry (Silow et al., 2016:330; Renzetti et al., 2016:31; Lucas et al., 2018:199). Also, with the whole BGN puff pastry pie, the fat melted and migrated out of the pastry, thus not allowing a great leavening effect (Silow et al., 2016:335; Silow et al. 2018:8). In all three fat variations, 100% fat had a more desirable texture and appearance in terms of pastry lift and layers; as seen in Figure 4.4d. The leavening effect was less on the 120% fat pastry (Figure 4.4d), which had a higher fat ratio to flour, resulting in a flatter structure and less pastry lift volume. With the 80% fat pastry, the crust and crumb were less soft compared to the 100% and 120% fat variations.

The baking quality of puff pastry dough is associated with forming a structure of alternating fat and dough layers. The method determined the resultant layers, their formation, and the distinct number of layers (Renzetti et al., 2016:28). For this study, the number of layers was not considered, but the formation and existence of distinct layers. Some studies, by Renzetti et al. (2016:30) and Silow et al. (2016:335) have done image analysis on puff pastry layering structure and volume. Wickramarachchi et al. (2015:1069) reported that strong flours contribute to enhanced pastry elevation while weaker flours lead to decreased pastry lift due to the early disruption of layers during lamination.

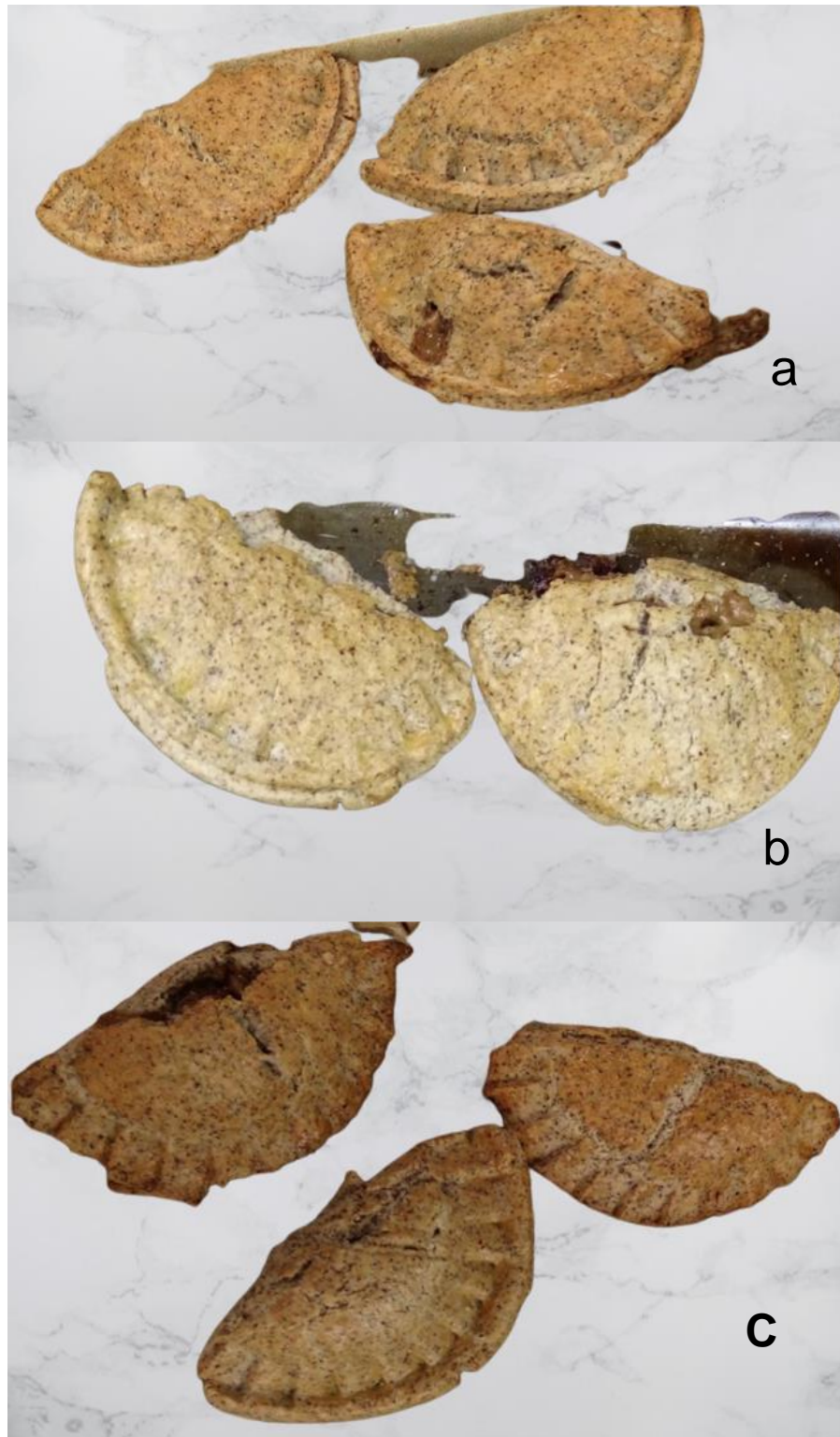


Figure 4.3 Whole Bambara groundnut shortcrust pies with different fat contents (a) 60%, (b) 70% and (c) 80%

The outcome is inadequate gas retention and reduced pastry lift. In the case of whole grain flour, the entire grain component's presence might disturb the layers' structure, frequently causing a reduction in elevation and flakiness.



Figure 4.4 Whole Bambara groundnut puff pastry pies of different fat variations (a) 80%, (b) 100%, (c) 120% and (d) 100% showing distinct layering

The reduction in elevation and flakiness was more impacted by the absence of gluten protein than the effect of protein content during processing and baking (Wickramarachchi et al., 2015:1069). Consequently, 100% fat content in Figure 4.4b and d exhibited the best layering, pastry lift, and tenderness compared to 80% and 120% fat variations. Furthermore, the tearing of the pastry which Wickramarachchi et al. (2015:1070) reported, could arise from the dough's inadequate relaxation and resting periods

In conclusion, the suitable shortcrust pastry product was the 60% fat content pie. The pie exhibited a more suitable and desirable product as well as a much firmer pie crust compared to the other fat contents. The more fat the pastry contained the crumblier the pie crust texture. The nature of the whole BGN flour gave way to the formation of a shortcrust dough and crust.

The 100% fat-content puff pastry was more desirable in texture and appearance. However, the distinct puff pastry layers were disrupted due to the use of the whole BGN grain and the migration out of the fat after it melted. The objective of obtaining a suitable or desirable whole BGN dough shortcrust and puff pastry was attained.

4.3.2 Firmness of whole and dehulled BGN and wheat pastries

Baked shortcrust (60 and 70% fat) and puff pastry (80, 100 and 120% fat) were used for the puncture test. The firmness of the pies is depicted in Table 4.1. The maximum load for the 60% and 70% shortcrust pies were 22.44 N and 22.00 N respectively.

Table 4.1 Firmness of whole BGN shortcrust and puff pastry pies¹

Pastry	Fat (%)	Maximum load (N)	Extension at maximum load (mm)
Shortcrust	60	22.44 ± 8.28 ^a	14.24 ± 4.10 ^a
	70	22.00 ± 2.58 ^a	10.66 ± 1.34 ^a
Puff	80	34.24 ± 11.74 ^b	15.77 ± 1.81 ^b
	100	44.24 ± 20.95 ^b	19.00 ± 1.43 ^b
	120	30.16 ± 1.94 ^b	13.40 ± 0.25 ^b

¹Values are means ± standard deviation. Different letters in the same column indicate significant mean differences ($p \leq 0.05$)

The extension at maximum load was 14.24 mm and 10.66 mm for 60 and 70% fat content, respectively. There was no significant difference in extension at maximum load between 60% and 70% of the shortcrust samples. There was also no significant difference in the force required to puncture the pie samples. The difference between the samples is not large enough to be considered significant. The fat content variations didn't effect meaningful changes in the physical properties of the samples. The action by the probe is like when pies are crushed by cuspids and bicuspid (canine teeth) in the mouth. That reflects whether the softness or firmness of the pie crust can have implications for the sensory perception of consumers (Bourne, 2002:43).

Puff pastry pie samples of 80, 100 and 120% fat contents were punctured using the same parameters as those of shortcrust pastry. The maximum load for 80, 100 and 120% fat contents were 34.25, 44.24 and 30.16 N, respectively. The extension at maximum load was 15.77, 19.00 and 13.40 mm for the 80, 100 and 120% fat variations. Higher fat content usually decreases the product firmness in puff pastries, as noted by Silow et al. (2018:7), hence the 100% fat content being more suited than 80% fat content.

The results indicated no significant differences between the firmness of shortcrust pastry samples with 60% and 70% fat content. Fat content in puff pastry significantly affected the firmness, with 100% fat content resulting in higher maximum load and extension at maximum load compared to 80% and 120% fat contents. These findings provide valuable insights into the firmness and texture of different pastry samples. Manzocco et al. (2012:177) did work for pastries made from Palm oil or hydrogel where those with hydrogel were firmer than those with palm oil. This is about the type of shortening fat that was used for making the shortcrust and puff pastry samples for this study.

The pie crust's firmness was compared for the shortcrust and puff pastry samples, whole BGN, dehulled BGN and wheat as shown in Table 4.2. There was a significant difference in the firmness of the crust of the three shortcrust pastry samples. The maximum load for whole and dehulled BGN shortcrust pastry were 29.17 N and 20.77 N, respectively compared to a lower maximum load of 6.16 N for what shortcrust pastry. The texture of the wheat pastry crust was less firm than that of both the BGN shortcrust pastry samples.

The extension at maximum load was significantly ($p < 0.05$) longer for wheat shortcrust pastry at 21.60 mm than the BGN shortcrust pastries with 12.92 N, respectively showing the whole and dehulled BGN shortcrust pastry crusts to be softer than the wheat shortcrust pastry crust. Whole and dehulled BGN exhibited significantly firmer textures than wheat, with higher maximum load values and a shorter extension at maximum load. The wheat pastry crust was less firm than the BGN shortcrust pastry.

Table 4.2. Comparison of firmness of pie crust for whole BGN, dehulled BGN and wheat shortcrust and puff pastry¹

Pastry	Maximum load (N)	Extension at maximum load (mm)
Shortcrust		
Whole BGN	29.17 ± 4.45 ^a	12.92 ± 0.54 ^a
Dehulled BGN	20.77 ± 3.70 ^b	12.92 ± 1.18 ^a
Wheat	6.16 ± 2.51 ^a	21.60 ± 1.24 ^b
Puff		
Whole BGN	19.07 ± 3.54 ^b	18.04 ± 0.68 ^a
Dehulled BGN	15.89 ± 2.62 ^b	16.69 ± 2.09 ^a
Wheat	7.71 ± 1.99 ^a	27.44 ± 1.13 ^b

¹ Values are means ± standard deviation. Different letters in the same column indicate significant mean differences ($p \leq 0.05$).

The maximum load of whole BGN puff pastry was 19.07 N, dehulled BGN puff pastry was 15.89 N, and the wheat puff pastry was 7.71 N, which differed significantly ($p < 0.05$). The extension at maximum loads 18.04 mm, 16.69 mm and 27.44 mm for whole BGN, dehulled BGN and wheat puff pastry, respectively differed significantly ($p < 0.05$). The wheat puff crust was significantly firmer than the BGN puff pastries. Consumers are generally known not to like chewy puff pastry but prefer a crispy and soft one with lower firmness.

4.3.3 Cutting properties of whole BGN shortcrust and puff pastry

According to Schreuders et al. (2021:2), the Warner–Bratzler test is useful for measuring maximum shear force as a function of a knife cutting through a product. The cutting process assisted in knowing the strength of the shortcrust and puff pastry samples. Paula et al. (2014) reported that the instrumental forces (maximum force) derived from the V-shaped probe correlate strongly with the hardness and adhesiveness of sensory attributes. According to Bourne (2002:138), the Warner–Bratzler measuring apparatus measures the maximum force (maximum load) during the product cutting rather than the probe's true shear. Table 4.3 shows cutting parameters for shortcrust and puff pastry pies. The shortcrust pies' maximum force for 60% was 56.37 N and for 70% was 37.47 N, so it takes longer for the 60% fat-content pie sample to break

(less brittle). The extension at maximum load for 60% was 23.03 mm and 22.46 mm for 70%. There was no significant difference between the 60% and 70% fat-content pie samples. Notably, the 60% fat content gave a firmer texture than that of the 70% fat content.

Table 4.3. Cutting properties for shortcrust and puff pastry pies¹

Pies	Fat content (%)	Maximum load (N)	Extension at maximum load (mm)
Shortcrust pastry	60	56.37 ± 10.88 ^a	23.03 ± 0.87 ^a
	70	37.47 ± 5.35 ^b	22.46 ± 2.06 ^a
Puff pastry	80	36.46 ± 2.82 ^a	14.97 ± 0.42 ^b
	100	37.20 ± 2.85 ^a	19.49 ± 4.82 ^b
	120	35.27 ± 1.79 ^a	9.16 ± 0.92 ^a

¹ Values are means ± standard deviation. Different letters in the same column indicate significant mean differences ($p \leq 0.05$).

The maximum load can predict the tenderness of the product, of which 70% of fat seems to be more tender than 60%. Since using this probe assists in knowing the strength of the samples, the 60% fat content samples resulted in a much stronger and less fractured pie structure (Schreuders et al., 2021:4). The results exhibit that 60% fat content was less brittle and had a firmer texture compared to 70% fat content shortcrust pastry. So, the 60% fat content pastry took longer to break and had a firmer texture than the 70% fat content. However, there was no significant difference between them. Since maximum load predicts tenderness of the product, 70% fat content was more tender than the 60% fat content pastry. Puff pastry pie samples with 80, 100 and 120% fat content had a maximum load of 36.46, 37.20 and 35.27 N, respectively; the extension at maximum load was 14.97 mm for 80% fat content, 19.49 mm for 100% fat content and 9.16 mm for 120% fat content. The maximum load or maximum force needed for the fat content variations did not differ significantly. However, the extension at maximum load for 120% fat content significantly differed from that of 80 and 100% fat contents. These findings suggest that the fat content affects the texture and tenderness of the pastry. Also, the importance of the maximum load in predicting the tenderness was highlighted. Furthermore, the results give insights into the relationship between fat contents and the mechanical properties of pastry products. Also, the type of fat that is used affects the water content, flavour and handling range of the pastry. Fat is also known as the flavour

carrier and is responsible for the characteristics of the final product such as good structure, mouthfeel, and texture. (Schreuders et al., 2021:2-3; Bourne, 2002:138).

The cutting properties for the whole BGN, dehulled BGN and wheat shortcrust pastries gave maximum load values of 42.75 N, 40.99 N and 34.58 N respectively, as observed in Table 4.4. No significant difference was observed in the maximum load, with whole BGN shortcrust having a higher maximum load than dehulled BGN and wheat shortcrust pastries. The wheat shortcrust pastry had the highest extension at a maximum load value of 27.37 N, with whole BGN shortcrust pastry having a value of 14.70 N and dehulled BGN shortcrust pastry at 18.23 N. No significant difference was observed as well for the extension at maximum load. Overall, no significant difference was observed in the cutting ability of the shortcrust pastry samples, with BGN shortcrust pastry being softer than the firmer wheat shortcrust pastry.

Table 4.4 Cutting properties for whole BGN, dehulled BGN and wheat shortcrust and puff pastry¹

Pastry	Maximum load (N)	Extension at maximum load (mm)
Shortcrust pastry		
Whole BGN shortcrust pastry	42.75 ± 3.78 ^a	14.70 ± 3.70 ^a
Dehulled BGN shortcrust pastry	40.99 ± 7.35 ^a	18.23 ± 10.34 ^a
Wheat shortcrust pastry	34.58 ± 6.18 ^a	27.37 ± 0.90 ^a
Puff Pastry		
Whole BGN puff pastry	38.79 ± 2.68 ^a	19.04 ± 2.99 ^a
Dehulled BGN puff pastry	42.22 ± 6.95 ^a	25.44 ± 3.33 ^a
Wheat puff pastry	51.49 ± 13.76 ^a	33.90 ± 3.83 ^b

¹ Values are means ± standard deviation. Different letters in the same column indicate different means (p < 0.05).

The comparison of puff pastry samples for the maximum load was 38.79 N for the whole BGN, 42.22 N for dehulled BGN, and 51.49 N for wheat. The results showed no significant difference in the maximum load for the puff pastry samples. Extension at maximum load was 19.04 N, 25.44 N, and 33.90 N for whole BGN, dehulled BGN and wheat puff pastry, respectively. There was a significant difference in extension at the maximum load of the puff pastry samples. A statistically significant difference was observed in the cutting ability for the whole BGN, dehulled

BGN, and wheat puff pastry samples. Literature does not provide much evidence of pies going through a cutting characterisation process of Warner Bratzler, mostly done for meat and meat analogues which have very different characteristics as seen with work done by Schreuders et al. (2021:2), although he does mention work that was previously done on chapatis that were folded in 4 layers and they had a maximum force that gave a correlation coefficient of 0.928 (positive relationship between the tearing resistance and the maximum force. What was observed though in the cutting process of meat and meat analogues is that sensory tenderness of meat products was measured, and shear values correlated well with descriptive sensory descriptors as well as consumer sensory evaluation attributes e.g., hardness. To further understand this, it is crucial to observe notes made by Schreuders et al. (2021:4) that the Warner-Bratzler method was seen as more effective in predicting texture than methods such as TPA as it relates better with sensory data. Ultimately the cutting test or Warner-Bratzler test gives information about the strength of the product. Also, the maximum force needed to break the pastry is positively correlated with its peak force which indicates hardness, which is like what was observed with the meat and the analogues (Schreuders et al., 2021:4).

4.3.4. Proximate composition of whole and dehulled Bambara groundnut and wheat pastry.

The proximate composition of whole BGN, dehulled BGN and wheat pastry pies are detailed in Table 4.5. The protein content for whole BGN, dehulled BGN and wheat shortcrust pastry samples were 13.45% 18.27% and 7.87%, respectively. There was a significant difference between the three types of shortcrust pastry samples. The dehulled shortcrust pastry was higher in protein than the whole BGN and wheat shortcrust pastry. The protein content of whole BGN shortcrust pastry was like that of soybean-fortified gluten-free rice pasta which had an improved protein content, that increased the protein intake of consumers (Bolarinwa & Oyesiji, 2021:3). Also, a study by Agu et al. (2020:6) for acha and malted BGN biscuits, the biscuits had a protein content in the same range as the whole BGN shortcrust pastry. The moisture content, which is important for product storage stability, for whole BGN shortcrust pastry was 10.33%, 10.77% for dehulled BGN shortcrust pastry and 15.11% for wheat shortcrust pastry (Bolarinwa et al. 2021:3). The wheat shortcrust pastry was significantly different to both whole and dehulled BGN shortcrust pastry pies. The moisture content for the BGN pastries was like that of gluten-free soybean pasta reported by Bolarinwa and Oyesiji (2021:3). Ash content was 2.45% for whole BGN shortcrust, 1.97% for dehulled BGN shortcrust and 1.05% for wheat shortcrust pastry. The ash content for the shortcrust pastry was significantly different from each other and the whole BGN shortcrust pastry had a

higher content, which interprets the good source of mineral content and vitamins of the shortcrust pastry samples.

Agu et al. (2020:6) noted similar results for acha and malted BGN biscuits, as well as Bolarinwa et al. (2021:3) for soybean-fortified rice pasta. Fat content for shortcrust pastry pies of whole BGN, dehulled BGN and wheat was 11.16%, 8.62% and 0.76%, respectively.

Table 4.5 Proximate composition of pastry products from whole BGN, dehulled BGN and wheat.¹

Pastry products	Protein (%)	Moisture (%)	Ash (%)	Fat (%)	Carbohydrates (%)
Shortcrust pastry					
Whole BGN	13.45 ± 0.06 ^a	10.33 ± 0.13 ^a	2.45 ± 0.01 ^a	11.16 ± 0.81 ^a	62.61
Dehulled BGN	18.27 ± 1.91 ^c	10.77 ± 1.21 ^a	1.97 ± 0.09 ^b	8.62 ± 0.02 ^b	60.37
Wheat	7.87 ± 0.50 ^a	15.11 ± 0.28 ^b	1.05 ± 0.15 ^a	0.76 ± 0.08 ^c	75.21
Puff pastry					
Whole BGN	14.41 ± 3.32 ^b	12.29 ± 0.18 ^b	2.73 ± 0.04 ^c	9.72 ± 0.67 ^b	60.85
Dehulled BGN	13.41 ± 0.61 ^b	7.42 ± 0.19 ^a	2.02 ± 0.17 ^b	12.68 ± 1.58 ^b	64.47
Wheat	5.41 ± 0.47 ^a	11.93 ± 0.64 ^b	1.24 ± 0.06 ^a	1.20 ± 0.06 ^a	80.22

¹ Values are means ± standard deviation. Values with different superscripts in the same column within each category are significantly different ($p < 0.05$). *Carbohydrates were determined by difference

They were significantly different when compared with each other; the whole BGN shortcrust pastry had the highest fat content. Carbohydrates were determined by difference, 62,61% for whole BGN shortcrust pastry, 60.37% for dehulled BGN shortcrust pastry and 75.21% for wheat shortcrust pastry. Wheat shortcrust pastry had a higher carbohydrate content than whole BGN and dehulled BGN shortcrust pastry. The whole and dehulled BGN shortcrust pastry samples' carbohydrate content was like that of the carbohydrate content of Acha and malted BGN biscuits that were sweetened with date palm (Agu et al., 2020:6).

The proximate composition for puff pastry pie samples was, protein content was 14.41%, 13.41% and 5.41% for whole BGN, dehulled BGN and wheat pie. There was a significant difference between the pie samples and both BGN pies differed significantly from wheat puff pastry

pies. The protein content reported in this study for whole and dehulled BGN puff pastry is like what was written in a study done by Bolarinwa et al. (2021:3) on gluten-free soybean pasta, consuming the BGN puff pastry samples may contribute to the intake of protein for gluten intolerant individuals. The moisture content of the puff pastry samples was 12.29% for whole BGN, 7.42% for dehulled BGN and 11.93% for wheat. Wheat and whole BGN pies were significantly different from that of dehulled BGN. Wheat and whole BGN puff pastry moisture content was in the range of what Bolarinwa et al. (2021:3) reported for soybean pasta, which was more stable and longer shelf life when more soybean pasta was added. Ash content was 2.73%, 2.02% and 1.24% for whole BGN, dehulled BGN and wheat puff pastry pies. There was a significant ($p < 0.05$) difference between the samples. Whole BGN and dehulled BGN puff pastry had higher ash content than wheat puff pastry. The BGN puff pastry samples also had a similar result to that reported by Bolarinwa et al. (2021:3), a higher ash content of 2.17% for soybean-fortified pasta. The fat content for the whole BGN dehulled BGN and wheat samples were 9.72%, 12.68% and 1.20%, respectively. They differed significantly, with both whole BGN and dehulled BGN having a significant difference from wheat puff pastry pie. The high-fat content of whole BGN and dehulled BGN puff pastry could assist with the required energy supply to the body (Agu et al., 2020:6). The carbohydrate content was determined by difference; the whole BGN, dehulled BGN and wheat puff pastry had 60.85%, 64.47% and 80.22%, respectively. The wheat puff pastry had a higher carbohydrate and fibre content than the BGN puff pastry samples.

Overall, the aim of determining the proximate composition for whole BGN, dehulled BGN and wheat shortcrust and puff pastry products was achieved (Bolarinwa et al. 2021:3; Murevanhema, 2012:158). The findings of this study indicate that the whole BGN and dehulled shortcrust and puff pastry are rich in protein, minerals and fats, which are beneficial for nutritional requirements or dietary preferences. There is research that noted that hard and drier samples that are high in protein are perceived as more satiating, which may be beneficial, not only for gluten-intolerant and coeliac sufferers but also for individuals who follow a healthy lifestyle (Wahlgren, 2015:54).

4.3.5 Colour of shortcrust and puff dough and pastry

The data for colour in the different fat contents did not follow a normal distribution hence the non-parametric ANOVA, Kruskal Wallis test was used. There was no significant difference between lightness (L^*), red/green (a^*) and blue/yellow (b^*) for the fat content of 60 and 70%. Lightness (L^*) (Figure 4.5) differed significantly between the crumb and crust, crumb and dough and between crust and dough of the different fat contents (60 and 70%) of shortcrust whole BGN, dehulled BGN

and wheat dough and pastry samples. The dough is positively skewed for lightness was lighter than the crust and the crumb which had a lower median.

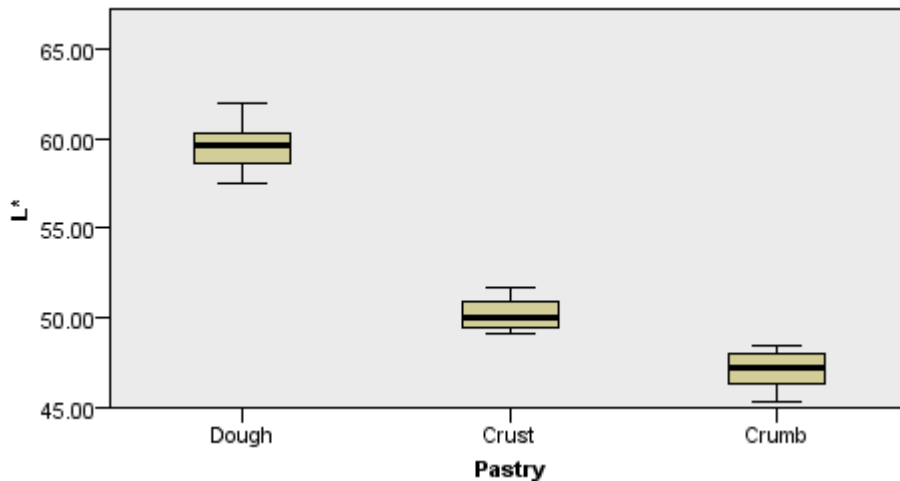


Figure 4.5 Box plot for Lightness of shortcrust dough, crust and crumb

There was a significant difference in the pairwise comparison of redness/greenness (a^*) Figure 4.6) for dough and crumb as well as with the dough and crust pairwise comparison of fat contents for whole BGN, dehulled BGN and wheat shortcrust dough and pastry. However, there was no significant difference between crumb and crust pairwise comparison of the different fat contents of whole BGN, dehulled BGN and wheat shortcrust dough and pastry, as seen in the box plot diagram. The crust has a higher median than the crumb and the crust. Dough had an outlier, which did not form part of the plot for dough. Crust had a higher median but with a lower quartile. The crust was greener or skewed to the greenness. The crumb had a more symmetrical median for red/green coordinates and dough had the lowest median.

There was no significant difference between the pairwise comparison of yellowness/blueness (b^*) for dough and crumb of whole BGN, dehulled BGN and wheat shortcrust samples.

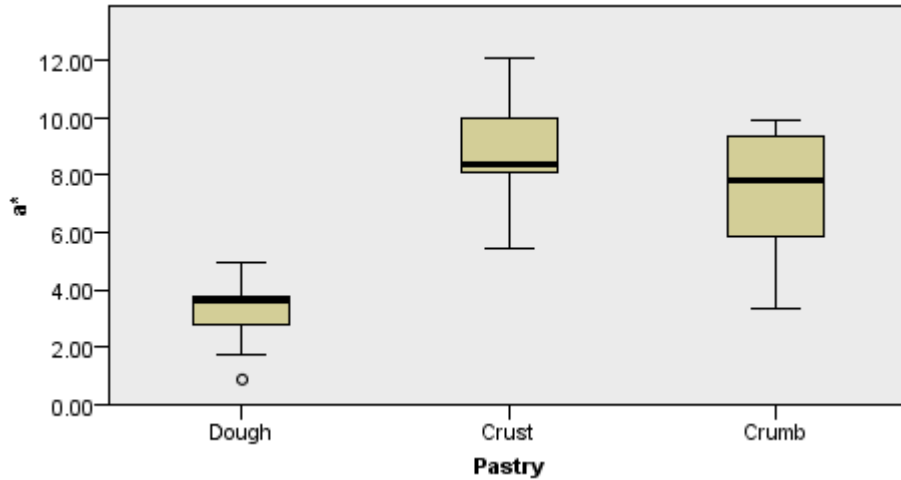


Figure 4.6 Box plot of red/green coordinates for shortcrust dough, crust, and crumb

Significant differences between dough and crust as well as between crumb and crust of 60 and 70% fat contents of whole BGN, dehulled BGN and wheat shortcrust were observed in the box plot diagram of Figure 4.7. The dough in Figure 4.7 had a similar minimum to the lower quartile and the maximum was the upper quartile. Thus, the minimum and maximum overlaps. Crust had a higher median for blue/yellow coordinates however the data was positively skew (yellow), and the crumb was positively skew. Dough also had an outlier that was not part of the plot.

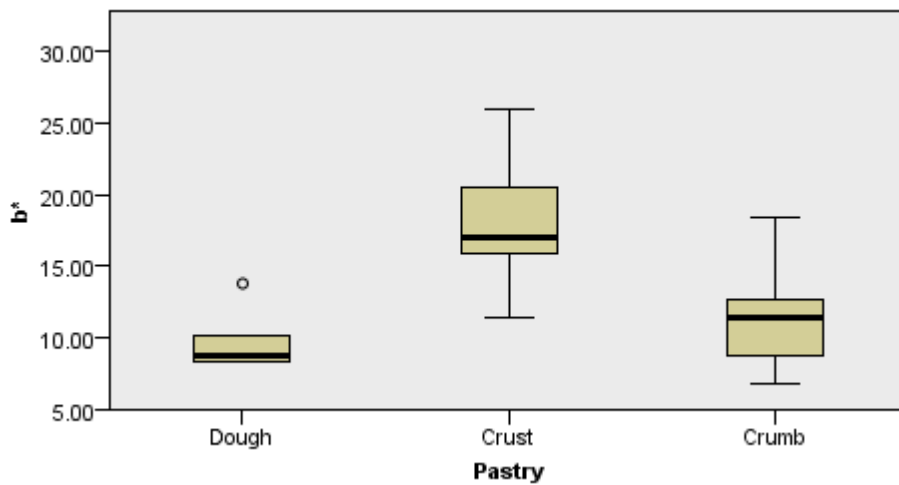


Figure 4.7 Box plot of blue/yellow coordinates for shortcrust dough, crust and crumb.

Thus 60% fat content was preferred because the distribution of L^* , a^* and b^* across the categories of the fat content was the same. Therefore, the null hypothesis that the distribution of L^* , a^* and b^* would be the same across pastry categories was retained.

Puff pastry samples of 80, 100 and 120% were analysed for colour as well and the different pastry forms were considered when looking at the colour (Figure 4.8 to 4.10). That is whole BGN, dehulled BGN wheat dough, crumb, and crust. The results for the Lightness (L^*) of dough, crust and crumb of whole BGN puff pastry were 66.57, 34.42 and 45.13, respectively. The redness/greenness (a^*) of dough, crust and crumb were 3.12, 13.67 and 8.68, respectively. b^* Values were 12.18, 18.94 and 19.49. There was a significant difference between the dough, crust, and crumb for Lightness (L^*) and redness/greenness (a^*) but no significant difference for yellowness/blueness (b^*). The dehulled BGN puff pastry dough, crust and crumb amounted to 75.49, 49.76 and 51.43 respectively for L^* . The results for a^* were 3.43, 14.52 and 13.48 for dough, crust, and crumb. Lastly for b^* the values were 18.56 for dough, 31.88 for crust and 26.47 for crumb.

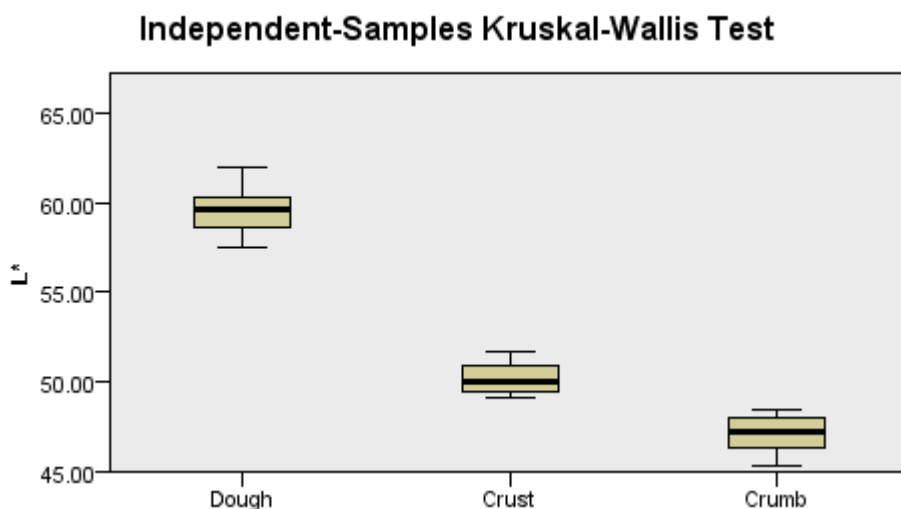


Figure 4.8. Box plot of Lightness for puff dough, crust and crumb

There was a significant difference in the colour values for L^* and b^* dough, crust, and crumb. However, for a^* dough was significantly different from the crust and the crumb. For wheat puff pastry, the dough, crust, and crumb had L^* values of 79.80, 47.78 and 61.59. The a^* values

were 1.67, 14.78 and 5.83 for dough, crust, and crumb, respectively. The b^* values for the dough were 19.99, for the crust 28.23 and crumb 30.82. The dough, crust and crumb colour values were significantly different for L^* and a^* and for b^* the crust had no significant difference to the values of dough and crumb, and significant difference between dough and crust and crust and crumb. In Figure 4.8 the pairwise comparison for L^* values between all the pastry forms (that is between crust and crumb), between crumb and dough and between crust and dough had a significant difference between them. The dough was lighter and had a longer range compared to the crust and the crumb which had a lower median and shorter range from maximum to minimum. The Lightness values are more spread out with the dough than with the rest of the pastry. The darkening of the crust is known to be desirable in gluten-free products as it eliminates the lighter crust colour that may appear artificial (Paciulli et al., 2016:94).

The pairwise comparison for the a^* values (Figure 4.9) between dough and crumb and between dough and crust were significantly different and the pairwise comparison between the crumb and crust was not significantly different. The dough median and upper quartile overlap. The a^* values had a lower range for dough and a higher range for crust and crumb. The crumb had a larger interquartile range than the dough and crust.

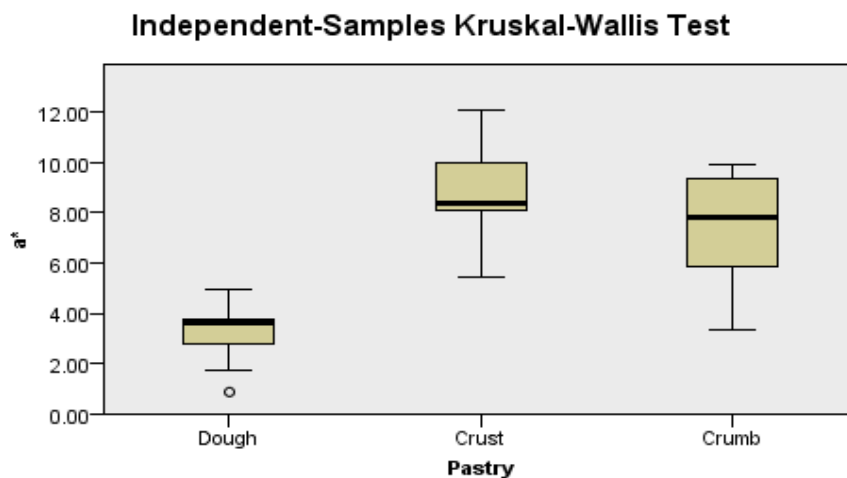


Figure 4.9 Box plot of red/green coordinates for puff dough, crust and crumb

The pairwise comparison for b^* values between dough and crumb were not significantly different (Figure 4.10). Then between dough and crust and between crumb and crust, there was a significant difference. The distribution of L^* , a^* and b^* was the same across all categories of fat contents thus the null hypothesis was retained for all values. The crust data for b^* values was distributed on a much longer range with a higher minimum and maximum compared to the crumb and dough, hence the blue/yellowness is higher for the crust, with a higher median that is positively skewed for blue/yellow coordinates. The dough had an outlier again which did not form part of the plot for dough.

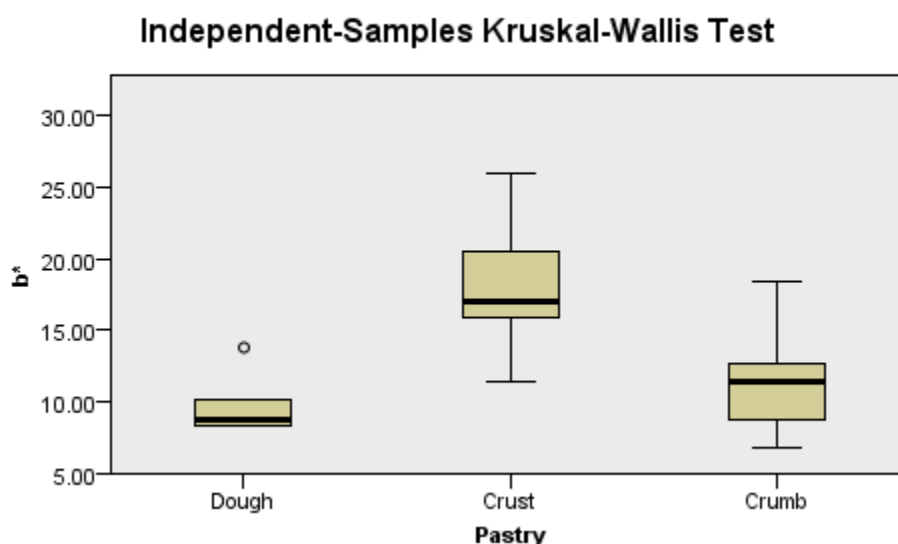


Figure 4.10 Box plot of blue/yellow coordinates for puff pastry

Mirhosseini et al. (2015:187; 189) and Baardseth et al. (1995:74) both studied different aspects of the colour of gluten-free flours, specifically Baardseth et al. (1995:74) observed colour of Danish pastry with fat content and fat type used, they only noted the “significance with a^* (redness) and not with the other values”. This was because of the nature of the gluten-free flour for example chestnut together with rice flour had a higher redness due to the presence of sugars which partake in the Maillard reaction (browning and caramelisation that results in browning, which is not the primary case with whole BGN flour (Zhu, 2017:1182; Baardseth et al., 1995:76). The resulting colour of the pastry crumb and crust is very much dependent on the ingredients used when making

the pastry and the phenolic compounds inherent in the hulls that are included in the flour compared to dehulled BGN flour (Harris et al., 2018:9; Paciulli et al., 2016:94)

4.3.6 X-ray computed tomography and Imaging of BGN shortcrust and puff pastry baked pies.

The images obtained from X-ray computed tomography were used to study the different holes in all the images (Figure 4.11 – 4.14). From the images, it can be deduced that the whole and dehulled BGN flour could coat the fat globules to form shortcrust pie structures and develop texture.

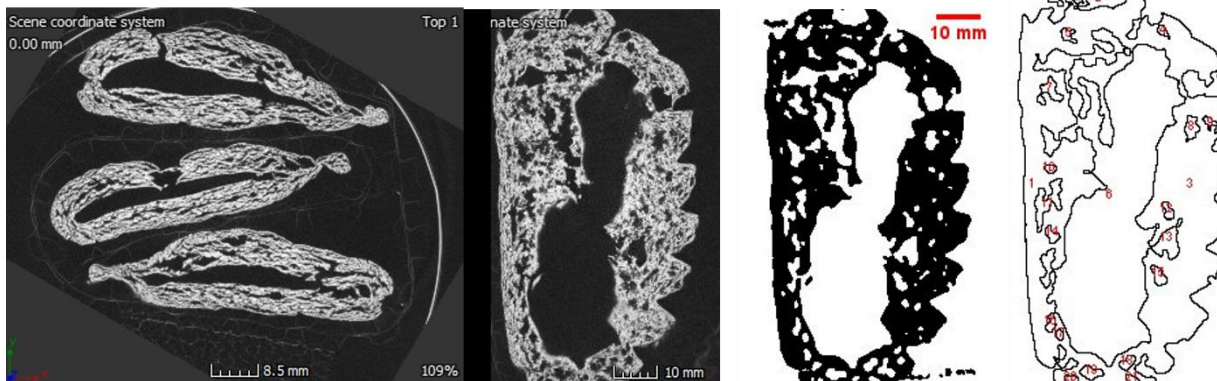


Figure 4.11 X – ray computed tomography images on whole Bambara groundnut shortcrust pastry.

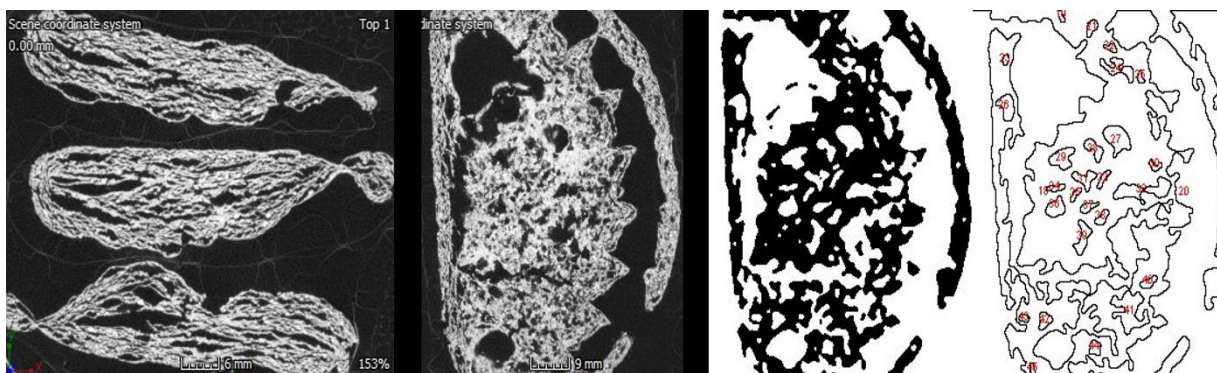


Figure 4.12 X–ray computed tomography images on dehulled Bambara groundnut shortcrust pastry.

This assisted in understanding the significance of those holes better and to determine the fat distribution within the as well as air pockets which are important especially for puff pastry (Figure 4.13 and 4.14).

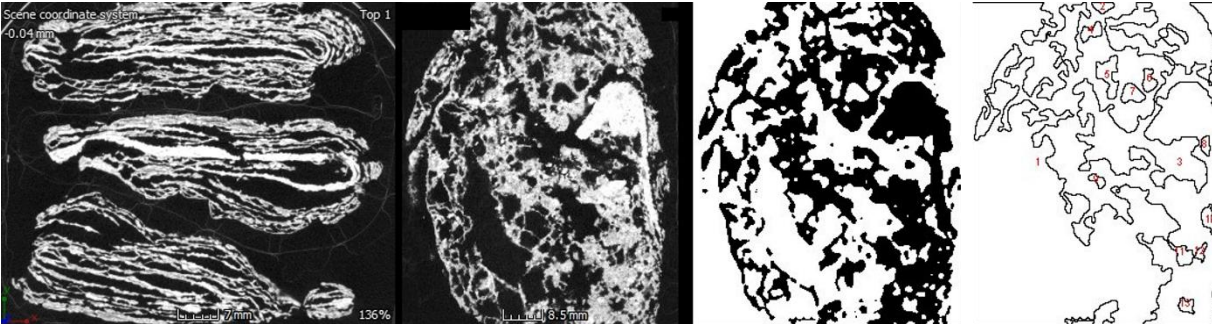


Figure 4.13. X-ray computed tomography images on whole Bambara groundnut puff pastry.

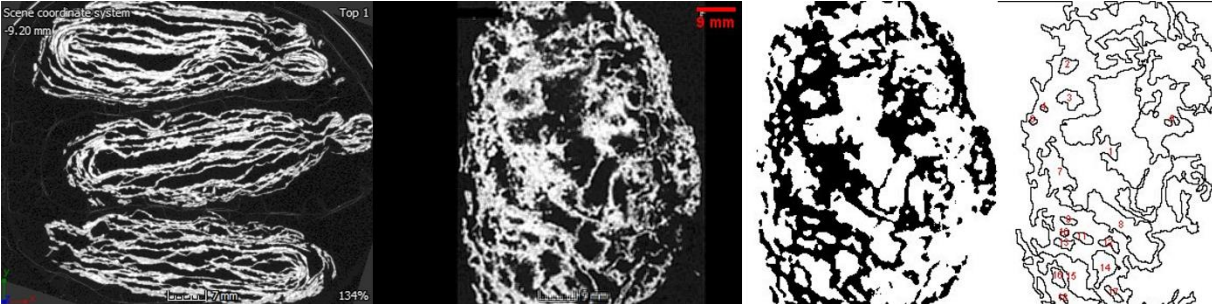


Figure 4.14. X-ray computed tomography images on dehulled Bambara groundnut puff pastry.

It is important to note that these pie samples had no filling in them, which then for figure 4.11, the whole BGN pie samples, for example, a huge whole is observed in the first image where filling would have been put. In an image analysis study of baked wheat goods, it was observed that wheat-based samples displayed larger holes compared to other samples, which in turn affected the tenderness and firmness of the baked goods (Germishuys, 2021:93).

The images were subjected to principal component analysis (PCA), which elaborated on the variability of the data, in Figure 4.15. Two components were extracted (from a scree plot). From there a plot was produced to study and compare the different components differentiating between the pastry samples (area, perimeter, circularity, aspect ratio, round, and solidity) (Garcia-Valle et al., 2021:9; Murevanhema, 2012:80). In the principal component analysis plot in Figure 4.15, it is evident that the dehulled BGN puff and whole BGN puff pastry pie sample holes were impacted by the linear dimension (perimeter, area, radius, and diameter) of the holes in comparison to both dehulled and whole BGN shortcrust samples. The roundness had an effect on the puff pastry samples and not the shortcrust pastry. The aspect ratio was an outlier, it was not a good separator. Circularity had an effect on the whole BGN shortcrust samples. Solidity had an effect on the puff pastry samples as well. Most of the sample's data variation (55.6%) was explained using component 1, and only 35.9% by component 2, with a combined cumulative variation of 91.5% of the variation explained by both components (Murevanhema, 2012:80).

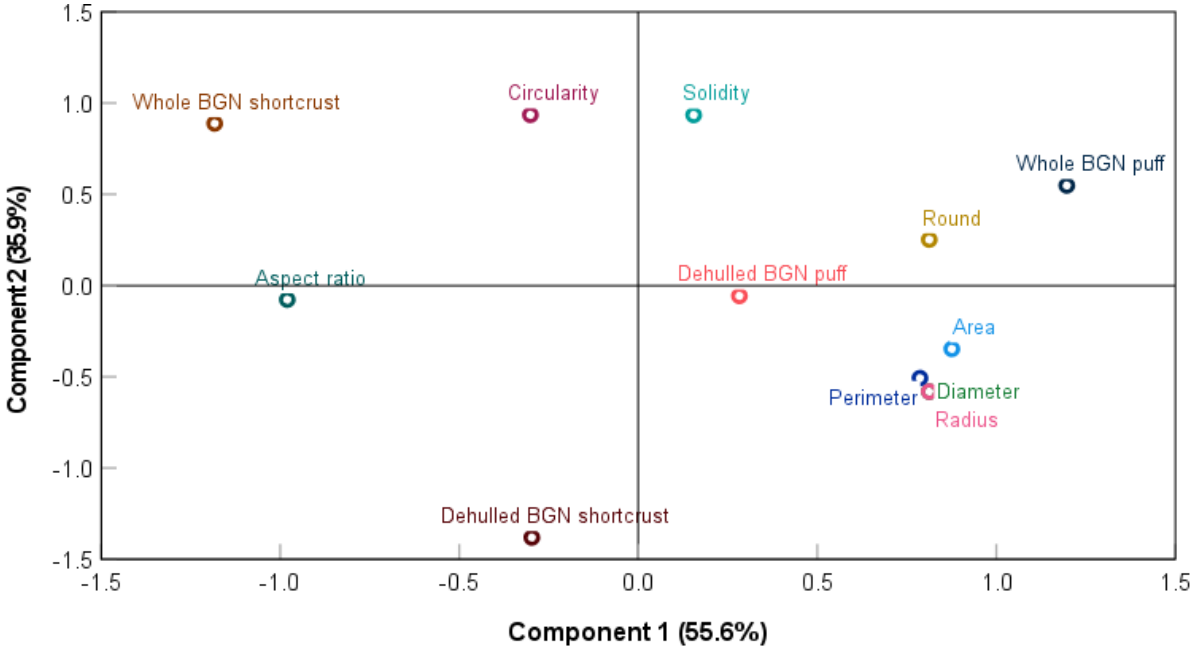


Figure 4.15 PCA plot for whole BGN and dehulled BGN shortcrust and puff pastry pies

In summary, the analysis showed that the size and shape of holes in the pastry samples had a significant effect on their classification, especially with puff pastry. Roundness influenced puff

pastry, while aspect ratio was less important. Circularity affected whole BGN shortcrust pastry, and solidity had an effect on whole and dehulled puff pastry. Component 1 explained much of the data variation, followed by Component 2, with a combined explanation of 91.5% (Garcia-Valle et al., 2021:9; Murevanhema, 2012:80). All the holes were observed to be the same; therefore, there was no significant difference between the shortcrust and puff pastry samples.

4.4 Conclusion

The aim of assessing the textural properties of shortcrust and puff pastry with various fat contents was achieved. The 60% fat-content shortcrust pastry was found to be the most suitable, having a firmer crust and a desirable texture compared to the other fat amounts. The more fat the pastry contained, the crumblier the pie crust texture. The 100% fat content for puff pastry had a favourable appearance and texture; however, the distinct layers were disrupted by fat migration after melting, and the whole BGN's presence of hulls. Overall, the objective of creating a suitable dough and pie for both shortcrust and puff pastry was achieved. The nutritional richness of whole BGN shortcrust and puff pastry in terms of protein, minerals, and fats, making them beneficial for various dietary preferences, including gluten intolerance and a healthy lifestyle, was highlighted by the proximate composition obtained.

The cutting test using the Warner-Bratzler method provided insights into the strength and hardness of the pastries, correlating well with sensory evaluations. The image analysis by characterizing the holes in the pastry revealed significant influences on classification, particularly in puff pastry. Roundness affected whole and dehulled BGN puff pastry, while aspect ratio was less crucial. Circularity influenced whole BGN shortcrust samples, and solidity impacted whole and dehulled puff pastry puff pastry. Component 1 explained much of the data variation, followed by Component 2, with a combined explanation of 91.5%. Overall, the findings suggest that the chosen parameters play a significant role in the classification of shortcrust and puff pastry products. In future research, the incorporation of leavening agents in puff pastry production could be explored to achieve increased pastry elevation and more defined layers. Additionally, further exploration into identifying suitable fats for both whole and dehulled BGN could be pursued. Lastly, an alternative image analysis approach could be employed to examine the structure of whole and dehulled BGN pastry products.

4.5 References

AACC. 2000. Approved methods of the American Association of Cereal Chemists. *American Association of Cereal Chemists*.

- Adebowale, K.O., Afolabi, T.A. & Lawal, O.S. 2002. Isolation, chemical modification and physicochemical characterisation of Bambara groundnut (*Voandzeia subterranea*) starch and flour. *Food Chemistry*, 78: 305–311.
- Adeyi, O., Ikhu-Omoregbe, D. & Jideani, Victoria. 2014. Emulsion Stability and Steady Shear Characteristics of Concentrated Oil-in-Water Emulsion Stabilized by Gelatinized Bambara Groundnut Flour. *Asian Journal of Chemistry*, 26(16): 4995–5002.
- Agu, H.O., Onuoha, G.O., Elijah, O.E. & Jideani, V.A. 2020. Consumer acceptability of acha and malted Bambara groundnut (BGN) biscuits sweetened with date palm. *Heliyon*, 6(11).
- Alakali, J.S., Irtwange, S. V & Mzer, M.T. 2010. Quality evaluation of beef patties formulated with Bambara groundnut (*Vigna subterranea* L.) seed flour. *Meat Science*, 85(2), 215–223. <https://doi.org/10.1016/j.meatsci.2009.12.027>.
- Alozie, Y.E., Iyam, M.A., Lawal, O., Udofia, U. & Ani, I.F. 2009. Utilization of Bambara Groundnut Flour Blends in Bread Production. *Journal of Food Technology*, 7(4): 111–114.
- GreedyScholars. 2017. How does altering the fat-to-flour ratio affect the pastry? : 1–2. <https://cooking.stackexchange.com/questions/85338/how-does-altering-the-fat-to-flour-ratio-affect-the-pastry> 22 June 2022.
- AOAC. 2005. Official methods of analysis of the Association of Official Analytical Chemists. Methods 920.39; 990.03; 942.05
- Aziz, I. & Sanders, D.S. 2014. Patients Who Avoid Wheat and Gluten: Is That Health or Lifestyle? *Digestive Diseases and Sciences*, (59): 1080–1082.
- Baardseth, P., Naes, T. & Vogt, G. 1995. Roll-in Shortenings Effects on Danish Pastries Sensory Properties Studied by Principal Component Analysis. *Lebensmittel-Wissenschaft & Technologie*, 28(1): 72–77.
- Barimalaa, I.S., Agoha, G., Oboh, C.A. & Kiin-Kabari, D.B. 2005. Studies on Bambara groundnut flour performance in Okpa preparation. *Journal of the Science of Food and Agriculture*, 85(3): 413–417.
- Baryeh, E.A. 2001. Physical properties of Bambara groundnuts. *Journal of Food Engineering*, 47(4): 321–326.
- Bolarinwa, I.F. & Oyesiji, O.O. 2021d. Gluten free rice-soy pasta: proximate composition, textural properties, and sensory attributes. *Heliyon*, 7(1): e06052.
- Bourne, Malcolm C. 2002. *Food Texture and Viscosity: Concept and Measurement*. 2nd ed. M. C. Bourne, ed. New York: Academic Press. [https://www.academia.edu/38698369/Food Texture and Viscosity Concept and Measurement](https://www.academia.edu/38698369/Food_Texture_and_Viscosity_Concept_and_Measurement) [01 August 2023].

- Bousquieres, J., Deligny, C., Challos, S. & Lucas, T. 2014. Using confocal laser scanning microscopy to examine the breakdown of fat layers in laminated dough. *Food Research International*, 62: 359–365.
- Cauvain, S., & Young, L. 2001. 8 – Laminated products. In *Baking Problems Solved*. Woodhead publishing. 124–135. <https://doi.org/10.1533/9781855736184.124>.
- de Cindio, B. & Lupi, F.R. 2011. 15 – Saturated fat reduction in pastry. In *Reducing Saturated Fats in Foods*. 301–317. <http://dx.doi.org/10.1016/B978-1-84569-740-2.50015-4>.
- Codex Stan, A. 2008. Codex Standard for Foods for Special Dietary Use for Persons Intolerant to Gluten. *Codex Alimentarius: Codex Stan 118-1979 Rev. in 2008*
- Day, L., Augustin, M.A., Batey, I.L. & Wrigley, C.W. 2006. Wheat-gluten uses and industry needs. *Trends in Food Science and Technology*, 17(2): 82–90.
- Deligny, C., Collewet, G. & Lucas, T. 2017. Quantitative MRI study of layers and bubbles in Danish pastry during the proving process. *Journal of Food Engineering*, 203: 6–15.
- Deligny, C. & Lucas, T. 2015. Effect of the number of fat layers on expansion of Danish pastry during proving and baking. *Journal of Food Engineering*, 158: 113–120.
- Einarsdottir, H., Ersboll, B.K. & Larsen, R. 2016. *Image Analysis for X-ray Imaging of Food*. Technical University of Denmark. 1-136. <https://backend.orbit.dtu.dk/ws/portalfiles/portal/127631392/Thesis.pdf> [02 June 2023]
- Fulladosa, E., Garcia-Gil, N., Santos-Garcés, E., i Furnols, M.F., Muñoz, I. & Gou, P. 2011. Computed tomography in food science. In *Focus on Food Engineering*. 157–186.
- Garcia-Valle, D.E., Agama-Acevedo, E., Nuñez-Santiago, M. del C., Alvarez-Ramirez, J. & Bello-Pérez, L.A. 2021. Extrusion pregelatinisation improves texture, viscoelasticity and in vitro starch digestibility of mango and amaranth flours. *Journal of Functional Foods*, 80. <https://doi.org/10.1016/j.jff.2021.104441>.
- Germishuys, Z. (2021). X-ray micro-computed tomography (μ CT) evaluation of bubble structure to determine quality of dough and bread made from roasted wheat flour. <https://scholar.sun.ac.za:443/handle/10019.1/109867>
- Harte, J.B. 2003. Pastry products: types and production, in *Encyclopaedia of Food Sciences and Nutrition* (eds B.Caballero, L.Trugo, and P.M Finglas), Academic Press, San Diego, CA. 4407–4412.
- Hughes, N., Askew, K., Scotson, C.P., Williams, K., Sauze, C., Corke, F., Doonan, J.H. & Nibau, C. 2017. Non-destructive, high-content analysis of wheat grain traits using X-ray micro computed tomography. *Plant Methods*, 13. <https://doi.org/10.1186/s13007-017-0229-8>.
- Jan, N., Naik, H.R., Gani, G., Bashir, O., Hussain, S.Z., Rather, A.H., Zargar, I.A., Wani, S.M. & Amin, T. 2021. Optimization of process for the development of rice flour incorporated low-

- gluten wheat-based pretzels: Evaluation of its physicochemical, thermal and textural characteristics. *Journal of the Saudi Society of Agricultural Sciences*, 20(2): 116–127.
- Kaptso, K.G., Njintang, Y.N., Nguemtchouin, M.M.G., Scher, J., Hounhouigan, J. & Mbofung, C.M. 2015. Physicochemical and micro-structural properties of flours, starch and proteins from two varieties of legumes: bambara groundnut (*Vigna subterranea*). *Journal of Food Science and Technology*, 52(8): 4915–4924.
- Lucas, T., Collewet, G., Bousquière, J. & Deligny, C. 2018. The size of eye-shaped bubbles in Danish pastry in relation to the size of fat fragments; A reverse engineering approach of the alveolar structure. *Journal of Food Engineering*, 237: 194–203.
- Lyon, B.G. & Lyon, C.E. 1998. Assessment of Three Devices Used in Shear Tests of Cooked Breast Meat. *Poultry Science*, 77(10): 1585–1590.
- Manzocco, L., Anese, M., Calligaris, S., Quarta, B. & Nicoli, M.C. 2012. Use of monoglyceride hydrogel for the production of low-fat short dough pastry. *Food Chemistry*, 132(1): 175–180.
- Marston, K., Khouryieh, H. & Aramouni, F. 2016. Effect of heat treatment of sorghum flour on the functional properties of gluten-free bread and cake. *LWT - Food Science and Technology*, 65: 637–644.
- Masure, H.G., Fierens, E. & Delcour, J.A. 2016. Current and forward-looking experimental approaches in gluten-free bread making research. *Journal of Cereal Science*, 67: 92–111.
- Mir, S.A., Shah, M.A., Naik, H.R. & Zargar, I.A. 2016. Influence of hydrocolloids on dough handling and technological properties of gluten-free breads. *Trends in Food Science and Technology*, 51: 49–57. <http://dx.doi.org/10.1016/j.tifs.2016.03.005>.
- Mir, S.A., Bosco, S.J.D. & Shah, M.A. 2019. Technological and nutritional properties of gluten-free snacks based on brown rice and chestnut flour. *Journal of the Saudi Society of Agricultural Sciences*, 18(1): 89–94.
- Miranda, J., Lasa, A., Bustamante, M.A., Churruca, I. & Simon, E. 2014. Nutritional Differences Between a Gluten-free Diet and a Diet Containing Equivalent Products with Gluten. *Plant Foods for Human Nutrition*.69:182–187. <https://doi.org/10.1007/s11130-014-0410-4>.
- Mthombeni-Nkantsu, S.D. 2017. *Functionality of Bambara groundnut flour in pastry products*. Unpublished thesis, Cape Peninsula University of Technology, Bellville.
- Murevanhema, Y.Y. 2012. *Evaluation of Bambara groundnuts (Vigna subterranea (L .) Verdc .) milk fermented with lactic acid bacteria as a probiotic beverage*. Unpublished Master of Technology thesis. Cape Peninsula University of Technology, Bellville. https://etd.cput.ac.za/bitstream/20.500.11838/825/1/207226121_Murevanhema_YY_2012.pdf. [01 August 2023].

- Ogundele, O.M., Minnaar, A. & Emmambux, M.N. 2017. Effects of micronisation and dehulling of pre-soaked bambara groundnut seeds on microstructure and functionality of the resulting flours. *Food Chemistry*, 214: 655–663.
- Oyeyinka, S.A., Singh, S., Adebola, P.O., Gerrano, A.S. & Amonsou, E.O. 2015. Physicochemical properties of starches with variable amylose contents extracted from Bambara groundnut genotypes. *Carbohydrate Polymers*, 33 (2015): 171–178
<http://dx.doi.org/10.1016/j.carbpol.2015.06.100>
- Paciulli, M., Rinaldi, M., Cirilini, M., Scazzina, F. & Chiavaro, E. 2016. Chestnut flour addition in commercial gluten-free bread: A shelf-life study. *LWT - Food Science and Technology*, 70: 88–95.
- Paula, A.M. & Conti-Silva, A.C. 2014. Texture profile and correlation between sensory and instrumental analyses on extruded snacks. *Journal of Food Engineering*, 121(1): 9–14.
- Renzetti, S., de Harder, R. & Jurgens, A. 2016. Puff pastry with low saturated fat contents: The role of fat and dough physical interactions in the development of a layered structure. *Journal of Food Engineering*, 170: 24–32.
- Scherf, K.A., Koehler, P. & Wieser, H. 2015. Gluten and Wheat Sensitivities – an Overview. *Journal of Cereal Science*, 67: 2–11.
- Schreuders, F.K.G., Schlangen, M., Kyriakopoulou, K., Boom, R.M. & van der Goot, A.J. 2021. Texture methods for evaluating meat and meat analogue structures: A review. *Food Control*, 127: 1–14.
- Silow, C., Axel, C., Zannini, E. & Arendt, Elke K. 2018. Application of sourdough in the production of fat- and salt-reduced puff pastry. *European Food Research and Technology*, 244(9): 1581–1593.
- Silow, C., Zannini, E., Axel, C., Lynch, K.M. & Arendt, E.K. 2016. Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content. *Food Research International*, 89: 330–337.
- Silvester, J.A., Weiten, D., Graff, L.A., Walker, J.R. & Duerksen, D.R. 2016. Is it gluten-free? Relationship between self-reported gluten-free diet adherence and knowledge of gluten content of foods. *Nutrition*, 32(7): 777–783.
- Simovic, D.S., Pajin, B., Seres, Z. & Filipovic, N. 2009. Effect of low- *trans* margarine on physicochemical and sensory properties of puff pastry. *International Journal of Food Science & Technology*, 44(6): 1235–1244.
- Sliwinski, E.L., Kolster, P. & van Vliet, T. 2004. On the relationship between large-deformation properties of wheat flour dough and baking quality. *Journal of Cereal Science*, 39(2): 231–245.

- Vidhya, M., Varadharaju, N., Z, J. K., Amirtham, D., & D, M. J. 2017. Applications of X-Ray computed tomography in food processing. *Journal of Food Processing & Technology*, 08(05). <https://doi.org/10.4172/2157-7110.1000673>.
- Wahlgren, M.B. 2015. Oral processing and satiety perception of bread Understanding the role of texture and oral processing in consumers' perception of satiety. Norwegian University of Life Sciences. <http://hdl.handle.net/11250/294305> [02 June 2023].
- Wickramarachchi, K. S., Sissons, M., & Cauvain, S. P. (2015). Puff pastry and trends in fat reduction: an update. *International Journal of Food Science & Technology*, 50(5), 1065–1075. <https://doi.org/10.1111/ijfs.12754>
- Xing-li, L.I.U., Tai-hua, M.U., Hong-nan, S.U.N., Miao, Z. & Jing-wang, C. 2016. Influence of potato flour on dough rheological properties and quality of steamed bread. *Journal of Integrative Agriculture*, 15(11): 2666–2676.
- Zhu, F. 2017b. Properties and Food Uses of Chestnut Flour and Starch. *Food and Bioprocess Technology*, 10(7): 1173–1191.

CHAPTER FIVE

QUANTITATIVE DESCRIPTIVE ANALYSIS AND CONSUMER ACCEPTABILITY OF BAMBARA GROUNDNUT SHORTCRUST AND PUFF PASTRY PRODUCTS

Abstract

Around the world pastry products are consumed and enjoyed by a variety of people. However, most of these products are made with wheat and that excludes people who are gluten intolerant and coeliac sufferers. This then gives way to the creation of alternative gluten-free products using flour from naturally gluten-free flour sources such as Bambara groundnut (BGN). This study evaluated the sensory characteristics of Bambara groundnut shortcrust and puff pastry products. Shortcrust and puff pastry pies were analysed using quantitative descriptive analysis (QDA) with a trained panel and consumer sensory evaluation with an untrained panel. The QDA involved 10 trained panellists assessing 6 samples based on various categories, appearance, aroma texture and taste. The QDA involved 10 trained panellists assessing 6 samples based on such as crust colour, crumb colour, size of cracks, crust smoothness, nutty aroma, buttery aroma, typical pie aroma, softness, the juiciness of crumb, fat, cohesiveness, hardness, beany taste, saltiness, buttery taste and aftertaste. Consumer sensory evaluation, conducted with 47 untrained panellists, focused on appearance, aroma, taste, texture, and overall acceptability using the descriptors of the rating scale ranged from dislike very much (1), to neither like nor dislike (3) and ended with like very much (5) (6 samples evaluated). Whole BGN shortcrust and puff pastry pies exhibited characteristics like larger crack size in appearance, rough texture, and a stronger nutty aroma compared to wheat-based pies. Dehulled BGN puff pastry pies were perceived as oily, while whole and dehulled BGN shortcrust pastry pies were characterized as dry and crumbly. All BGN pie samples were noted for their beany taste, and none were perceived as too salty. There was a distinct perception of the presence or absence of an aftertaste in any of the pies. Consumer sensory evaluation revealed preferences for wheat shortcrust and puff pastry pies in terms of appearance, crust colour, crumb colour, aroma, taste, texture, and overall acceptability, with whole BGN shortcrust and puff pastry pie samples receiving moderate (average) ratings for appearance, crust colour and crumb colour compared to dehulled BGN and wheat shortcrust and puff pastry pies which were rated higher. This study provided insights into the sensory attributes of gluten-free pastry products, made from whole and dehulled BGN, and highlighted differences in perception between trained and untrained panels. The findings contribute to the understanding of

consumer preferences and can inform the development of alternative gluten-free pastry options for gluten-intolerant individuals and coeliac sufferers.

5.1 Introduction

Puff and shortcrust pastry are two of many widely used types of pastry. Each of them has unique sensory properties attributed to them. It is crucial to understand the potential impact of gluten-free flour on the sensory properties and application of these types of pastry, for product development and consumer acceptance (Verbon, 2017:1; Connelly, 2014:1). Typically, shortcrust pastry is known for its crumbly and dense texture and often used in pies and tarts. The texture of shortcrust pastry is short and crumbly as a result of fat being rubbed into the flour before the addition of liquid. This method prevents gluten formation and therefore leads to a fragile and tender structure that is prone to break apart easily when cut or bitten into (Verbon, 2017:1; Connelly, 2014:1). The flavour profile of shortcrust pastry is dependent on the type of fat used e.g. butter, lard, or shortening, with shortening more neutral than the rich and creamy taste of butter. Puff pastry, on the other hand, is famous for its airy, light, and flaky structure that is attained by the lamination process of repeatedly folding and rolling fat and dough layers (Patient, 1994:33). The texture of puff pastry has a layered structure that is crisp and flaky, which is provided by the leavening effect of fat and steam during baking (Patient, 1994:33). Also, just like shortcrust, the flavour of puff pastry is influenced by the type of fat used.

The incorporation of gluten-free flours has been seen to alter the texture and flavour of pastry formulations. This all requires adjustments and manipulation of the fats and liquids used to make the pastry (Silow *et al.*, 2018:11; Kusinska *et al.*, 2012:121). Puff pastry, however, relies heavily on the formation of the gluten network for its structure. Gluten-free flours since they lack gluten may compromise the ability of the pastry to maintain the airy and flaky layers of puff pastry. The use of additives such as hydrocolloids can mitigate and assist in the layering process to get the desired flaky structure (Silow *et al.*, 2018:11; Kusinska *et al.*, 2012:121). Consumer acceptability of these gluten-free pastries is all dependent on consumer preference.

Some researchers have investigated the sensory attributes of various pastry products using diverse evaluation methods. For instance, Baardseth *et al.* (1995:72) reported on the effect of roll-in-shortenings on Danish pastry using quantitative descriptive analysis. Simovic *et al.* (2009:1235) examined the effect of low trans margarine on the sensory properties of puff pastry, using a points-based method. Ruiz-Cano *et al.* (2016:624) reported on the study they did on Spanish artisan meat pie; they used a consumer panel that assessed for acceptability using a 9-point hedonic scale. Lastly, Silow, (2018:51-52) used the QDA method to analyse puff pastry with

sourdough and reduced fat and salt. However, it's noteworthy that, to date, no research has delved into the sensory attributes of gluten-free pies made from Bambara groundnut flour. So, this gap in literature underscores the need for studies to explore and understand the acceptability, and quantitative and qualitative descriptors of gluten-free pastry products.

Bambara groundnut (BGN) is a leguminous plant that is predominantly found in different parts of Africa in countries like Senegal, Nigeria, Kenya, and South Africa just to mention a few. It has been reported as a nutritious plant that has health significance (Murevanhema & Jideani, 2015:1485). Its inherently gluten-free nature allows it to be studied, especially its flour as an alternative to wheat flour for gluten intolerant and coeliac sufferers, in baked products, specifically pastry. Thus, this study aimed to establish consumer acceptability and the quantitative descriptive profile of whole and dehulled BGN shortcrust and puff pastry pies.

5.2 Materials and methods

5.2.1 Production process of shortcrust and puff pastry pies for sensory evaluation

The shortcrust pastry pies were produced following this formulation, whole BGN flour mix (1000 g) and 1 g of salt (for taste) were mixed with 60% fat in a Kenwood MAJOR Titanium mixer for 5 min at medium speed. The 800 ml of water was added to create dough at medium speed for 5 min. The dough was rested for 30 minutes in the fridge. Whilst the dough was resting, mince was cooked in a stainless-steel pot. Onion clove, green pepper and two carrots were chopped and sautéed in 15 ml vegetable oil with 20 g of spices for 5 min and occasionally stirred with a big spoon. Mince was added and cooked for 10–15 minutes at medium heat, stirring occasionally until brown. Knorr instant soup was added to make the mince filling more viscous, stirred and brought to a boil. The heat was reduced, and the pot was allowed to simmer for 5 min. The pot was set aside to cool down. The dough was rolled top-to-bottom and sideways to ensure uniformity with a plastic rolling pin. Using a pastry cutter, the dough was cut and shaped. A scoop of 15 g of mince was filled into each shaped dough and closed using the pastry cutter. They were glazed with eggs, baked in a preheated oven at 180°C for 20 minutes, and cooled. Dehulled Bambara groundnut shortcrust and wheat shortcrust pies were also baked for comparison with the whole BGN shortcrust pies.

Puff pastry pies were also produced, whole BGN flour mix of 1000 g with different added fat of 100% and 1 g salt were added into the mixer (Kenwood MAJOR Titanium). Initially, only one-quarter of the fat was added to the mixer at medium speed for 5 minutes; then 800 ml of water was added and mixed for another 5 minutes to form a dough. The dough was rolled out in a rectangular shape on a floured surface, and another quarter of the fat was placed on one end of

the dough. The dough was folded into a book fold, half turned and rolled out into a rectangular book shape, another quarter of fat was added, and the same procedure was repeated until all fat was used. The dough was rested in the fridge for an hour; whilst the dough rested, minced meat was cooked. Thereafter, the dough was removed and rolled with a plastic rolling pin in a top-to-bottom and sideways style to ensure uniformity. The dough was cut into circles (14 cm in diameter) using a pastry cutter and shaped. Five of the cut pastries were filled with mince, closed using the cutter and set aside. The two other remaining were baked blind. Both were glazed with egg and put into the oven. The pies were baked in a preheated oven at 180°C for 18 minutes, removed and cooled for 30 min. Dehulled Bambara groundnut puff pastry pies and wheat puff pastry pies were also baked using the same method, for comparison with the whole BGN puff pastry pies.

All the pie samples were baked in the morning and evaluated in the afternoon and evening for consumer sensory and QDA samples were kept in the freezer and baked before evaluation in the evening.

5.2.2 Quantitative descriptive analysis of shortcrust and puff pastry pies.

The method for quantitative descriptive analysis was adapted from Ferreira et al. (2016:148), Puri et al. (2015:1239), and Leighton et al. (2010:3). The quantitative descriptive sensory analysis was done throughout four sessions. A group of 15 people was recruited, a questionnaire was used to test suitability to participate, and a basic taste test (Figure 5.1) was used to check the threshold sensitivity to the four basic tastes (sweet, salty, sour, and bitter). Solutions and respective dilutions of those solutions were made for the basic test, these are sucrose solution for sweet; salt solution for salty; citric acid for sour and caffeine for bitter, as observed in Table 5.1. From there a panel of 10 people were trained to evaluate pies, using basic commercial wheat-based shortcrust and puff pastry pies. They were trained for descriptive terms used to describe pies' appearance, taste, aroma, and texture.



Figure 5.1 Basic taste test.

Table 5.1 Basic taste test solutions and dilutions

Code	Taste	%Concentration	Volume*(ml/L)
A	Sour	0.02	20
B	Sweet	0.40	20
C	Sour	0.03	30
D	Bitter	0.02	40
E	Salty	0.08	8
F	Sweet	0.60	30
G	Bitter	0.03	60
H	Water		
J	Salty	0.15	15
K	Sour	0.04	40

*Volume of relevant stock solution (mL/L)

The descriptors for each were provided based on Ferreira et al. (2016:150), Puri et al. (2015:1240) Leighton et al. (2010:6,9), and they are detailed in Table 5.2. The attributes were quantified with intensity anchors based on the nature of the attribute; for instance, the crumb colour had an intensity scale from light to dark. The scale was a 15 cm line that was anchored. When the

panellists were familiar with the attributes, a mock analysis was done using commercial wheat pies. Each panellist was given an evaluation form with all the attributes and their intensity ratings.

The instructions as stated in the form were as follows: “You have received three samples of pies. Evaluate one sample at a time in terms of all the attributes. Taste samples from left to right. Please place a slash mark across the scale below according to judgement of the intensity of the specified attribute”. They were required to rinse their palates with water between the different tasting samples. The results from there were analysed.

Table 5.2 Attributes, descriptors, and their definitions for quantitative descriptive analysis of shortcrust and puff pastry pies.

Attributes	Descriptors	Definitions
1. Appearance	<i>Crust colour</i>	Intensity of crust colour. (Lighter or darker)
	<i>Crumb colour</i>	Intensity of crust (Light or dark brown).
	Size of cracks	Size of cracks on surface (small/big).
	Crust smoothness	Smoothness (visual appearance) on the surface (smooth to rough).
2. Aroma	Nutty	The aromatic characteristics associated with mixed nuts (weak/strong).
	Buttery	The sweet aromatic flavour impression of products produced from butter (Present /absent).
	Typical pie Aroma	The degree of intensity associated with a typical aroma of pastry sample (Intense or not intense).

3. Texture	Softness	Feeling perceived by compressing the pastry crumb (Soft/hard).
	Juiciness of crumb	Degree of perceived juiciness (Juicy/dry).
	Fat	Degree of residual oiliness left on the oral cavity after swallowing (Oily/not oily).
	Cohesiveness	The extent of which the chewed sample holds together (Crumbly/holding).
	Hardness	Force required to bite sample completely (Hard/soft).
4. Taste	Beany	A slightly brown, musty and slightly nutty starchy flavour associated with cooked dry beans (absent to present).
	Saltiness	The degree of perceived salt taste as a basic taste (Less salty/too salty).
	Buttery	Rich smell of melted butter (Weak/ strong).

5.2.3 Consumer sensory evaluation of shortcrust and puff pastry whole and dehulled Bambara groundnut pies.

The shortcrust and puff pastry pies (38 g each) were evaluated for consumer acceptability by a randomly selected untrained panel of (n = 47) staff and students at Cape Peninsula University of Technology, Bellville campus and from Brackenfell. The age of the individuals ranged from below 20 to above 40 years old with 27.7% male, 63.8% female and 8.5% unknown. Three types of shortcrust and puff pastry samples were randomly coded with three-digit numbers for anonymity, and evaluated using a 9-point hedonic scale, where 1 indicated extreme dislike and 9 indicated extreme like.

The panellists were given a consent form to sign, and an explanation was detailed to them about the samples they would evaluate. The samples were served simultaneously in clear sealable plastic sample bags coded with three-digit numbers in randomised, order as shown in Figure 5.2. They were requested to evaluate the samples' appearance, colour, texture, flakiness, taste, and overall acceptability using a 5-point hedonic scale, 1 = dislike extremely to 5 = like extremely. They could also provide notes or comments for each attribute where necessary. Water was provided to cleanse their palate between tasting the samples. The sensory evaluation was performed at the Food Science and Technology sensory laboratory (Cape Peninsula University of Technology, Bellville campus) in separate tasting booths (Oliveira et al., 2019:3; Stokes et al., 2017:334; Steingass et al., 2016:35).

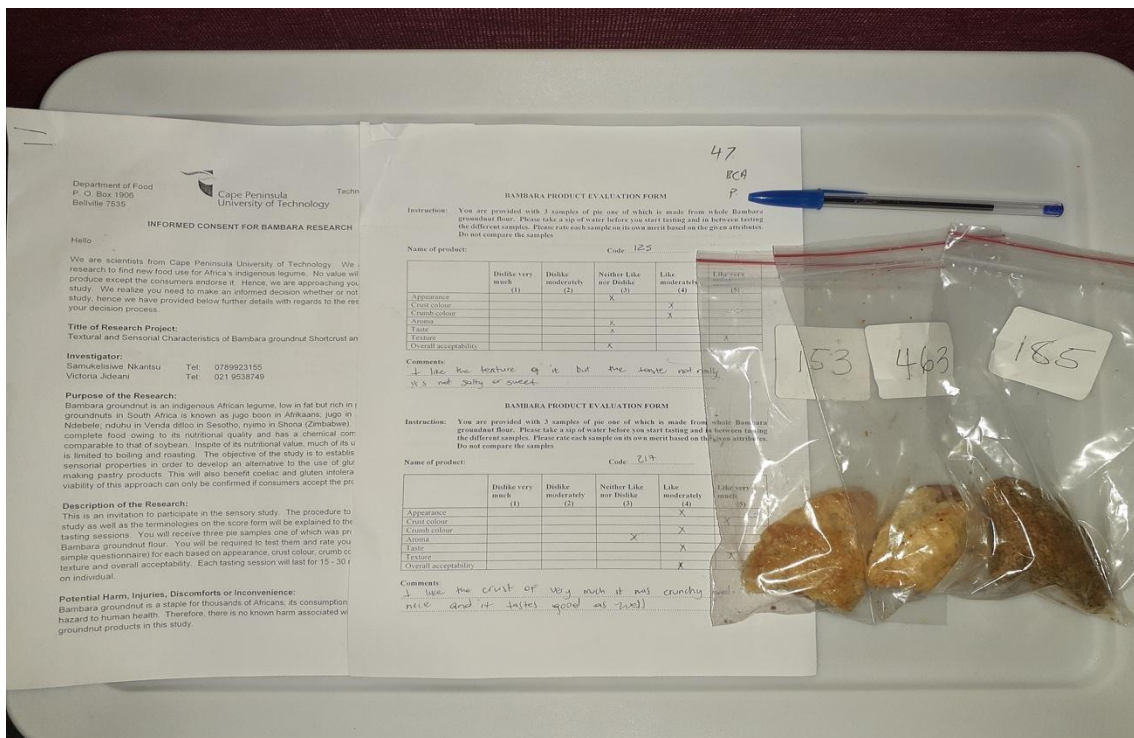


Figure 5.2 Consumer acceptability consent and evaluation form with randomised marked pies

5.3 Results and discussions

5.3.1 Quantitative descriptive profile of puff and shortcrust pastry pies.

The quantitative descriptive profile of the pies is displayed in Table 5.3, and it shows the differences in the descriptive sensory profile between the puff pastry pies. The categories and

their attributes were appearance (crust colour, crumb colour, crack sizes, crust smoothness), aroma (nutty, buttery, typical pie aroma), texture (softness, juiciness of crumb, fat, cohesiveness, hardness) and Taste (beany, saltiness, buttery). The crust colour for the whole BGN, dehulled BGN and the wheat puff pastry was 11.17, 8.04, and 6.49 respectively. There was a significant difference in the crust colour between the 3 pies ($p = 0.000$). Whole BGN puff pastry was described by the panel as having a darker crust colour than the lighter dehulled and wheat puff pastry pies. This may be due to using the entire seed of the whole Bambara groundnut and not dehulling it before use, eliminating the different colours obtained from the hulls which result in a darker colour. The phenolic compounds, for instance, tannins, had an effect on the outcome of the final products (pies) from Bambara groundnut flour (Harris et al., 2018:2; Murevanhema et al., 2012:90). Dehulling affected the colour which was evident with the different crust colour appearance between whole BGN and dehulled BGN pies. The crumb colour was 9.79, 7.01, and 5.60 for whole BGN, dehulled BGN, and wheat puff pastry, respectively. The pastry pies differed significantly ($p = 0.000$), with whole BGN puff pastry having darker intensities. The whole BGN crumb colour was interpreted by the panel to be closer to dark brown whilst the dehulled and wheat samples were more lighter.

This result showed a similar pattern to that of gluten-free breads that were studied by Matos & Rosell (2012:107; 111). There was a significant difference in crumb colour appearance. A similar observation could be seen for crumb colour, just like crust colour, which is due to the tannins found in the hulls of the Bambara groundnut. Whole BGN, dehulled BGN and wheat puff pastry pies had crack size values of 10.31, 8.35 and 4.34 respectively. The size of the cracks differed significantly from each other, with the whole BGN shortcrust pastry pie having the biggest crack size of all the pies. The difference in the crack size of the pies was not significant. Since BGN flour is gluten-free it is crucial to not overwork the dough as it is prone to breaking and that can result in the cracking of the final product which was the case. There were additives included in the BGN flour to mitigate the elasticity and pliability offered by gluten however the amount used affected the whole compared to the dehulled BGN flour mix due to hulls being present in the whole BGN puff pastry. Also puff pastry making for wheat usually requires cold temperatures to keep the fat or shortening as cold as possible, with gluten-free dough, the dough shouldn't be too cold as it can easily crack (Sauvage, 2010:3). The crust smoothness points for the pies were 10.07 for whole BGN, 9.10 for dehulled BGN, and 4.98 for wheat puff pastry. The whole BGN and dehulled BGN had a rougher crust than the wheat puff pastry pies.

Table 5.3 Quantitative descriptive sensory profiling of whole BGN, dehulled BGN and wheat puff pastry*

		Puff pastry pies		
Categories	Descriptors	Whole BGN	Dehulled BGN	Wheat
Appearance	Crust colour	11.17 ± 2.73 ^a	8.04 ± 3.03 ^b	6.49 ± 3.30 ^b
	Crumb colour	9.79 ± 3.62 ^a	7.01 ± 3.32 ^b	5.60 ± 3.31 ^b
	Crack size	10.31 ± 3.84 ^a	8.35 ± 3.66 ^a	4.34 ± 3.25 ^a
	Crust smoothness	10.07 ± 3.84 ^a	9.10 ± 2.91 ^{a, b}	4.98 ± 2.39 ^c
Aroma	Nutty	9.60 ± 4.81 ^a	7.67 ± 4.23 ^{a, b}	3.14 ± 3.50 ^c
	Buttery aroma	4.82 ± 3.95 ^{a, b}	5.90 ± 3.40 ^{a, b, c}	6.63 ± 4.49 ^b
	Pie aroma	4.11 ± 3.14 ^a	4.79 ± 3.55 ^a	8.63 ± 4.69 ^b
Texture	Softness	7.63 ± 3.72 ^a	7.99 ± 2.78 ^a	5.15 ± 2.82 ^b
	Juiciness	7.86 ± 3.59 ^{a, b}	6.75 ± 2.64 ^b	4.18 ± 2.29 ^c
	Fat	8.56 ± 4.18 ^{a, b}	8.11 ± 4.05 ^a	8.45 ± 3.98 ^a
	Cohesiveness	8.62 ± 4.27 ^a	6.75 ± 3.67 ^{a, b, c}	4.98 ± 4.24 ^c
	Hardness	7.35 ± 4.19 ^a	6.81 ± 3.54 ^a	3.24 ± 2.17 ^b
Taste	Beany	9.26 ± 4.65 ^a	8.75 ± 4.10 ^a	3.76 ± 3.34 ^b
	Saltiness	5.25 ± 2.91 ^a	5.12 ± 2.46 ^a	4.96 ± 2.06 ^a
	Buttery taste	6.87 ± 3.30 ^{a, b}	6.25 ± 3.37 ^a	8.75 ± 3.15 ^c
	Aftertaste	5.46 ± 4.49 ^a	5.60 ± 4.77 ^a	4.02 ± 4.27 ^a

*Results are mean ± standard deviation. Any mean values in the same row with the same letters are not significantly different ($P \leq 0.05$).

This could be because whole BGN flour has hulls included in the flour mix, which were not completely milled in the production process. There was a significant difference in the crust smoothness of the puff pastry pies ($p = 0.000$).

The nutty aroma for the puff pastry pies was 9.60 for whole BGN, 7.67 for dehulled, and 3.14 for wheat puff pastry. The panel perceived dehulled BGN and whole BGN puff pastry as

having a stronger nutty flavour and that can be attributed to the groundnut seed itself. Heat treatment (in the form of baking) is known to enhance the aroma of BGN (Murevanhema & Jideani, 2012:21). The nutty aroma differed significantly between the puff pastry pies ($p = 0.000$). Whole BGN, dehulled BGN puff, and wheat puff pastry had a buttery aroma of 4.82, 5.90, and 6.63. The pies had a significant difference ($p = 0.008$), with wheat puff pastry pies having a stronger presence of buttery aroma. The typical pie aroma of puff pastry pies was 4.11 for whole BGN, dehulled BGN was 4.79, and wheat 8.63. The wheat puff pastry pie had a stronger typical pie aroma, the gluten network could have been the contributing factor to this as it is known to retain fat which gives puff pastry pie its signature aroma (de Cindio et al., 2011:302). There was a significant difference in the puff pastry pies' perceived pie aroma ($p = 0.000$). The softness of the puff pastry pies was 7.63 for whole BGN, 7.99 for dehulled BGN and wheat puff pastry was 5.15. The softness of the shortcrust pie samples showed a significant difference from each other ($p = 0.000$), and the wheat puff pastry pies were softer than both BGN pies, the leavening effect of the fat was more for the wheat pies than it was for the BGN pies, thus the wheat pies were softer as the rise in the puff pastry flaky layers results in a soft texture. The Juiciness of the pies was 7.86, 6.75, and 4.18, for whole BGN, dehulled BGN, and wheat puff pastry, respectively. There was a significant difference in the juiciness of the different pies ($p = 0.000$). Whole BGN puff pastry was observed to be dry compared to dehulled BGN and wheat pies, fat seeped out of the structure of the pie during baking which resulted in a drier end product compared to the other pies. The perceived fat was 8.56 for whole BGN, 8.11 for dehulled BGN and 8.45 for wheat puff pastry. The panellists perceived only dehulled BGN puff pastry to be oilier compared to the other pies. There was no significant difference in the fat values of the puff pastry pies. In observing the dehulled BGN piecrust was drier and flatter which could then imply that the fat couldn't have an effective leavening effect on the pastry during baking. The cohesiveness was 8.62 for whole BGN, 6.75 for dehulled BGN, and 4.98 for wheat puff pastry. There was a significant difference in the cohesiveness of the puff pastry pies ($p = 0.013$). The BGN whole and dehulled BGN pies had a crumblier texture compared to that of the wheat pies which were seen to be more cohesive. Now, the additives used to assist the dough in being more pliable need to be studied further because it does not seem as though they assisted in achieving a more cohesive baked pie for both whole and dehulled BGN pies. Hardness for the pies was 7.35, 6.81, and 3.24, for whole BGN, dehulled BGN and wheat puff pastry pies respectively. Dehulled BGN and the whole BGN puff pastry were seen as hard compared to the wheat pies. There was a significant difference in the hardness of the pies ($p = 0.000$). Wahlgren (2015:4) reported a similar result with hardness for a study on bread. The nature of the BGN, whether whole or dehulled, results in a harder texture if the solid

ingredients used increase, then the texture will be drier than expected, which could have been the case in this instance (Charoenphun, 2019:25).

The beany taste was 9.26, 8.75, and 3.76, for whole BGN, dehulled BGN, and wheat puff pastry. There was a significant difference in the taste of puff pastry pies ($p = 0.000$). There was no beany taste in the wheat puff pastry pies, it was present for the BGN pies which was expected from the legume flours. The saltiness for the pies was 5.25 for whole BGN, 5.12 for dehulled BGN, and 4.96 for wheat puff pastry pies. There was no significant difference in the pies' saltiness; none of them were perceived to be too salty. The values for the buttery taste were as follows; whole BGN puff pastry was 6.87, dehulled BGN puff pastry was 6.25, and wheat puff pastry was 8.75. There was a significant difference in the intensity of the buttery taste in the pies ($p = 0.001$). Wheat puff pastry pies had a stronger intensity of the buttery taste than the BGN pies. The aftertaste presence or absence was 5.46 for whole BGN puff pastry, 5.60 for dehulled BGN puff pastry, and 4.02 for wheat puff pastry. There was no significant difference in the pies' presence or absence of aftertaste. The same was observed in work done by Matos and Rosell (2012:107), who also showed no significant difference in the aftertaste intensity observed on the gluten-free bread.

In summary, the whole BGN puff pastry pies were profiled as having a darker crust and crumb colour, due to the hulls being included as most of the colour pigment comes from the phenolic compounds found in the hulls (Harris et al., 2018:2). Whole BGN puff pastry pies had a big crack size mean value. Whole BGN and dehulled BGN puff pastry were less smooth and had a stronger nutty aroma (due to the groundnut seed). Wheat puff pastry pies had a strong buttery aroma, pie aroma and buttery taste compared to the other pies. Whole BGN puff pastry pies were perceived as dry. Dehulled BGN puff pastry pies were perceived as oily. All the BGN shortcrust pies were perceived as beany. None of the pies were profiled as too salty. There was no significant difference in the presence or absence of aftertaste in any of the pies.

The quantitative descriptive profile of shortcrust pastry pies is shown in Table 5.4, along with the differences of the pies. The categories were appearance (crust colour, crumb colour, crack sizes, crust smoothness), aroma (nutty, buttery, typical pie aroma), texture (softness, juiciness of crumb, fat, cohesiveness, hardness), and Taste (beany, saltiness, buttery) The crust colour for whole BGN dehulled BGN and the wheat shortcrust pastry was 11.09, 7.45 and 7.63 respectively. There was a significant difference in the crust colour for all 3 pies ($p = 0.000$).

Table 5.4 Quantitative descriptive sensory profiling of whole BGN, dehulled BGN and wheat shortcrust pastry*

Shortcrust pastry pies				
Categories	Descriptors	Whole BGN	Dehulled BGN	Wheat
Appearance	Crust colour	11.09 ± 3.44 ^a	7.45 ± 3.16 ^b	7.63 ± 3.71 ^b
	Crumb colour	9.59 ± 4.53 ^a	6.61 ± 3.48 ^b	6.24 ± 3.76 ^b
	Crack size	26.27 ± 106.00 ^a	5.21 ± 3.67 ^a	4.39 ± 3.87 ^a
	Crust smoothness	9.82 ± 3.87 ^a	7.38 ± 3.80 ^{b, c}	6.15 ± 3.89 ^{c, d}
Aroma	Nutty	7.71 ± 5.17 ^{a, b}	7.10 ± 4.70 ^b	4.23 ± 4.29 ^c
	Buttery aroma	4.34 ± 3.85 ^a	4.31 ± 3.27 ^a	7.51 ± 4.81 ^b
	Pie aroma	3.27 ± 2.57 ^a	3.67 ± 3.00 ^a	7.47 ± 4.67 ^b
Texture	Softness	10.35 ± 3.82 ^a	9.88 ± 3.50 ^b	9.01 ± 3.52 ^{b, c}
	Juiciness	9.27 ± 3.91 ^a	8.48 ± 3.69 ^{a, b}	6.91 ± 3.51 ^b
	Fat	10.50 ± 2.99 ^a	9.74 ± 3.72 ^{a, b}	9.37 ± 4.01 ^{a, b}
	Cohesiveness	7.60 ± 4.74 ^{a, b}	6.93 ± 4.31 ^{a, b, c}	5.59 ± 3.84 ^{b, c}
	Hardness	9.64 ± 3.22 ^a	8.22 ± 3.90 ^{a, b}	7.55 ± 3.27 ^b
Taste	Beany	10.03 ± 3.80 ^a	9.66 ± 3.96 ^a	3.73 ± 3.86 ^b
	Saltiness	4.84 ± 2.07 ^a	5.47 ± 2.44 ^a	4.63 ± 2.61 ^a
	Buttery taste	5.86 ± 3.23 ^a	6.18 ± 2.42 ^a	8.37 ± 3.19 ^{b, c}
	Aftertaste	4.32 ± 4.25 ^a	4.85 ± 5.12 ^a	3.59 ± 3.81 ^a

*Results are mean ± standard deviation. Any mean values in the same row with the same letters are not significantly different ($P \leq 0.05$).

Whole BGN shortcrust had a darker crust colour than the dehulled and wheat shortcrust, which were perceived as lighter, this is due to the phenolic compounds found in the Bambara seed hulls which were used in the flour mix for this study (Murevanhema et al., 2012:90). The whole seed was involved in the production process which affects the final product colour, unlike the Dehulled BGN where there are no seed coats or hulls included. Colour is also dependent on the pigment of the seeds as well as the tannin characteristics found in legumes, which determines what the final

product may be in appearance (David Wesley et al., 2021:30; Charoenphun, 2019:23) The crumb colour was 9.59, 6.61 and 6.24 whole BGN, dehulled BGN and wheat shortcrust pastry respectively. The pastry pies differed significantly ($p = 0.000$), with whole BGN pastry having darker intensities. This shows a similar pattern observed by Matos et al. (2012:111) in specifically crumb colour appearance of gluten-free breads that also differed significantly from each other, the presence of the tannins from the whole BGN seeds like crust colour contributed to the appearance of the crumb colour. The crack size for whole BGN, dehulled BGN and wheat shortcrust pastry pies were 26.27, 5.21 and 4.39. There was no significant difference in the crack size of the pies. The crack size measured for the whole BGN was an outlier as the line used for QDA was 15 cm. A large crack size could have occurred with the whole BGN because of the nature of the dough during the production process, however, 26.27 is a big outlier. The crust smoothness for the pies was 9.82 for whole BGN, 7.38 for dehulled BGN and 6.15 for wheat shortcrust pastry. The whole BGN pies had a rougher crust than the other pastry pies. The rough crust of the whole BGN is because of including hulls in the production process, especially with shortcrust the dough-making process is not as rigorous as other methods. There was a significant difference in the crust smoothness of the pies ($p = 0.000$).

The Nutty aroma for the shortcrust pastry pies is 7.71 for whole BGN, 7.10 for dehulled and 4.23 for wheat shortcrust pastry. The nutty aroma differed significantly between the shortcrust pies ($p = 0.000$). The whole BGN shortcrust pastry, according to the panel, had a stronger nutty flavour which is strongly related to the groundnut seeds' characteristics as a legume and its aroma is enhanced by baking and other heat treatments (Murevanhema et al., 2012:90). Whole BGN, dehulled BGN and the wheat shortcrust pastry had buttery aromas of 4.34, 4.31, and 7.51, respectively. The pies had a significant difference ($p = 0.008$) in the buttery aroma, with wheat pies having a stronger presence of buttery aroma. The type of fat used influences the buttery aroma in this case shortening. The typical pie aroma in the pies was, for whole BGN shortcrust pastry was 3.27, dehulled BGN shortcrust pastry was 3.67 and lastly wheat shortcrust pastry was 7.47. There was a significant difference in the shortcrust pastry pies' typical pie aroma ($p = 0.000$). The wheat pies had a stronger typical pie aroma than the BGN pies. The more potent aroma in the BGN pies was observed to be nuttiness or nutty, than the typical pie aroma, which is influenced by the baking of BGN pies which enhances the phenolic compounds such as flavonoids (Murevanhema et al., 2012:90; Harris et al., 2018:2). The softness of the pies was 10.35 for whole BGN, dehulled BGN was 9.88 and wheat shortcrust pastry was 9.01.

The softness of the pies was significantly different from each other ($p = 0.000$). All the shortcrust pastry pies were perceived to be harder with wheat being less hard than the other pies,

with shortcrust pastry only 60% of fat was used in ratio to the flour. During baking moisture from the fat evaporates and the crust and crumb softness depend on that. The juiciness of the pies was 9.27, 8.48, and 6.91 for whole BGN, dehulled BGN, and wheat shortcrust pastry respectively. Whole BGN shortcrust and dehulled BGN pastry were observed to be dry compared to the wheat pies. The amount of liquid and fat contributes to the final softness and tenderness of the pie, if a lot of water is used the result is a tough or hard crust (Bastin, 2010:1-2). There was a significant difference in the juiciness of the different shortcrust pastry pies ($p = 0.000$). Perceived fat was 10.50 for whole BGN 9.74 for dehulled BGN and 9.37 for wheat shortcrust pastry. Dehulled BGN and wheat were perceived to be oilier compared to whole BGN pies. There was no significant difference in the perceived fat of the pies. Cohesiveness was 7.60 for whole BGN shortcrust pastry, 6.93 for dehulled BGN shortcrust pastry and 5.59 for wheat shortcrust pastry. There was a significant difference in the cohesiveness of the shortcrust pastry pies ($p = 0.013$). The whole and dehulled BGN shortcrust pies had a crumbly texture compared to that of the wheat pies. Fat used affects the cohesiveness of shortcrust pastry, if the fat has a more oil-to-water ratio then it will produce a crumblier crust (Bastin, 2010). Also, if the product contains fibre like whole BGN, it will have challenges with preventing a crumbly end product. Hardness measures for the pies were 9.64, 8.22, and 7.55 for whole BGN, dehulled BGN, and wheat shortcrust pies respectively. Dehulled BGN and the whole BGN shortcrust were seen as hard compared to the softer wheat pies. There was a significant difference in the hardness of the pies ($p = 0.000$). Wahlgren (2015:54) had similar results with hardness for a study on bread. The hardness of the BGN pies could also result from an increase in protein and fibre found in legumes as noted by (Schmelter et al. (2021:2) in the study of producing gluten-free legume-based cookies.

The beany taste was 10.03, 9.66, and 3.73, for whole BGN, dehulled BGN wheat shortcrust pastry. There was no taste in the wheat shortcrust pies; it was present for the BGN pies due to the nature of the Bambara seed. There was a significant difference in the presence of the beany taste in the pies ($p = 0.000$). The potent taste is based on the enhancement that increases during the baking of the product (Murevanhema et al., 2012:90) The saltiness values for the shortcrust pies were 4.84 for whole BGN shortcrust, 5.47 for dehulled BGN shortcrust pastry and 4.63 for wheat shortcrust pastry pies. There was no significant difference in the saltiness of the pies. None of the shortcrust pastry pies were perceived to be too salty than the other. This is crucial as consumers have become health conscious and associate high salt content with obesity, hypertension and cardiovascular-related diseases (Silow, et al., 2018:1). The amount of salt used during the production of the pies was not a lot which assisted in the final products not being high in salt or too salty. The buttery taste of whole BGN was 5.86, dehulled BGN was 6.18 and wheat

shortcrust pastry was 8.37. There was a significant difference in the intensity of the buttery taste in the pies ($p = 0.001$). Wheat shortcrust pies had a strong intensity of the buttery taste. This was very much influenced by the shortening that was used in the production of the pies, which also influenced the mouthfeel of the pies after baking (Bastin, 2010:1). The aftertaste presence or absence was 4.32 for whole BGN, 4.85 for dehulled BGN and 3.59 for wheat shortcrust pastry. There was no significant difference in the shortcrust pies' presence or absence of aftertaste. The same was observed in work done by Matos et al. (2012:107), who also observed no significant difference in gluten-free bread. So, none of the products according to the panellist were perceived to have a lingering taste of the pies after consumption.

In summary, the whole BGN shortcrust pastry pies had a darker crust and crumb colour, primarily due to the presence of hulls, which significantly contributed to the overall darker brown colour. Whole BGN shortcrust pies had a larger crack size value. The overall texture of the whole BGN shortcrust was less smooth and emitted a more pronounced nutty aroma, attributed to the inclusion of BGN seeds. In contrast, wheat shortcrust pastry pies emitted a robust buttery aroma and a distinct pie aroma and buttery taste compared to other varieties. Wheat shortcrust pastry pies had a strong buttery aroma, pie aroma and buttery taste compared to the other pies. Both whole BGN shortcrust pastry pies and dehulled BGN shortcrust were perceived as dry. Whole and dehulled BGN shortcrust pastry pies were less cohesive (crumbly). Whole and dehulled BGN shortcrust pastry pies were profiled as hard. All BGN pies were recognized for their beany flavour, while none were found to be excessively salty. No significant difference was detected in the presence or absence of an aftertaste among any of the shortcrust pies.

5.3.2 Consumer sensory characteristics of whole BGN and dehulled shortcrust and puff pastry pies.

The demography of the untrained panellists who participated in the consumer sensory evaluation for shortcrust and puff pastry pies is indicated in Table 5.5. A total of 47 panellists participated in the consumer sensory evaluation of the pies. Of the panellists who participated, 69.8% of whom were females, 83.7% were African black, 16.3% were coloured, 41.9% were students, staff were 11.6%, 7.0% were international students and 39.5% were neither students nor staff. The age demographics for panellists who evaluated shortcrust pastry pies were 63% for panellists that were less than 29 years of age, 17.4% for panellists 40 years old and above, 6.5% for panellists that were unknown (or who did not indicate) and 13% for panellists that were within 30 – 39 years of age.

Table 5.5 Demography of panelists for consumer sensory evaluation of whole and dehulled Bambara groundnut shortcrust and puff pastry pies.

Item	Shortcrust pastry	Puff pastry
	Frequency (percentage)	Frequency (percentage)
Gender¹		
Male	13 (30.2)	13 (30.2)
Female	30 (69.8)	30 (69.8)
Race¹		
Black (African)	36 (83.7)	36 (83.7)
Coloured	7 (16.3)	7 (16.3)
Status¹		
Staff	5 (11.6)	5 (11.6)
Student	18 (41.9)	18 (41.9)
International student	3 (7)	3 (7)
Neither student or staff	17 (39.5)	17 (39.5)
Age^{1,2}		
0	3 (6.5)	0
< 29 years	29 (63.0)	29 (67.4)
30 – 39	6 (13.0)	6 (14.0)
> 40 and above	8 (17.4)	8 (18.6)

¹ 4 panelists did not respond to these demographic details

² 1 panellist did not respond for the age demographic.

The age demographics for panelists who evaluated puff pastry pies were 67.4% for panelists less than 29 years old, 14.0% for panellists between 30 – 39 years old, and 18.6% for panelists that were 40 years old and above.

The multivariate analysis of variance (MANOVA) conducted for shortcrust and puff pastry pies revealed significant variations amongst panellists in their ratings of appearance, crust colour, crumb colour, aroma, taste, texture and overall acceptability. These were rated ranging from dislike very much (1), to like very much (5). The panellists who participated in the sensory

evaluation process were from diverse backgrounds, demographics and cultures, hence their ratings were statistically different from each other (Murevanhema et al. 2012:83).

The shortcrust pastry pies' ratings (as observed in Table 5.6) for appearance were 3.55 for the whole BGN, 4.11 for dehulled BGN and 4.36 for wheat pies. The observed significant difference ($p = 0.001$) in the appearance of the shortcrust pastry pies can be attributed to the variations in the types of flour. Dehulled BGN and wheat pies had a higher rating than the whole BGN shortcrust pies. The crust colour ratings were 3.49, 4.11, and 4.45 for whole BGN, dehulled BGN and wheat pastry pies respectively. The crust colour differed significantly ($p = 0.000$), with wheat and dehulled BGN pies being favoured more by the panellists. The crumb colour ratings were significantly different ($p = 0.001$). The trend continued with crumb colour, where dehulled BGN and wheat pies received higher mean ratings than whole BGN pies. For aroma, the mean ratings were 3.38, 3.68, and 4.15 for whole BGN, dehulled, and wheat pies, respectively. The wheat pies were more favourable for aroma than the BGN pies. There is a significant difference between the pies ($p = 0.003$). For taste, whole BGN was 2.98, dehulled BGN was 3.06 and wheat pies were 4.09. They differed significantly in taste ($p = 0.000$), with the BGN pies being more on the neither like nor dislike range and wheat being moderately liked. The texture ratings were 3.17, 3.45, and 4.11 for whole BGN, dehulled BGN and wheat pies respectively. The texture was higher for wheat pies, and it differed significantly from the BGN pies ($p = 0.001$). The overall acceptability was 3.28 for whole BGN, 3.43 for dehulled BGN and 4.00 for wheat pies. The pies were significantly different ($p = 0.008$), with wheat pies surpassing BGN pies in preference.

Table 5.6 Consumer sensory characteristics for shortcrust pastry pies.^{1,2}

Shortcrust pastry pies			
Pastry Attributes	Whole BGN	Dehulled BGN	Wheat
Appearance	3.55 ± 1.21^a	4.11 ± 1.13^b	4.36 ± 0.85^b
Crust colour	3.49 ± 1.18^a	4.11 ± 1.03^b	4.45 ± 0.78^b
Crumb colour	3.43 ± 1.08^a	3.91 ± 1.06^b	4.26 ± 0.90^b
Aroma	3.38 ± 1.13^a	3.68 ± 1.14^a	4.15 ± 0.88^b
Taste	2.98 ± 1.33^a	3.06 ± 1.36^a	4.09 ± 0.95^b
Texture	3.17 ± 1.34^a	3.45 ± 1.23^a	4.11 ± 0.96^b
Overall acceptability	3.28 ± 1.23^a	3.43 ± 1.18^a	4.00 ± 1.08^b

¹ BGN – Bambara groundnut. ² Values are mean \pm standard deviation. Values with different superscripts in each row are significantly different from each other.

The consumer perception or acceptability of the whole BGN, dehulled BGN and wheat shortcrust pastry pies based on the attributes of appearance, crust colour, crumb colour, aroma, taste and overall acceptability were significantly different (with p-values ranging from 0.000 to 0.008). For appearance, crust colour and crumb colour the consumers seemed to favour dehulled BGN pies and wheat pies more than whole BGN pies. The Aroma of wheat pies was preferred more than the aroma of BGN pies, with taste though wheat pies were moderately liked while the perception of the BGN pies was neutral. The texture of the wheat pies is significantly higher than the whole and dehulled BGN pies, and the overall acceptability was rated higher for the wheat pies as well. The difference in the findings was due to the variations in the flour types used for making these pies as this impacts the final product and how consumers eventually perceive the final product. Notable differences were observed in crust colour, crumb colour, aroma, taste and texture with wheat pies outperforming BGN pies. The overall acceptability which also favoured wheat pies, signified a preference for them over the BGN alternatives. The reason consumers prefer wheat pies over whole and dehulled BGN pies could be familiarity with the taste. Since wheat is a common and widely used ingredient, consumers may also be accustomed to the wheat pies' taste, texture, and aroma. Cultural and dietary habits could also influence their choice as wheat-based products are a staple in many cultures as they are widely available and accessible compared to gluten-free alternatives. These findings are consistent with what has been reported on the sensory properties of other products made from Bambara groundnut flour in literature (Atoyebi et al., 2017:820; Abdualrahman et al., 2012:845).

The comments made by the panelists for whole BGN, dehulled BGN and wheat shortcrust pastry pies are displayed in Table 5.7. The consumers leaned more towards negative and neutral sentiments for whole BGN pies. While there were positive comments about the taste and texture of the whole BGN pies, there were also some negative comments about the aftertaste, dryness, and the need for texture improvement. Additionally, several neutral comments did not express a positive or negative sentiment. Thus, the overall sentiment of all BGN pies is mixed with a slight leaning towards negative and neutral sentiments.

Consumers had mixed opinions about dehulled BGN shortcrust pastry pies. This included the taste, texture, and aftertaste of the dehulled BGN pies. Some consumers appreciated the taste, texture, and appearance of the pies while other consumers found the taste and aftertaste less appealing.

Table 5.7 Consumer sensory panelist's comments for shortcrust pastry pies¹

Shortcrust pastry comments		
Whole BGN	Dehulled BGN	Wheat
Texture like a cookie	The taste was not good	More like a bread than pie
It was not good for me	I don't do carrots, so I don't recommend	This is actually nice, I love it
You should change more on the appearance and the colour as well as crumb colour	It looks nice as you taste	It is tasty I like it very much
It is a bit dry for a pie	Improve the texture	Has a buttery taste
It is very delicious	Tasty and great texture	Good
do not like the aftertaste	Crumbly and slightly bitter	A very good product
Need to improve texture	Okay	Good
Ok	The product tastes very good and I am really enjoyed it	I did not enjoy 194
Good	Crumb - gluten structure/bread, taste - Bitter aftertaste	I like the colour and the texture, but the taste was not good enough
Dry	I could not taste the filling inside	Tastes nice, I would eat it anytime, the texture is amazing, it just passes through my mouth sweetly
A good taste product, I have enjoyed it	Not so tasty as everything else	Very good
Enjoyed the second one, tasty	Liked the taste and it has good appearance	Very nice 10 out of 10
No real aroma	The vegetable flavour gives an aftertaste, but it is okay	Very nice
Good colour and the texture were so attractive, but I did not enjoy it also	Taste good	It appears too white like it's not fully cooked. The texture is more of biscuit not of a pie.

Taste good	Has a bitter taste, the crumb is nice	Good it's close to the normal pies. I do not like that it taste oil/fat
Has a very bitter unpleasant taste. The appearance is not inviting	I don't really prefer this one, it taste like burned maize otherwise it looks good	This was very nice
I love this one, the taste and the smell	It has a nice taste at first, however it leaves an unpleasant aftertaste	
I like the peanut butter taste in this one	Interesting food	
It is an acquired taste	Do not like the aftertaste	
Contradictions	It has an aftertaste, that I would not like to have. Very interesting though	
Too crispy	Not used to but it has nice texture. Taste can be improved	
It will take a lot of getting used to. The crust is very hard though.	I don't like the taste	
Taste like a biscuit		

¹ Bambara groundnut.

The overall sentiment based on the comments is that the composition of the pies could be improved. The sentiment for wheat shortcrust pastry pies was mixed as well. Some consumers expressed positive comments and sentiments to the pies, others expressed negative sentiments. Overall, the sentiment ranges from positive to negative feedback which reflected a diverse range of opinions about the wheat pies. Some comments expressed positive sentiments highlighting the taste and texture, while negative comments mentioned dissatisfaction with the taste. The mixed sentiment in the comments suggests that the perception of wheat pies is subjective and varies among individuals. The overall sentiment of wheat shortcrust pastry pies is mostly positive, with some neutral and a few negative comments.

The puff pastry pies' ratings for the different attributes are recorded in Table 5.8. There was a significant ($p = 0.000$) difference in the pie in appearance, with wheat and dehulled BGN puff pastry being moderately rated than whole BGN puff pastry pie. The dehulled and wheat puff pastry pie were rated significantly higher in crust colour, unlike the whole BGN puff pastry pie. There was a significant ($p = 0.000$) in crumb colour between the pies. The dehulled BGN puff pastry and wheat puff pastry were both more desirable to the panellists than the whole BGN puff pastry. The two BGN shortcrust pie samples were neither liked nor disliked; wheat had a higher rating of moderately liked, and their difference was significant ($p = 0.004$).

Table 5.8 Consumer sensory parameters for puff pastry pies. ^{1,2}

Pastry Attributes	Puff pastry pies		
	Whole BGN	Dehulled BGN	Wheat
Appearance	3.09 ± 1.37 ^a	3.98 ± 0.98 ^b	4.38 ± 0.97 ^b
Crust colour	3.00 ± 1.35 ^a	4.13 ± 0.81 ^b	4.30 ± 0.88 ^b
Crumb colour	3.02 ± 1.31 ^a	3.87 ± 0.88 ^b	4.06 ± 0.87 ^b
Aroma	3.40 ± 1.28 ^a	3.46 ± 1.17 ^a	4.11 ± 0.89 ^b
Taste	3.06 ± 1.33 ^a	3.07 ± 1.37 ^a	4.02 ± 1.07 ^b
Texture	3.06 ± 1.29 ^a	3.33 ± 1.19 ^a	4.11 ± 1.05 ^b
Overall acceptability	3.15 ± 1.23 ^a	3.37 ± 1.06 ^a	4.19 ± 0.88 ^b

¹ BGN – Bambara groundnut. ² Values are mean ± standard deviation.

Values with different superscripts in each row are significantly different from each other.

The mean ratings for taste were 3.06 for the whole BGN puff pastry pie samples, 3.07 for dehulled BGN puff pastry pie samples and 4.11 for wheat puff pastry pie samples. These were significantly ($p = 0.000$), different from each other and wheat had a more desirable taste rating than the Bambara groundnut puff pastry pies. The mean rating for texture was 3.06, 3.33, and 4.11 for whole BGN, dehulled BGN and wheat puff pastry respectively. The ratings of whole BGN and dehulled BGN puff pastry pies ranged in the neither like nor dislike rating and they were significantly ($p = 0.000$) different from the wheat puff pastry pie samples. The overall acceptability mean ratings were 3.15, 3.37 and 4.19 for whole BGN, dehulled BGN and wheat puff pastry pies. The panellists seemed to neither like nor dislike whole BGN puff pastry pies, they rated wheat

moderately liked. These were all significantly different to each other ($p = 0.000$), and wheat is what the consumers are used to as wheat puff pastry pies are very common in South Africa.

The consumers rated puff pastry pies for wheat significantly higher in appearance, crust colour, taste, texture and overall acceptability than the BGN puff pastry pies. A similar trend was observed in a puff pastry study by Silow et al. (2018:9-10) whereby the control puff pastry (wheat flour without sourdough) was given a higher score than the other samples for appearance, which is the case for this study as well. The dehulled BGN pie was rated higher in appearance, crust colour, and crumb colour. The ratings showed significant differences for each attribute between the three types of pies. The significant differences in ratings between whole BGN, dehulled BGN and wheat puff pastry pies indicate that the panellists were able to distinguish the differences in appearance, crust colour, taste, texture, and overall acceptability. The consumers appeared to be more accustomed to wheat puff pastry pies as they are widely accessible, as wheat is a staple in many regions, hence the favourable ratings (Silow et al., 2018:9; Silow et al., 2016:336). Overall, the evaluation suggests that both dehulled and wheat pies surpassed whole BGN pies in various attributes with wheat puff pastry being particularly favoured.

Table 5.9 Consumer sensory panelist's comments on puff pastry pies.

Comments		
Whole BGN¹	Dehulled BGN¹	Wheat
It looks like a fried meat product, caught some rancid notes, I like the appearance but not the pie. Sample disintegrates	The taste for me was not good	Tastes oily
I didn't enjoy this one at all	I don't like it	The taste and texture were good for me
I like it	Tasty I like it.	It is very delicious you cannot even feel that is made up with beans.
It is a moderate taste; it is nice, but it tastes like mince, but I am not a fan of mince.	It is hard to chew the product	I think you need a little bit of salt and also improve the texture, but it tastes good

Slightly bland, crust was too soft was more ideal for short bread sweets	It has zero taste with a slight bitterness	Smooth and dough like
The product taste good, but you need to improve the texture of the product	okay, aroma can be improved	okay
Grainy	Enjoyed how the dough isn't too crumbly or spongy	The product tastes very good
The texture is very crumbly texture is hard, taste is good	The product tastes good	No flaking. Doughy layers
	549 has an aftertaste that I did not like	I wish the portion was bigger, I enjoyed 144
the product tastes very good and I enjoyed it	Also crumbles in your hand	Can need some more flavour taste
Appearance would work more on biscuits	I do not think I like the appearance, but the taste was good.	Good colour and very good taste
Did not enjoy this one	Too bad	This for me was the best
Nice but falls apart or crumbles in your hand	The taste is not nice, appearance is inviting	The pie tastes nice, it's not really what I would go for, the taste does not really make me feel amazing, but I would eat it.
I did enjoy this one, but the colour was not attractive	I can't seem to allocate the taste doesn't taste nice but not bad either.	Taste good
I am much more into food that have too much flavour, in my opinion code 518 is not for me the texture is amazing though	Bad aftertaste and very doughy	It was burnt and the texture is all messy
Not good for me	There is an aftertaste, but I do not like nor dislike it.	It tastes divine, I love the crust and meatiness
The texture is not nice, appearance is not inviting	acquired taste	It could use more flavour

I like this one its tastes nice and scrumptious	Appear to be little raw	Lovely but could be better
The appearance is not very appealing. Big no for texture		Texture looks a bit raw
The pastry feels wet, but I like it		Perfect. Everything is good.
strange food		Wow.
I like the crust of very much it was crunchy and nice, and it tastes good as well		The inner part tasted damp
I like the texture of it but the taste not really, it's not salty or sweet		
Very nice I like everything about it.		
The inner part (crumb) is nicer than the outside (crust)		

¹Bambara groundnut

Comments made by the panelists for the puff pastry pies are shown in Table 5.9. Based on the comments made by the consumer panelists for whole BGN puff pastry pies, the sentiments towards the pies were positive, negative, and mixed sentiments. Some in the panel enjoyed the taste and texture of the pies, some did not enjoy the pies at all and some had both positive and negative sentiments about the pies, liking certain aspects while disliking others. Overall the sentiment was mixed with both positive and negative opinions expressed. The sentiment expressed towards dehulled BGN puff pastry pies is predominantly negative. Some of the consumers expressed dissatisfaction with the taste, texture, and appearance of the pies. However, there are a few positive comments as well. Overall the comments indicated a mixed sentiment, with the negative comments outweighing the positive ones.

Based on the comments expressed, the sentiment towards the wheat shortcrust pastry pies is mixed. Some consumers expressed. However, there were also negative comments expressed by the consumers. Also, there was a neutral sentiment with consumers giving feedback

on the size, flavour and texture of the pies. Overall the sentiment towards the wheat pies is not overwhelmingly positive or negative, but rather mixed, positive, negative and neutral.

5.4 Conclusion

Whole BGN puff and shortcrust pastry pies had a darker crust and crumb colour. Whole BGN puff pastry pies had a big crack size mean value, but whole the BGN shortcrust pies had a bigger crack size mean value. Whole BGN shortcrust and puff pastry and dehulled BGN puff pastry were rough, and they had a stronger nutty aroma. Wheat shortcrust and puff pastry pies had a strong buttery aroma, pie aroma and buttery taste. The shortcrust pies were perceived as hard. Whole BGN shortcrust and puff pastry pies and dehulled BGN shortcrust were profiled as dry. Dehulled BGN puff pastry pies were profiled as oily. Whole and dehulled BGN shortcrust pastry pies were crumbly. Whole and dehulled BGN shortcrust pastry pies were profiled as hard. All the BGN samples were perceived as beany. None of the samples were profiled as too salty. There was a distinct perception of the presence or absence of an aftertaste in any of the pie samples.

Consumer sensory was conducted with an untrained panel with different demographics. Whole BGN shortcrust pies had an average rating for appearance, crust colour and crumb colour compared to dehulled BGN and wheat shortcrust pie samples which were rated higher. Aroma, taste, texture and overall acceptability for wheat pie samples were moderately desirable than the whole BGN shortcrust pie samples which were neither liked nor disliked. Whole BGN shortcrust pastry pies did not gain preference with most of the panel.

Similar to the shortcrust pastry pie samples, the appearance, crust colour and crumb colour ratings for whole BGN were rated lower than dehulled BGN and wheat puff pastry pies, which were desirable to the panellists. The aroma, taste, texture and overall acceptability showed the panellists neither liked nor disliked whole BGN as well as dehulled BGN puff pastry samples and they preferred the wheat puff pastry pies. This shows that the panellists would favour or prefer what they are accustomed to rather than something novel and different to what they are accustomed to. Improvements can be made to enhance the texture of the pies, addressing issues such as crumbliness and crust cracking. As a follow-up to this study, it is advisable to perform a sensory assessment involving individuals who follow a gluten-free diet to gain insights into their perception of the whole and dehulled BGN dough.

5.5 References

Abdualrahman, M.A.Y., Ah, A.O., Elkhalifa, E.A. & Sulieman, A.E. 2012. Effect of Bambara groundnut flour (*Vigna subterranea (L.) Verdc.*) supplementation on chemical, physical,

- nutritional and sensory evaluation of wheat bread. *Pakistan Journal of Biological Sciences*, 15(17): 845–849.
- Atoyebi, J.O., Osilesi, O. & Adebawo, O. 2017. *Sensory Evaluation of Bambara Groundnut (Vigna subterranea (L.) Verdc.) Food Products in Ibadan, Nigeria*. <https://www.researchgate.net/publication/318672438>.
- Baardseth, P., Naes, T. & Vogt, G. 1995b. Roll-in Shortenings Effects on Danish Pastries Sensory Properties Studied by Principal Component Analysis. *Lebensmittel-Wissenschaft & Technologie*, 28(1): 72–77.
- Bastin, S. 2010. Pies and Cobblers. College of Agriculture, University of Kentucky. https://fcs-hes.ca.uky.edu/sites/fcs-hes.ca.uky.edu/files/2ssc_pies_cbblpub.pdf [02 December 2023].
- Callejo, M.J. 2011. Present situation on the descriptive sensory analysis of bread. *Journal of Sensory Studies*, 26(4): 255–268.
- Campo, E., Del Arco, L., Urtasun, L., Oria, R. & Ferrer-Mairal, A. 2016. Impact of sourdough on sensory properties and consumers' preference of gluten-free breads enriched with teff flour. *Journal of Cereal Science*, 67, 75–82. <https://doi.org/10.1016/j.jcs.2015.09.010>.
- Charoenphun, N. 2019. Utilization of pineapple residue for pineapple paste and gluten-free pie. *Journal of Food Health and Bioenvironmental Science*, 12(2): 20–28.
- Choi, S.E. 2013. Sensory evaluation. In S. Edelstein, ed. *Food Science an Ecological Approach*. New York: Jones and Bartlett Learning, LLC: 84–1111.
- de Cindio, B. & Lupi, F.R. 2011. 15 – Saturated fat reduction in pastry. In *Reducing Saturated Fats in Foods*. 301–317. <http://dx.doi.org/10.1016/B978-1-84569-740-2.50015-4>.
- Connelly, A. 2014. The science and magic of pastry. <https://www.theguardian.com/science/2014/feb/20/recipe-fat-flour-water-science-pastry> [06 August 2024].
- Drake, M.A. 2009. Modern sensory practices. Clark, S, Drake, M., Kaylegian, K. (eds.). *The Sensory Evaluation of Dairy Products*. Springer, Cham, US. 505–530. http://dx.doi.org/10.1007/978-0-387-77408-4_17.
- Fiorentini, M., Kinchla, A. J., & Nolden, A. A. 2020. Role of Sensory Evaluation in Consumer Acceptance of Plant-Based Meat Analogs and Meat Extenders: A Scoping review. *Foods*, 9(9), 1334. <https://doi.org/10.3390/foods9091334>
- Fogliatto, F.S., Albin, S.L. & dos Santos Silva, A.M. 2003. *A Method for Sensory Data Collection and Analysis in Product Development*. Porto Alegre. https://abepro.org.br/biblioteca/enegep2000_e0008.pdf

- Harris, T., Jideani, V. & Le Roes-Hill, M. 2018. Flavonoids and tannin composition of Bambara groundnut (*Vigna subterranea*) of Mpumalanga, South Africa. *Heliyon*, 4: 833. <https://doi.org/10.1016/j.heliyon.2018.e00833>.
- Komolka, P., Górecka, D., Szymandera-Buszka, K., Jędrusek-Golińska, A., Dziedzic, K. & Waszkowiak, K. 2016. Sensory qualities of pastry products enriched with dietary fibre and polyphenolic substances. *Acta Scientiarum Polonorum, Technologia Alimentaria*, 15(2): 161–170.
- Kusinska, E., Starek, A. 2012 Effect of fat content on the mechanical properties of texture of gingerbread pastry. *Teka Commission of Motorization and Energetics in Agriculture*, 12 (1): 121-125. <https://bibliotekanauki.pl/articles/792148.pdf>
- Leighton, C.S., Schönfeldt, H.C. & Kruger, R. 2010. Quantitative descriptive sensory analysis of five different cultivars of sweet potato to determine sensory and textural profiles. *Journal of Sensory Studies*, 25(25): 2–18.
- Matos, María Estela & Rosell, C.M. 2012. Relationship between instrumental parameters and sensory characteristics in gluten-free breads. *European Food Research and Technology*, 235(1): 107–117.
- Murevanhema, Y.Y. 2012. *Evaluation of Bambara groundnuts (Vigna subterranea (L .) Verdc .) milk fermented with lactic acid bacteria as a probiotic beverage. Unpublished Master of Technology thesis.* Cape Peninsula University of Technology, Bellville. https://etd.cput.ac.za/bitstream/20.500.11838/825/1/207226121_Murevanhema_YY_2012.pdf. [01 August 2023].
- Murevanhema, Y.Y. & Jideani, V.A. 2015a. Production and Characterization of Milk Produced from Bambara Groundnut (*Vigna subterranea*) Varieties. *Journal of Food Processing and Preservation*, 39(6): 1485–1498.
- Patient, D. 1994, The Chemistry of Pastry Products, *Nutrition & Food Science*, 94 (4):. 33-35. <https://doi.org/10.1108/00346659310060223>
- Puri, R., Khamrui, K., Khetra, Y., Malhotra, R. & Devraja, H.C. 2015. Quantitative descriptive analysis and principal component analysis for sensory characterization of Indian milk product cham-cham. *Journal of Food Science and Technology*, 53(2): 1238–1246.
- Rodrigues Ferreira, S.M., De Mello, A.P., De Caldas Rosa dos Anjos, M., Carneiro Hecke Krüger, C., Azoubel, P.M. & De Oliveira Alves, M.A. 2016. Utilization of sorghum, rice, corn flours with potato starch for the preparation of gluten-free pasta. *Food Chemistry*, 191: 147–151.
- Ruiz-Cano, D., López-Jiménez, J.Á., Frutos, M.J., Zamora, S. & Pérez-Llamas, F. 2016. Improvement of the healthy properties of a Spanish artisan meat pie maintaining the organoleptic quality. *LWT*, 65: 624–629.
- Sauvage, J. 2010. Puff Pastry, Gluten-Free. *Art of Gluten-Free Baking*: 1–35.

- Schmelter, L., Rohm, H. & Struck, S. 2021. Gluten-free bakery products: Cookies made from different Vicia faba bean varieties. *Future Foods*, 4: 1–23.
- Silow, C. 2018. *Fundamental studies on the reduction of fat and salt in laminated doughs*. Thesis. Cork: University College Cork. <http://hdl.handle.net/10468/7302>.
- Silow, C., Axel, C., Zannini, E. & Arendt, Elke K. 2018. Application of sourdough in the production of fat- and salt-reduced puff pastry. *European Food Research and Technology*, 244(9): 1581–1593.
- da Silva, P.P.M., Casemiro, R.C., Zillo, R.R., Camargo, A.C., Prospero, E.T.P. & Spoto, M.H.F. 2014. Sensory descriptive quantitative analysis of unpasteurized and pasteurized juçara pulp (*Euterpe edulis*) during long-term storage. *Food Science & Nutrition*, 2(4): 321–331.
- Simovic, D.S., Pajin, B., Seres, Z. & Filipovic, N. 2009. Effect of low-trans margarine on physicochemical and sensory properties of puff pastry. *International Journal of Food Science and Technology*, 44(6): 1235–1244.
- Steingass, C.B., Dell, C., Lieb, V., Mayer-Ullmann, B., Czerny, M. & Carle, R. 2016. Assignment of distinctive volatiles, descriptive sensory analysis and consumer preference of differently ripened and post-harvest handled pineapple (*Ananas comosus* [L.] Merr.) fruits. *European Food Research and Technology*, 242(1): 33–43.
- Stokes, C.N., O’ Sullivan, M.G. & Kerry, J.P. 2017. Hedonic and descriptive sensory evaluation of instant and fresh coffee products. *Eur Food Res Technol*, 243: 331–340.
- Verbon, A., 2017. The Science of Shortcrust Pastry (+ Basic Pie Crust Recipe) , <https://foodcrumbles.com/making-pies-with-short-crust-pastry/> [05 August 2024]
- Wahlgren, M.B. 2015. Oral processing and satiety perception of bread Understanding the role of texture and oral processing in consumers’ perception of satiety. Norwegian University of Life Sciences <http://hdl.handle.net/11250/294305> [02 June 2023].
- Wesley, S. D., André, B. H. M., & Clerici, M. T. P. S. 2021. Gluten-free rice & bean biscuit: characterization of a new food product. *Heliyon*, 7(1), e05956. <https://doi.org/10.1016/j.heliyon.2021.e05956>

CHAPTER SIX

GENERAL SUMMARY, CONCLUSION AND RECOMMENDATIONS

The textural and sensorial properties of Bambara groundnut (BGN) short crust and puff pastry products were investigated in this study. The following objectives were to be achieved in this study:

1. Characterise the texture of the whole BGN dough.
2. The texture of shortcrust and puff pastry products produced from whole and dehulled BGN dough will develop.
3. Quantitative descriptive sensory profiling of whole BGN dough pastry products compared to that of wheat dough pastry products.
4. Using X-ray tomography, establish the structure and cell size distribution of whole and dehulled BGN dough and wheat dough.

The first objective was achieved by determining the effect of CMC and modified starch on the pasting and texture profile of whole BGN dough. This was done using an augmented 2^2 factorial design, each point was in triplicate and there were 3 centre points which resulted in 15 runs being carried out. The data was subjected to a numerical optimisation using Design Expert 10, to establish the optimum flour mix. The optimal mix was obtained by mixing the BGN flour with 1% CMC and 5% modified starch, useful in the making of a gluten-free pastry product. It is worth noting that CMC had a more statistically significant role in the optimal mix than modified starch. Thus, the first objective was achieved as the optimal flour mix provided texture to whole BGN dough which was used further in developing gluten-free pastry products. The hypothesis that the texture of whole and dehulled BGN would be pliable like wheat dough was accepted.

The process of achieving the second objective included analysing the textural properties of whole and dehulled BGN shortcrust and puff pastry products. To explore this, the effect of different fat contents on the texture, firmness and cutting properties was investigated. Shortcrust pastry was analysed using three fat contents, 60, 70 and 80%. The results showed that higher fat content in the pie crust increased crumbliness which resulted in easier breakage. Thus, shortcrust pastry products made with 60% fat content had more desirable attributes including firmness and structural integrity. The puff pastry was studied using three distinct fat contents, 80, 100 and 120%. The study determined that 100% fat content resulted in an optimal layering and pastry lift that increased in volume and produced distinct layers which are important in puff pastry production. Also, 100% fat content had a significant influence on the firmness of the pastry compared to the 80 and 120%. The hypothesis that short crust and puff pastry products made from dehulled and whole BGN dough will develop texture was accepted. More work can be done to improve the

texture and possibly merge mechanical textural analysis with sensory evaluation to study the effects in more detail.

The third objective was achieved by quantitative descriptive analysis (QDA) and consumer sensory evaluation. A trained panel of 10 panelists assessed whole BGN, dehulled BGN and wheat shortcrust and puff pastry on various QDA attributes: appearance, aroma, texture and taste. Whole BGN shortcrust and puff pastry pies were perceived with characteristics like larger crack size in appearance, rough texture, and a stronger nutty aroma compared to wheat-based pies. Dehulled BGN puff pastry pies were perceived as oily, while whole and dehulled BGN shortcrust pastry pies were characterised as dry and crumbly. All BGN pie samples were noted for their beany taste, and none were perceived as too salty. There was no distinct perception of the presence or absence of an aftertaste in either shortcrust or puff pastry pies. Consumer sensory evaluation was conducted for 47 untrained panellists, they evaluated appearance, aroma, taste, texture and overall acceptability. The rating scale used was 1-5, with 1 being dislike extremely and 5 being like extremely. There was a more positive sentiment towards wheat shortcrust and puff pastry compared to whole BGN pies which was mostly negative and neutral with a few positive sentiments and dehulled BGN pies had more neutral, negative and positive sentiments towards it. Most of the consumer sensory panel rated and commented mostly based on what they were accustomed to. Thus, the hypothesis that the whole and dehulled BGN pastry products will be acceptable to the quantitative descriptive analysis panel and profiling data will display adequate comparison results of wheat dough and whole and dehulled BGN dough pastry products, was accepted. In the future, it would be beneficial to have a panel of gluten-free consumers for quantitative descriptive analysis and consumer sensory. That will assist to get a better understanding of the target market and the overall sentiment of the Bambara groundnut pastry pies.

The fourth and last objective was achieved by image analysis using X-ray computed air pockets and the holes and layers within the pastry pies. Principal component analysis (PCA) was used to analyse the images obtained. The image analysis by characterizing the holes in the pastry revealed significant influences on classification, particularly in puff pastry. Roundness affected whole and dehulled BGN puff pastry, while aspect ratio was less crucial. Circularity influenced whole BGN shortcrust samples, and solidity impacted whole and dehulled puff pastry puff pastry. Principal component analysis (PCA) was applied to assess the influence of various parameters on the structural attributes of the pastry products. Solidity exhibited an influence on puff pastry, while circularity was a significant factor affecting whole BGN shortcrust pies. Component 1 explained much of the data variation, followed by Component 2, with a combined explanation of

91.5%. The hypothesis that fat distribution and the structure of whole and dehulled BGN and wheat pies will be determined was accepted.

The following conclusions can be made from this study:

1. Optimal whole BGN and dehulled BGN flour mix was obtained, and it can be used in the process of making gluten-free pastry products. CMC and modified starch are a good combination of additives to use to achieve gluten-free pastry pies.
2. The fat content of 60% for shortcrust pastry and 100% for puff pastry was suitable for making suitable pies.
3. The panel used for QDA evaluated whole BGN shortcrust and puff pastry pies as Having a darker crust, larger crack size, overall smooth texture, dry, crumbly, and hard. They also perceived a nutty aroma, beany flavour and no aftertaste on the whole BGN pies.
4. Consumer sensory evaluation showed that consumers were more neutral and negative towards BGN pastry products.
5. Proximate composition analysis unveiled the nutritional richness of both whole and dehulled BGN pastry products, highlighting their elevated protein, mineral, and fat content, which caters to the needs of individuals who are gluten intolerant, coeliac sufferers and those who are health conscious. The use of whole BGN is beneficial as it increases fibre intake and assists with satiation.
6. The use of BGN flour, whether whole or dehulled, imparted distinct colour characteristics to the pastry products (especially whole because of the tannins found in the hulls), diverging from those of wheat flour, with variations in L*, a*, and b* values.
7. Ultimately, this study contributed to the development of pastry items that offer improved quality and nutritional value, catering to diverse dietary preferences and requirements and alternatives, especially for gluten-free consumers.

There is more that could be done to improve the texture of the whole and dehulled BGN dough and pies. Therefore, it is recommended that future studies be conducted to enhance and improve the texture of the gluten-free BGN dough and pies. More studies should be done on the amount of CMC to modified starch required to get a more elastic and pliable dough that will not break easily. More types of pastry products can be studied and not limited to pastry to increase the variety of options for gluten-free consumers. Further studies should be done on the image analysis to evaluate the structure of the dough and pies.

APPENDICES

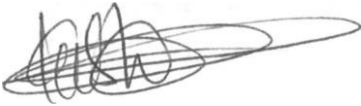
APPENDIX I: ETHICAL CLEARANCE



University of Technology

Statement of Permission

Data/Sample collection permission is required for this study.

Reference no.	211282537/01/2020
Surname & name	Nkantsu, SD
Student Number	211282537
Degree	Master of Food Science and Technology
Title	Textural and sensorial characteristics of Bambara groundnut shortcrust and puff pastry products
Supervisor(s)	PROF VICTORIA ADAORA JIDEANI
FRC Signature	
Date	2020/04/04



Cape Peninsula
University of Technology

P.O. Box 1906 • Bellville 7535 South Africa •Tel: +27 21 953 8677 (Bellville), +27 21 460 4213 (Cape Town)

Ethics Approval Letter Reference no: 21 1282537/01/2020

<p>Office of the Chairperson Research Ethics Committee</p>	<p>Faculty of Applied Sciences</p>
--	------------------------------------

On 31 January 2020, the Ethics Committee of the Faculty of Applied Sciences granted ethics approval to Nkantsu, SD for research activities related to a project to be undertaken for a degree (Master of Food Science and Technology) at the Cape Peninsula University of Technology.

<p>Title of project:</p>	<p>Textural and sensorial characteristics of Bambara groundnut shortcrust and puff pastry products</p>
--------------------------	--

Comments (Add any further comments deemed necessary, e.g. permission required)

1. Human subjects are included in the proposed study.
2. This permission is granted for the duration of the study.
3. Research activities are restricted to those detailed in the research proposal.

4. The research team must comply with the conditions outlined in AppSci/ASFREC/2015/1.1

VI, CODE OF ETHICS, ETHICAL VALUES AND GUIDELINES FOR RESEARCHERS.

<hr/> <p>Signed: Chairperson: Research Ethics Committee</p>	<p>31/01/2020</p> <hr/> <p>Date</p>
---	-------------------------------------

APPENDIX II: EMAIL COMMUNIQUE FOR PERMISSION TO USE FIGURES FROM THE MUSTAPHA BUNU BLOG

6/11/2018 Gmail - Re: [The wisebaker] New message received.



Re: [The wisebaker] New message received.

1 message

Mustapha Bunu <mustaphabunu8@gmail.com> To: Samukelisiwe <smthombeni877@gmail.com>

Hey! Samukelisiwe.

You are free to use my illustrations for your research project. Good luck.

Samukelisiwe D. <smthombeni877@gmail.com>

9 June 2018 at 19:32

On Wed, Jun 6, 2018, at 3:30 PM, Blogger Contact Form <no-reply@blogger.com> wrote:
Could I please get permission to use your threefold and fourfold illustrations for my research project?

Regards,
Samukelisiwe | smthombeni877@gmail.com

Note: This email was sent via the Contact Form gadget on <https://www.thewisebaker.co>

On Wed, Jun 6, 2018, at 3:30 PM, Blogger Contact Form <no-reply@blogger.com> wrote:
Could I please get permission to use your threefold and four-fold illustrations for my research project?

Regards,
Samukelisiwe | smthombeni877@gmail.com

Note: This email was sent via the Contact Form gadget on <https://www.thewisebaker.com>

APPENDIX III: EMAIL COMMUNIQUE FOR PERMISSION TO USE THE PASTRY METHOD FROM THE JEANNE SAUVAGE BLOG

14/11/2023, 02:51

Gmail – Gluten-free Puff pastry



Gluten-free Puff pastry

5 messages

Samukelisiwe D. Nkantsu <smthombeni877@gmail.com> To: thejeannesauvage@gmail.com

Good day Jeanne

Samukelisiwe D. Nkantsu <smthombeni877@gmail.com>

9 July 2019 at 03:06

My name is Samukelisiwe Nkantsu. I am currently completing my Master's degree in Food Science and technology at the Cape Peninsula University of Technology. My work is focused on Gluten-free Pastry using an underutilised African legume flour.

I would like to request to refer to your work or rather your recipe for Puff pastry, as there are points in your recipe that I want to try out to see if I can achieve my goal of making pies without breaking or cracking.

Kind Regards,

Samukelisiwe D. Nkantsu

MSc Food Science and Technology Student Department of Food Science and Technology Cape Peninsula University of Technology Bellville Campus

Cape Town, South Africa

Cell: 0789923155

Many are the plans in a man's heart, but it's the Lord's purpose that prevails. Proverbs 19:21

Sender notified by

Mailtrack

Mailtrack Reminder <reminders@mailtrack.io> 10 July 2019 at 03:07 Reply-To:

thejeannesauvage@gmail.com

To: smthombeni877@gmail.com

Your email to thejeannesauvage@gmail.com has not been opened yet. Snooze for 24H or 48H (disable)
Jeanne Sauvage <thejeannesauvage@gmail.com> 10 July 2019 at 04:03

To: "Samukelisiwe D. Nkantsu" <smthombeni877@gmail.com>

Samukelisiwe:

Greetings! Thank you for the nice note! Yes, you are welcome to reference my work—thank you for asking!

Let me know how it goes!

—Jeanne

Sent from my iPad

Samukelisiwe D. Nkantsu <smthombeni877@gmail.com> To: Jeanne Sauvage <thejeannesauvage@gmail.com>

Hi Jeanne

12 July 2019 at 12:16

Thank you very much for your permission. I did use your method and I got puff pastry this time around. I still have to work on the breaking of the dough though, I saw on your recipe that the breaking could also occur if the dough is too cold.

Otherwise thanks for your recipe.

Jeanne Sauvage <jeanne@artofglutenfreebaking.com>
To: "Samukelisiwe D. Nkantsu" <smthombeni877@gmail.com>

Samukelisiwe:

I am so glad you got puff pastry! And yes, it does take practice.

Happy baking!

—Jeanne

19 July 2019 at 01:54

APPENDIX IV: EVALUATION FORM FOR QUANTITATIVE DESCRIPTIVE ANALYSIS FOR SHORTCRUST AND PUFF PASTRY PIES MADE OF WHOLE BAMBARA GROUNDNUT, DEHULLED BAMBARA GROUNDNUT AND WHEAT FLOUR.

Evaluation Form

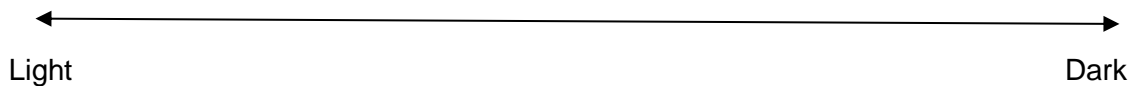
Name _____ Date _____

Instructions

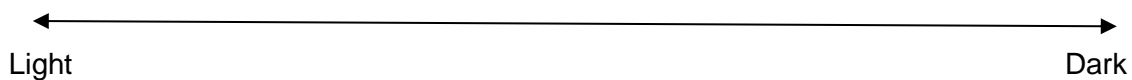
You are provided with three samples of pie. Please take a sip of water before you start tasting and in between samples. Do not compare samples and rate each sample on its merit based on the attributes. Draw a vertical line on the line at the point you feel is appropriate for each attribute.

APPEARANCE

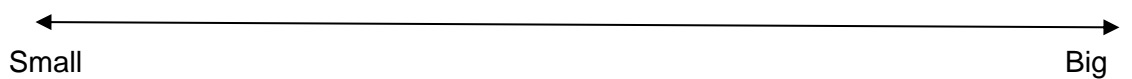
1. Crust colour



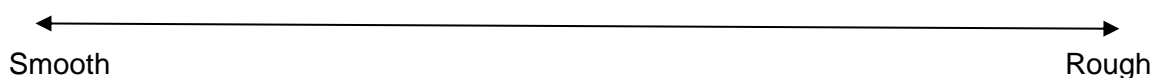
2. Crumb colour



3. Size of cracks

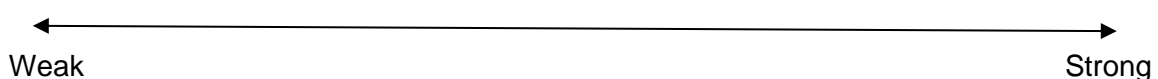


4. Crust Smoothness

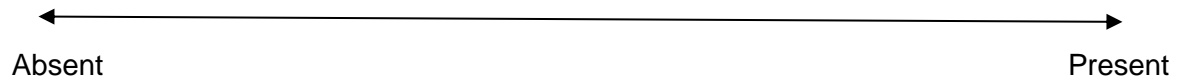


AROMA

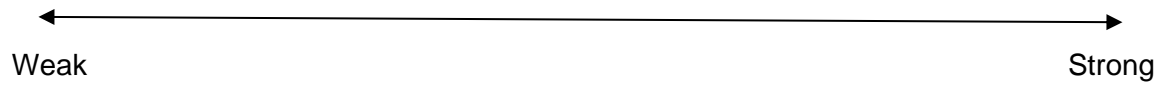
1. Nutty



2. Buttery

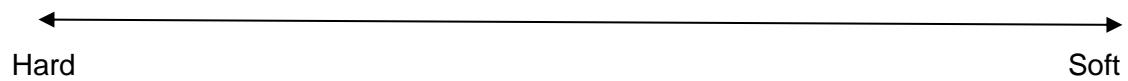


3. Typical pie aroma

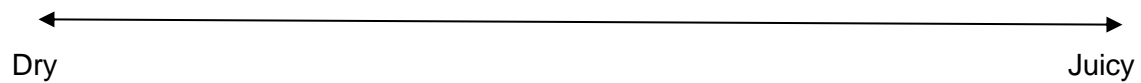


TEXTURE

1. Softness (Touch)



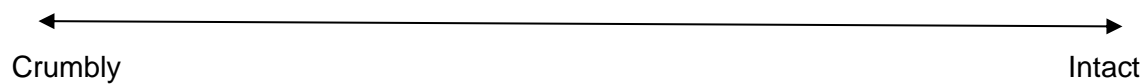
2. The juiciness of crumb (moistness)



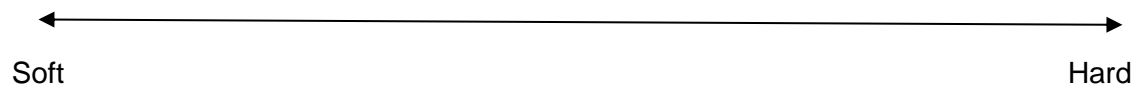
3. Fat



4. Cohesiveness

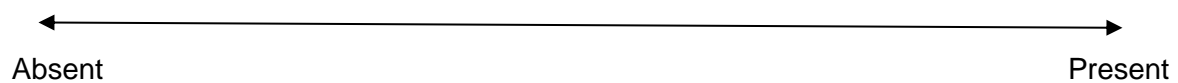


5. Hardness

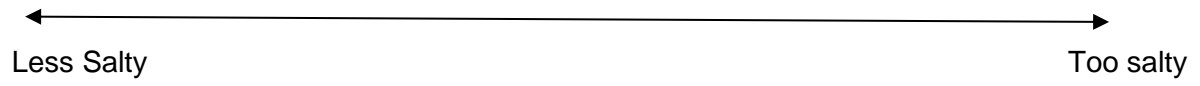


TASTE

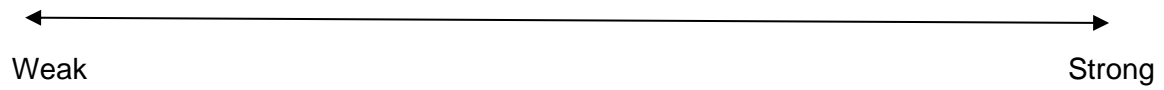
1. Beany



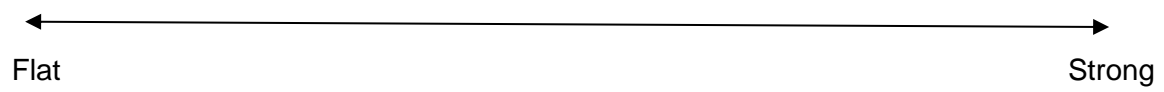
2. Saltiness



3. Buttery



4. Bland



5. Aftertaste

