

PEARL MILLET MALTING: FACTORS AFFECTING
PRODUCT QUALITY

LOUIS AUGUSTO MUTOMENE PELEMBE

PELEMBE, LOUIS AUGUSTO MUTOMENE

PEARL MILLET MALTING: FACTORS AFFECTING PRODUCT QUALITY

Ph.D. (Food Science)

U.P.

2001

November 2001

PEARL MILLET MALTING: FACTORS AFFECTING PRODUCT QUALITY

by

LOUIS AUGUSTO MUTOMENE PELEMBE

Submitted in partial fulfillment of the requirements for the degree

Doctor of Philosophy (Food Science)

Department of Food Science

Faculty of Natural and Agricultural Sciences

University of Pretoria

I declare that the thesis hereby submitted to the University of Pretoria, has not been submitted to any other university or institution of higher learning.

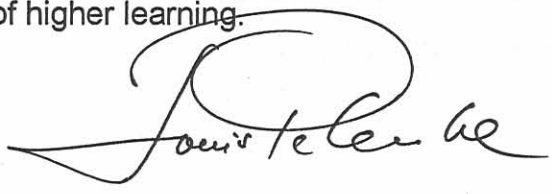
Pretoria

November 2001



DECLARATION

I declare that the thesis herewith submitted for the Ph.D. (Food Science) degree at the University of Pretoria, has not been previously submitted by me for a degree at any other university or institution of higher learning.



ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude and appreciation to the following persons and institutions for their contribution to the successful completion of this study:

Prof. John RN Taylor, University of Pretoria, my supervisor and mentor, for his constant motivation, invaluable guidance, expert advice and personal encouragement throughout my studies. Thanks for your patience and kindness. Dr. Janice Dewar, CSIR, my co-supervisor, for her technical support, constructive criticism and invaluable advice particularly during the last part of this project.

The Universidade Eduardo Mondlane (UEM), Maputo, for allowing me to continue my post-graduate studies. Special thanks to Prof. Dr. Eng. Gabriel L. Amos, Dean of the Faculty of Engineering, for his support. The Capacity Building Project at UEM for awarding me its bursary for my Ph.D. studies.

Prof. A. B. Obilana, Dr. E. Monyo and Ms. Effie Chinhema of SADC/ICRISAT, Matopos Research Station, Bulawayo, Zimbabwe, for the donation of pearl millet of variety SDMV 89004 used in this research.

CSIR – Bio/Chemtek (Food Division) for providing the malting facilities. Ms. Carin Carstens of CSIR – Bio/Chemtek (Division of Food, Biological and Chemical Technologies) for her suggestions and inputs during the malting stage.

Mr. Allan N. Hall of the Laboratory for Microscopy and Microanalysis, University of Pretoria, for his assistance with microscope analysis.

The entire staff and post-graduate students here at the Department of Food Science, University of Pretoria for being helpful in many different ways.

A special thanks to all sensory panelists for their patience and perseverance. My heartfelt gratitude to Miss Paballo Gloria Mokoena for her assistance in sensory preparation.

My wonderful wife, Lucília, and my beautiful children, Jennifer Moyass "Moya-de-papá" and Melanie Lucy "Dona Pukurucha/Vovó Gaveya", who gave me the encouragement I so often needed and give me so much to live for.

My admirable mother, Violeta, who gave me the motivation and support, needed to get the most out of life, for her continuous support. This thesis may be the result of years of study on my part but it is the culmination of a lifetime of love and care on hers.

My brothers, Calvin (Camilo), Buta, Aduto, Marito "Sr. Pelembe" and friends for all the support they offered during the course of this project.

Co-Supervisor: Dr. Jarrod Dewar

Finally, to all not mentioned here but without their support could not possible to finish this project. I owe you a special thank you. Khanimambo¹!

¹Khanimambo /kaneemam:boo/n - thank you in southern Mozambican languages.

ABSTRACT

PEARL MILLET MALTING: FACTORS AFFECTING PRODUCT QUALITY

by

Louis Augusto MUTOMENE PELEMBE

Supervisor: Prof. John RN Taylor

Co-Supervisor: Dr. Janice Dewar

Department: Food Science

Degree: Ph.D. (Food Science)

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a drought tolerant cereal crop grown primarily as a food grain in southern Africa. In this southern Africa region, the grain is traditionally processed either by germination or fermentation prior to consumption. Malting involves the limited germination of cereal grain in moist air under controlled conditions.

Malts were prepared by malting two varieties of pearl millet, SDMV 89004 and SDMV 91018. The grain was steeped for 8 h with a cycle of 2 h wet and 2 h dry (air rest) and germinated at four temperatures, 20 °, 25 °, 30 ° and 35 °C over 5 days. The malts were then dried at 50 °C for 24 h.

Modification of starch granules and protein bodies in pearl millet grain structure due to germination was found to start at the germ-floury endosperm interface and move in the direction of the peripheral endosperm. Aleurone layer, cell wall and vitreous endosperm were not greatly involved in modification process.

Ungerminated pearl millet grains do not exhibit Diastatic Power (DP), α - or β -amylase activity. DP, α - and β -amylase activity increase as germination time and temperature increases. DP, total and soluble β -amylase activity increase with germination time and watering treatment probably because high moisture promotes high metabolic activity.

Free amino nitrogen (FAN) increases as the germination time, temperature and watering treatment increases. This may be related to the fact that high temperature and moisture promote the growth of roots and shoots, which are a good source of malt FAN.

Malt extract increases with germination time and watering treatment. This increase in hot water extract is an indication of the progress of modification of the malt during the germination process. The increase in malting loss with germination time, temperature and watering treatment observed is related to the high respiratory activity during germination.

A germination temperature of 25-30 °C and germination time of 3-5 days, medium watering treatment are optimum for pearl millet. These conditions result in high DP, α - and β -amylase activity, good FAN and moderate malting loss. The levels of DP, FAN, α -amylase activity and malting loss of pearl millet malts, which are similar to sorghum malts, represent an excellent potential for utilisation of pearl millet malt for sorghum beer brewing purposes. Additionally, pearl millet malt could be a better alternative than sorghum for lager beer brewing due to the fact that it has higher β -amylase activity.

Phytic acid decreases during malting, probably due to phytase activity. Soluble proteins and the Nitrogen Solubility Index increase due to partial hydrolysis of storage proteins by endogenous proteases. This is complimented by an increase in *in vitro* protein digestibility of pearl millet malts. A reduction in the viscosity of flours made from pearl millet malts, which is due to increased α -amylase activity, may contribute to the use of this malt to improve the energy and nutrient density of porridges for young children.

Germination significantly reduces the mousy odour, characteristic of ground pearl millet meals when stored. This is probably due to the growth of lactic acid bacteria which decrease the pH in the grain affecting the water soluble phenolics which leached out. These phenolics are believed to be responsible for the mousy odour of the stored pearl millets meals.

Pearl millet malt represents an excellent potential for utilisation of pearl millet for sorghum beer and it appears that it can be used in lager beer brewing. The improved nutritional and functional properties of pearl millet malt are an indication that the malting process, a low-

cost processing technology, usable at both rural and industrial level, can be successfully applied to prepare nutritious and functional food products.

LIST OF TABLES	xiv
LIST OF FIGURES	xv
CHAPTER 1: INTRODUCTION	1
1.1 STATEMENT OF THE PROBLEM	2
1.2 OBJECTIVES	2
CHAPTER 2: LITERATURE REVIEW	3
2.1 MORPHOLOGY OF PEARL MILLET	4
2.2 CHEMICAL COMPOSITION OF PEARL MILLET	5
2.2.1 Nutritional Value of Pearl Millet	5
2.2.2 Antioxidants in Pearl Millet	6
2.3 MALTING OF CEREALS	7
2.3.1 Malting Technology	7
2.3.2 Malting Science	8
2.3.3 Malt Quality	9
2.3.4 Sorghum and Malt	10
2.4 SUMMARY	11
CHAPTER 3: EXPERIMENTAL	12
3.1 EXPERIMENTAL DESIGN	13
3.2 MATERIALS	14
3.3 PEARL MILLET MALTING PROCESS	15
3.3.1 Steeping	15
3.3.2 Germination	16
3.3.3 Drying	17
3.4 ANALYTICAL METHODS	18
3.4.1 Moisture content	18
3.4.2 Protein	19
3.4.3 Fat	20

TABLE OF CONTENTS

LIST OF TABLES	xiv
LIST OF FIGURES	xv
CHAPTER 1: INTRODUCTION	1
1.1 STATEMENT OF THE PROBLEM	2
1.2 OBJECTIVES	3
CHAPTER 2: LITERATURE REVIEW	5
2.1 MORPHOLOGY OF PEARL MILLET	5
2.2 CHEMICAL COMPOSITION OF PEARL MILLET	6
2.2.1 Nutritive Value of Pearl Millet	13
2.2.2 Antinutrients in Pearl Millet	14
2.3 MALTING OF CEREALS	15
2.3.1 Malting Technology	16
2.3.2 Malting Science	20
2.3.3 Malt Quality	25
2.3.4 Sorghum and Millet Malting	26
2.4 SUMMARY	40
CHAPTER 3: EXPERIMENTAL	42
3.1 EXPERIMENTAL DESIGN	42
3.2 MATERIALS	45
3.3 PEARL MILLET MALTING PROCESS	47
3.3.1 Steeping	47
3.3.2 Germination	48
3.3.3 Drying	50
3.4 ANALYTICAL METHODS	50
3.4.1 Moisture content	51
3.4.2 Protein	51
3.4.3 Fat	51

3.4.4 Ash	51
3.4.5 Total carbohydrate and the total carbohydrate which was enzyme-susceptible	52
3.4.6 Fibre	52
3.4.7 Phytic acid	52
3.4.8 Total polyphenols	53
3.4.9 Amylose/amylopectin ratio	53
3.4.10 Germinative Energy (GE) and Germinative Vigour (GV)	54
3.4.11 Malting loss	54
3.4.12 Roots and shoots	55
3.4.13 Green malt moisture	55
3.4.14 Water uptake	55
3.4.15 Grain hardness	56
3.4.16 Diastatic Power (DP)	56
3.4.17 Alpha-amylase activity	57
3.4.18 Beta-amylase activity (by inactivation of α -amylase)	57
3.4.19 Beta-amylase activity (Betamyl method)	58
3.4.20 Free α -amino nitrogen (FAN)	58
3.4.21 Hot water extract (HWE)	59
3.4.22 Water Absorption Index (WAI)	59
3.4.23 Water Solubility Index (WSI)	60
3.4.24 Percentage of soluble nitrogen and Nitrogen Solubility Index (NSI)	60
3.4.25 <i>In vitro</i> protein digestibility	60
3.4.26 Amino acid analysis	61
3.4.27 Scanning electron microscopy (SEM)	62
3.4.28 Odour generation and evaluation of the odour generated	62
3.4.29 Pasting properties	63
3.4.30 Statistical analysis	63
CHAPTER 4: RESULTS	64
4.1 ANALYSIS OF RAW MATERIALS	64
4.1.1 Proximate Analysis of Pearl Millet Varieties	64

4.1.2 Enzyme Susceptibility of Carbohydrates, Amylose/ Amylopectin Ratio and Gelatinisation Temperature Range of Pearl Millet Varieties	65
4.1.3 Antinutritional Factors in Pearl Millet Varieties	66
4.1.4 Endosperm Texture of the Pearl Millet Varieties	67
4.1.5 Geminative Energy (GE) and Germinative Vigour (GV) of Pearl Millet Varieties	67
4.1.6 Water Uptake of Pearl Millet Varieties	68
4.2 PEARL MILLET ENDOSPERM MODIFICATION DURING GERMINATION	70
4.3. BREWING QUALITY ANALYSES OF MALTS	78
4.3.1 Water uptake during steeping	78
4.3.2 Root and shoot growth during germination	78
4.3.3 Diastatic Power (DP)	80
4.3.4 Alpha-amylase activity	83
4.3.5 Beta-amylase activity	85
4.3.6 Free α -amino nitrogen (FAN)	89
4.3.7 Hot water extract	93
4.3.8 Malting loss	93
4.4 NUTRITIONAL AND FUNCTIONAL ANALYSES OF MALTS	98
4.4.1 Total Carbohydrate content and the percentage of the total carbohydrate which was enzyme susceptible	98
4.4.2 Water Absorption Index (WAI) and Water Solubility Index (WSI)	100
4.4.3 Fat	100
4.4.4 Protein	103
4.4.5 Nitrogen Solubility Index (NSI) and soluble nitrogen	103
4.4.6 <i>In vitro</i> protein digestibility	107
4.4.7 Amino acid composition	109
4.4.8 Phytic acid	111
4.4.9 Pasting properties	111
4.4.10 Sensory evaluation of the mousy-odour in pearl millet varieties	117
CHAPTER 5: DISCUSSION	119
CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS	147

CHAPTER 7: REFERENCES151

**APPENDIX A: SCORE SHEET USED IN THE SENSORY EVALUATION OF
 MOUSY ODOUR GENERATED BY PEARL MILLET174**

APPENDIX B: LIST OF PUBLICATIONS AND PRESENTATIONS175

Table 1: Nutrient composition (proximate composition) of sorghum and millet
 (Source: Seneviratne & Senanayake, 2007)

Table 2: Nutrient composition (proximate composition) of sorghum and millet
 (Source: Seneviratne & Senanayake, 2007)

Table 3: Properties of millet starches (Reviewed by Senanayake & Ranney, 2007)

Table 4: Amino acid composition of the proteins of millets (g/100 g N) (Reviewed by
 Senanayake & Ranney, 1995)

Table 5: Amino acid composition of storage proteins of pearl millet (g/100 g N)
 (Source: Laczity, 1944)

Table 6: Proximate composition (%) of the milled pearl millet (milled to 75 mesh) used
 in this investigation

Table 7: Enzyme susceptibility of pearl millet starches to amylose, amylopectin and
 gelatinisation temperature range of pearl millet starches used in this
 investigation

Table 8: Phytic acid and phosphorus content of pearl millet used in this
 investigation

Table 9: Germination of pearl millet (cv. Seneviratne) under different conditions
 used in this investigation

Table 10: Water uptake of pearl millet starches under different conditions
 and times

Table 11: Amino acid composition of the pearl millet starches used in this
 investigation

Table 12: Pasting properties of non- and germinated pearl millet starches

Table 13: Sensory evaluation of the mousy odour of pearl millet starches under
 different conditions and times

LIST OF TABLES

Table 1: Chemical composition of pearl millet and its anatomical parts (Source: Abdelraham, Hosene & Varriano-Marston, 1984)	7
Table 2: Nutrient composition (proximate composition) of sorghum and millets (Review by Serna-Saldivar & Rooney, 1995).....	7
Table 3: Properties of millet starches (Reviewed by Serna-Saldivar & Rooney, 1995)	8
Table 4: Amino acid composition of the proteins of millets (g/16 g N)(Reviewed by Serna-Saldivar & Rooney, 1995)	10
Table 5: Amino acid composition of storage proteins of pearl millet (g/16 g N) (Source: Lásztity, 1984)	11
Table 6: Proximate composition (%) of the two pearl millet varieties used in this investigation	64
Table 7: Enzyme susceptibility of carbohydrate, amylose-amylopectin ratio and gelatinisation temperature range of pearl millet varieties used in this investigation	65
Table 8: Phytic acid and polyphenol content of the two pearl millet varieties used in this investigation	66
Table 9: Germinative Energy and Germinative Vigour of the two pearl millet varieties used in this investigation	67
Table 10: Water uptake of the two pearl millet varieties at various steeping temperatures and times	69
Table 11: Amino acid composition of the two pearl millet varieties (g/100 g protein)	110
Table 12: Pasting properties of non- and germinated pearl millet varieties	116
Table 13: Sensory evaluation of the mousy odour in non- and germinated pearl millet varieties	117

LIST OF FIGURES

Figure 1: Changes in total protein during germination of Cereal grains (Dalby & Tsai, 1976) 35

Figure 2: Changes in prolamin during germination of cereal grains (Dalby & Tsai, 1976) 36

Figure 3: Changes in lysine content of cereal grains during sprouting (Dalby & Tsai, 1976) 38

Figure 4: Changes in tryptophan content of cereal grains during sprouting (Dalby & Tsai, 1976) 39

Figure 5: Flow chart of the experimental design of pearl millet malting 43

Figure 6: Pearl millet grains of variety SDMV 89004 46

Figure 7: Green malt moisture content at low, medium and high watering treatment of the two pearl millet varieties at 25 °C (variety SDMV 89004 (–) and variety SDMV 91018 (–)) at various watering treatments (●- Low watering; ×- Medium watering; ◆- High watering) 49

Figure 8: Pearl millet malts of variety SDMV 89004 germinated for 5 days (average mass of each kernel: 8.9 mg; average length of the roots and shoots: 15-20 mm) 71

Figure 9: Longitudinal section of malt of variety SDMV 91018 germinated for 5 days showing the large germ in proportion to the rest of the kernel and the wave of modification (arrows) (A-Germ; B-Floury endosperm; C-Horny endosperm; P-Pericarp; S-Scutellum) (Bar = 600 µm) 72

Figure 10: Floury endosperm of non-germinated pearl millet of SDMV 89004 variety showing both rounded (R) and polygonal (P) starch granules (Bar = 8 µm)... 73

Figure 11: Horny endosperm of non-germinated pearl millet grain of SDMV 91018 variety showing polygonal (P) starch granules and imprints (I) of protein bodies (Bar = 9 µm) 74

Figure 12: Floury endosperm adjacent to scutellar epithelium of pearl millet of variety SDMV 89004 after 24 h of germination showing pin holes (arrows) in the starch granules (CW- Cell wall; SG- Starch granule) (Bar = 8 µm)..... 75

Figure 13: Floury endosperm adjacent to scutellar epithelium of pearl millet of SDMV 89004 variety after 72 h of germination showing highly degraded starch granules (arrows) and intact cell wall (CW- Cell wall; SG- Starch granule) (Bar = 13 μ m).....	76
Figure 14: Scanning electron micrograph of completely degraded starch granule in modified pearl millet malt of variety SDMV 89004 germinated for 48 h (Arrows- Protein body; SG- Starch granule) (Bar = 3 μ m).....	77
Figure 15: Effects of germination time, temperature and variety on root and shoot growth of pearl millet (variety SDMV 89004 (–) and variety SDMV 91018 (--); (●- 20 °C; ×- 25 °C; ◆- 30 °C; ■- 35 °C).....	79
Figure 16: Effects of germination time, temperature and variety on Diastatic Power of pearl millet (variety SDMV 89004 (–) and variety SDMV 91018 (--); (●-20 °C; ×- 25 °C; ◆- 30 °C; ■- 35 °C).....	81
Figure 17: Effects of germination time, watering treatment and variety on Diastatic Power of pearl millet at 25 °C (variety SDMV 89004(–) and variety SDMV 91018 (--)) at various watering treatments (●- Low watering; ×- Medium watering; ◆- High watering).....	82
Figure 18: Effects of germination time, temperature and variety on α -amylase activity of pearl millet (variety SDMV 89004 (–) and variety SDMV 91018 (--); (●- 20 °C; ×- 25 °C; ◆- 30 °C; ■- 35 °C).....	84
Figure 19: Effects of germination time, temperature and variety on β -amylase activity (measured by inactivation of α -amylase) of pearl millet (variety SDMV 89004 (–) and variety SDMV 91018 (--); (●- 20 °C; ×- 25 °C; ◆- 30 °C; ■- 35 °C).....	86
Figure 20: Effects of germination time, watering treatment and variety on total β -amylase activity (measured by Betamyl assay) of pearl millet at 25 °C (variety SDMV 89004(–) and variety SDMV 91018 (--)) at various watering treatments (●- Low watering; ×- Medium watering; ◆- High watering).....	87

Figure 21: Effects of germination time, watering treatment and variety on soluble β -amylase activity (measured by Betamyl assay) of pearl millet at 25 °C (variety SDMV 89004(–) and variety SDMV 91018 (–)) at various watering treatments (●- Low watering; ×- Medium watering; ◆- High watering)	88
Figure 22: Effects of germination time, temperature and variety on malt Free Amino Nitrogen of pearl millet (variety SDMV 89004 (–) and variety SDMV 91018 (–)); (●- 20 °C; ×- 25 °C; ◆- 30 °C; ■- 35 °C).....	90
Figure 23: Effects of germination time, watering treatment and variety on malt Free Amino Nitrogen of pearl millet at 25 °C (variety SDMV 89004(–) and variety SDMV 91018 (–)) at various watering treatments (●- Low watering; ×- Medium watering; ◆- High watering).....	92
Figure 24: Effects of germination time, watering treatment and variety on malt extract of pearl millet at 25 °C (variety SDMV 89004(–) and variety SDMV 91018 (–)) at various watering treatments (●- Low watering; ×- Medium watering; ◆- High watering)	94
Figure 25: Effects of germination time, temperature and variety on malting loss of pearl Millet (variety SDMV 89004 (–) and variety SDMV 91018 (–)); (●- 20 °C; ×- 25 °C; ◆- 30 °C; ■- 35 °C)	95
Figure 26: Effects of germination time, watering treatment and variety on malting loss of pearl millet at 25 °C (variety SDMV 89004(–) and variety SDMV 91018 (–)) at various watering treatments (●- Low watering; ×- Medium watering; ◆- High watering)	97
Figure 27: Effects of germination time and variety on the total carbohydrate content and the percentage of the total carbohydrate which was enzyme susceptible of pearl millet (variety SDMV 89004(–) and variety SDMV 91018 (–)); total carbohydrate (●-); the total carbohydrate which was enzyme susceptible (×-)	99
Figure 28: Effects of germination time and variety on Water Absorption Index and Water Solubility Index of pearl millet (variety SDMV 89004(–) and variety SDMV 91018 (–)); water absorption index (●-); water solubility index (×-)	101

Figure 29: Effects of germination time and variety on fat content of pearl millet (variety SDMV 89004(-) and variety SDMV 91018 (--)).....102

Figure 30: Effects of germination time and variety on protein content of pearl millet (variety SDMV 89004(-) and variety SDMV 91018 (--)).....104

Figure 31: Effects of germination time and variety on the Nitrogen Solubility Index of pearl millet (variety SDMV 89004(-) and variety SDMV 91018 (--))105

Figure 32: Effects of germination time and variety on the percentage of soluble nitrogen of pearl millet (variety SDMV 89004(-) and variety SDMV 91018 (--))106

Figure 33: Effects of germination time and variety on the *in vitro* protein digestibility of pearl millet (variety SDMV 89004(-) and variety SDMV 91018 (--))108

Figure 34: Effects of germination time and variety on the phytic acid content of pearl millet (variety SDMV 89004(-) and variety SDMV 91018 (--))112

Figure 35: Effect of germination time on pasting profiles of pearl millet flour of SDMV 89004 variety113

Figure 36: Effect of germination time on pasting profiles of pearl millet flour of SDMV 91018 variety114

One of the main constraints in utilization of millets is their small size of the grain. It also has a hard pericarp, which hinders development of baby foods in which usual cereal meals are used. La Varenne-Maxion, 1984, reported that pearl millet meal is not suitable with 5 to 8 days of germination. Vamero-Maxion, 1984, reported that pearl millet flour is not suitable when stored for any length of time. Reddy, 1984, stated that the odour is not associated with regular germination, but that it will enzymatic deterioration, as it is often germinated under high moisture levels in the grits.

The utilization of millets is also limited due to the presence of various anti-nutrients, poor digestibility of proteins and carbohydrates, and low palatability (Sharma & Kapoor, 1997). Various processing technologies are however able to affect positively the physicochemical composition of food grains in