

Sorghum *injera* quality improvement through processing and development of
cultivar selection criteria

by

SENAYIT YE'NEBERK

Submitted in partial fulfillment of the requirements for the degree

PhD (Food Science)

in the

Department of Food Science
Faculty of Natural and Agricultural Sciences
University of Pretoria
Pretoria, South Africa

February 2004

Declaration

I hereby declare that the thesis herewith submitted for the degree of PhD (Food Science) at University of Pretoria is my work and has not previously been submitted by me for a degree at any other university or institution of higher education.



Dedication

This thesis is dedicated to the memory of my senior sister w/o Asegedetch Belehu, who passed away while I was studying for my doctoral degree in South Africa, with love.

ACKNOWLEDGEMENTS

I would like to sincerely acknowledge the following people and institutions.

My supervisor Professor J.R.N. Taylor, for his keen interest in my work, constant supervision and tremendous knowledge he imparted to me.

My co-supervisor Professor L.W. Rooney for his guidance, sharing his knowledge and the encouragements he extended to me.

The Ethiopian Agricultural Research Organization (EARO) for awarding the fellowship to enable me undertake this research and the financial support obtained through the Agricultural Research and Training Project (ARTP). I am indebted to the International Sorghum and Millet (INTSORMIL) Collaborative Research Support Program for the partial financial assistance extended to facilitate the completion of my studies.

The Ethiopian Sorghum Improvement Program (ESIP) of the Melkassa Agricultural Research Center for providing the sorghum cultivars used in this study. The Ethiopian Tef Improvement Program of the Debre Zeit Agricultural Research Center for supplying the tef cultivar used in this study.

Professor A. Minnaar, Head of the Department of Food Science, University of Pretoria for her encouragement and support as well as the academic and technical staff of the department for all the assistance they provided in facilitating my work. Postgraduate colleagues and friends for sharing their knowledge and experiences.

Mr. Alan N. Hall of the Laboratory for Microscopy and Microanalysis, University of Pretoria for his technical support and goodwill during the study. Dr. H.L. de Kock of the Department of Food Science, University of Pretoria for her technical guidance in the sensory work as well as Mrs. Janet Taylor for extending her constant and tremendous technical assistance.

My mother w/o Gete Kibru, and my father Ato Yetneberk Ewnetu (deceased) who inspired me to be who I am. My son Selamu Damtew for his companionship and understanding throughout the study period. To family members who contributed towards my success and indispensable friends at home and in South Africa who gladly shared my responsibilities in one way or another when I needed it.

ABSTRACT

Sorghum *injera* quality improvement through processing and development of cultivar selection criteria

by

Senayit Yetmeberk

Supervisor: Professor J. R. N. Taylor

Co-supervisor: Professor L. W. Rooney

Department: Food Science, University of Pretoria, South Africa

Degree: PhD Food Science

Injera is a fermented, leavened, flat and round pancake-like Ethiopian traditional bread made from cereals such as tef and sorghum, with tef preferred for the best quality *injera*. Because sorghum is less expensive in Ethiopia, there is great interest in improving the quality of sorghum *injera* through processing and cultivar selection.

The effects of the processing methods of decortication and compositing whole sorghum flour with tef on the *injera* making quality of high-tannin and non-tannin red sorghums were studied. Abrasive decortication was found to be more effective than hand pounding because acceptable *injera* was obtained with lower milling loss and higher tannin removal. Compositing of whole sorghum flour with tef flour improved *injera* quality as the proportion of tef increased. Tef probably acted mainly as tannin diluent, overcoming the inhibitory effects of tannins on fermenting microorganisms. Compositing with tef is a more useful method than decortication since grain losses are avoided.

Twelve Ethiopian sorghum cultivars grown for two seasons at Melkassa Agricultural Research Center were characterized in terms of their physico-chemical properties and used to make *injera* under standard conditions, and compared with white tef of good *injera* making quality. *Injera* quality was evaluated by descriptive sensory analysis of fresh *injera* and instrumental texture analysis of fresh and stored *injera* over a storage period of 48 hr.

Principal component analysis of sensory data associated fresh *injera* from sorghum cultivars AW (red, floury endosperm), 3443-2-op (white, intermediate endosperm), 76TI #23 (white, intermediate endosperm), and PGRC/E #69349 (white, relatively vitreous endosperm) with the positive *injera* texture attributes of softness, rollability and fluffiness. Across the two seasons, texture analysis showed *injera* prepared from AW and CR:35:5 (both with floury endosperm), required the least force to bend after 48 hr of storage. Thus, from the standpoint of *injera* making quality it appears that floury to intermediate endosperm sorghums are most suitable.

Sorghum flours were found to be distinctively different from tef flour. Lower water solubility index, higher water absorption index, higher hot paste, setback and cold paste viscosities with a soft gel texture are features of sorghum flours.

On the basis of linear regression correlations between physico-chemical properties and sensory data, it appears that the sorghum grain physical properties of endosperm texture, test weight, hardness, water solubility and water absorption indices affect the sensory textural attributes of *injera*. These relationships enabled the development of indirect and direct selection criteria for use in the Ethiopian Sorghum Improvement Program (ESIP) for selection of sorghum cultivars of good *injera* making quality. Grain endosperm texture (visual rating) of 3-5 (intermediate to floury), flour water solubility index of ≥ 2.5 g/100 g and water absorption index of ≤ 1.5 g/g are proposed as selection criteria at the early generation (nursery) breeding stage. Milling extraction rate (TADD) of 56.0-79.0%, test weight of 71.0-75.0 kg/hl, *injera* softness score of ≥ 6.7 , stickiness score of ≤ 2.0 , fluffiness score of ≥ 6.8 , rollability score of ≥ 7.2 grittiness score of ≤ 2.7 , for maximum force required to bend *injera* after 24 hr of storage ≤ 0.27 N and after 48 hr of storage ≤ 0.33 N are proposed as selection criteria for the advanced breeding stage. However, testing a larger number of sorghum lines, about 15-20 cultivars across 2-3 locations, from multilocation trials such as the Pre-National Variety Trial of the ESIP will be required to fine-tune these proposed selection criteria.

TABLE OF CONTENTS

Preliminary pages	Page
Title page	i
Declaration	ii
Dedication	iii
ACKNOWLEDGEMENTS	iv
ABSTRACT	vi
List of tables	xi
List of figures	xiii
1. INTRODUCTION	1
1.1. Statement of problem	1
1.2. Hypotheses	2
1.3. Objectives	2
2. LITERATURE REVIEW	4
2.1. Sorghum and tef: Origin distribution and importance	4
2.2. Anatomy of sorghum and tef grains	4
2.2.1. <i>Starch granules</i>	7
2.2.2. <i>Significance of endosperm texture</i>	9
2.3. Chemical components of sorghum and tef	10
2.3.1. <i>Starch</i>	10
2.3.2. <i>Protein</i>	17
2.3.3. <i>Lipids</i>	19
2.3.4. <i>Non-starch polysaccharides</i>	20
2.3.5. <i>Tannins</i>	20
2.6. Decortication and milling	22
2.7. Fermentation	24
2.8. Dough making and baking	26
2.9. Staling	27
2.10. Standardized <i>injera</i> making procedures	28

2.11. Sensory evaluation	29
2.12. Sorghum grain characteristics as related to flat bread quality	31
2.13. Conclusions	33
3. RESEARCH	
3.1. Improving the quality of sorghum <i>injera</i> by decortication and compositing with tef	35
Abstract	36
3.1.1. <i>Introduction</i>	37
3.1.2. <i>Materials and methods</i>	37
3.1.3. <i>Results and discussion</i>	40
3.1.4. <i>Conclusions</i>	51
3.1.5. <i>References</i>	52
3.2. Effects of sorghum cultivar on <i>injera</i> quality	55
Abstract	56
3.2.1. <i>Introduction</i>	57
3.2.2. <i>Materials and methods</i>	58
3.2.3. <i>Results and discussion</i>	64
3.2.4. <i>Conclusions</i>	77
3.2.5. <i>References</i>	78
3.3. Grain and flour quality of Ethiopian sorghums in respect of their <i>injera</i> making potential	81
Abstract	82
3.3.1. <i>Introduction</i>	83
3.3.2. <i>Materials and methods</i>	84
3.3.3. <i>Results and discussion</i>	86
3.3.4. <i>Conclusions</i>	107
3.3.5. <i>References</i>	108
4. GENERAL DISCUSSION	112
4.1. Methodologies: A critical review	112
4.2. Relating physico-chemical parameters to <i>injera</i> sensory	117

textural attributes	
4.3. Proposed selection criteria	121
<i>4.3.1. Early generation selection criteria</i>	121
<i>4.3.2. Advanced breeding stage selection criteria</i>	122
4.4. Future research needs	125
5. CONCLUSIONS AND RECOMMENDATIONS	127
6. REFERENCES	129
Appendix I. Publications and presentations from this work	144

List of tables

Table	Page
3.1.1. Grain characteristics of Seredo (tannin-containing) and IS 2284 (tannin-free) sorghum cultivars and tef	42
3.1.2. Sensory panel responses of <i>injera</i> prepared from sorghum flours of Seredo and IS 2284 decorticated by hand pounding and with TADD at different extraction rates	46
3.1.3. Sensory panel responses of <i>injera</i> prepared from composite flours of whole tannin-containing sorghum (Seredo) and tef flour composited at different proportions	48
3.2.1. Definitions of the 19 descriptors used by the trained sensory panel for scoring sorghum and tef <i>injera</i>	63
3.2.2. Pericarp and glume color, pericarp thickness, endosperm color, pigmented testa, endosperm texture and hardness of sorghums and a tef cultivar from the 1999 and 2000 growing seasons	66
3.2.3. Sensory textural attributes of <i>injera</i> from 12 sorghum cultivars and tef from the 1999 and 2000 growing seasons	67
3.2.4. Maximum force (N) required to bend <i>injera</i> stored at 25 °C over a period of two days from sorghums and a tef cultivar grown for two seasons	74
3.3.1. Pericarp color and thickness, pigmented testa and endosperm texture of sorghums and tef from the 1999 and 2000 growing seasons (from Chapter 3.2)	87
3.3.2. Significant correlations among physico-chemical parameters of the 12 sorghum cultivars across the 1999 and 2000 growing seasons	90
3.3.3. Significant correlations between sorghum physico-chemical parameters of the 12 sorghum cultivars and sensory and instrumental textural attributes of sorghum <i>injera</i> across the	91

1999 and 2000 seasons

3.3.4.	Kernel and flour colors (Lab values) of the 12 sorghum cultivars and tef from the 1999 and 2000 growing seasons	94
3.3.5.	Thousand kernel weight, test weight, extraction rate and endosperm texture of sorghum cultivars and tef from 1999 and 2000 growing seasons	95
3.3.6.	Chemical composition (dry weight basis) of whole grain sorghum and tef flours from the 1999 and 2000 growing seasons	99
3.3.7.	Water absorption and water solubility indices of whole sorghum and tef flours from the 1999 and 2000 growing seasons	101
3.3.8.	Pasting properties and gel firmness of whole sorghum and tef flours from the 1999 and 2000 growing seasons	104
4.1.	Correlations between sorghum grain and sorghum physico-chemical parameters and sensory textural attributes of sorghum <i>injera</i> across the 1999 and 2000 growing seasons	120
4.2.	Proposed criteria at early generation for selection of sorghum cultivars of good <i>injera</i> making potential	122
4.3.	Proposed criteria at advanced breeding stage for selection of sorghum cultivars of good <i>injera</i> making quality	125

List of figures

Figure	Page
2.1. Micrograph of longitudinal section of sorghum grain	5
2.2. Micrograph of longitudinal section of tef grain	6
2.3. Micrographs of starch granules and protein bodies in sorghum and tef	8
2.4. α -1,4 linkages of amylose	10
2.5. α -1,4 and α -1,6 glycosidic bonds of starch	11
2.6. Structure of sorghum procyanidin	21
3.1.1. Micrographs of Seredo (tannin-containing) and IS 2284 (tannin-free) sorghum grains. A , Seredo endosperm; B , IS 2284 endosperm; C , Seredo pericarp; D , IS 2284 pericarp. P = pericarp; VE = vitreous endosperm; FE = floury endosperm; G = germ	43
3.1.2. Effect of decortication on sorghum extraction rate. A , Hand pounding; B , Mechanical abrasion with TADD. Circles = Seredo (tannin-containing); Squares = IS2284 (tannin-free); Triangles = Tannin content of Seredo	44
3.1.3. Effect of sequential decortication of the tannin sorghum (Seredo) on pasting properties of flours. 54% _____ ; 66.8% - - - - ; 75.3% ; 83% - . - - ; 89% _____ ; 100% - - . . .	49
3.1.4. Changes in water solubility index and water absorption index of composite whole flours of a tannin-containing sorghum (Seredo) and tef composited in different proportions. Circles = WSI; Diamonds = WAI	50
3.1.5. Effect of compositing the tannin sorghum (Seredo) with tef on pasting properties of the flours. 100% sorghum _____ ; 50% sorghum + 50% tef - - - ; 100% tef	51
3.2.1. Variations in color, size and shape of the 12 sorghum cultivars and a white tef	59
3.2.2. Flow diagram of standardized <i>injera</i> making procedure	62

3.2.3.	Principal component analysis of <i>injera</i> from 12 sorghums and a tef cultivar grown in 1999. Plot of the first two principal component scores of the cultivars A . Plot of the first two principal component loading vectors of sensory attributes B . White-ts = whiteness of top surface; white-bs = whiteness of bottom surface; red-ts = redness of top surface; red-bs = redness of bottom surface; eye dis = eye distribution; eye even = eye evenness; sour-at = sour aftertaste; sweet-at = sweet aftertaste; bitter-at = bitter aftertaste	70
3.2.4.	Principal component analysis of <i>injera</i> from 12 sorghums and a tef cultivar grown in 2000. Plot of the first two principal component scores of the cultivars A . Plot of the first two principal component loading vectors of sensory attributes B . (see 3.2.3 above)	71
3.2.5.	Principal component analysis of <i>injera</i> from 12 sorghums and a tef cultivar grown in 2000. Plot of the first and third principal component scores of the cultivars A . Plot of the first and third principal component loading vectors of sensory attributes B . (see 3.2.3 above)	73
3.2.6.	Effect of storage time (1, 24, 48 hr) on maximum force required to bend sorghum <i>injera</i> from PGRC/E #69349 (high staler) from the 1999 growing season	76
3.2.7.	Effect of cultivar on maximum force required to bend <i>injera</i> stored for 48 hr from the 1999 growing season	76
3.3.1	Micrographs of the 12 sorghum cultivars varying in pericarp thickness from the 1999 growing season. P = pericarp; VE = vitreous endosperm; al = aleurone layer	88
3.3.2.	Micrographs of the longitudinal sections of the 12 sorghum cultivars with varying endosperm texture from the 1999 growing season. FE = floury endosperm; VE = vitreous endosperm; G = germ	96
3.3.3.	Double compression of sorghum and tef flour gels aged for 24 hr at 4 °C. Sorghum (76TI #23) and tef (DZ-01-196) ———	107