THE INFLUENCE OF SEED COAT AND COTYLEDON STRUCTURE ON COOKING CHARACTERISTICS OF COWPEAS

by

Luisa Penicela

Submitted in partial fulfilments of the requirements for the degree MSc (Agric) Food Science and Technology

Department of Food Science
Faculty of Natural and Agricultural Sciences
University of Pretoria

Pretoria 0002

Republic of South Africa

October 2010

DECLARATION

I declare the thesis that I hereby submit for the degree of MSc (Agric) Food Science and Technology at the university of Pretoria is my own work and not previously been submitted by me for a degree at another University or institution of higher education.

Luisa Penicela
October 2010

DEDICATION

I dedicate this thesis to the loving memories of my beloved parents Nora Jossias Mucambe and Penicela Malonguete Macie and to my brother Antonio. May your souls rest in Divine peace

and

To Him, the Lord who is everything to me.

Acknowledgements

I would like to sincerely acknowledge my supervisor Professor Amanda Minnaar and my co-supervisor Doctor Muhammad Naushard Emmambux, for their support and supervision. Your constant mentoring throughout the study period made this research work a reality and to end with success.

I gratefully acknowledge the USAID Bean/Cowpea Collaborative Research Support Program (CRSP) and Ministry of Science and Technology of Mozambique for the financial support towards my studies.

I acknowledge the Agricultural Research Institute of Mozambique (IIAM) for granting me a study leave. In particular I would like to sincerely acknowledge the IIAM general director Dr. Calisto Bias and the technical direct Dr Manuel Amane, for their moral support and encouragement throughout the study period.

I acknowledge the Faculty, staff and fellow postgraduate students of the Department of Food Science, University of Pretoria, for valuable contributions which enriched this study.

My acknowledgements go to Alan Hall and staff of the Laboratory of Microscopy and Microanalysis, for technical assistance with Scanning Electron Microscopy, to Marie Smith for her help on statistical analysis.

I deeply acknowledge my sister in law Esperança, for leaving her family back home and coming to look after me in South Africa when I was sick. I thank Dr Agnes Mwangwela and Denis who also took care of me like their sister. Thank you Alice and Kimondo for your friendship and help on sensory work. May the Lord bless you all. I thank my sisters Albertina and Felizarda and my brothers Urbano, Simoes and Samuel, for their moral support and encouragement during the study period.

I am thankful to the moral support employed by my friends, the fellow Mozambicans and students namely Laurinda, Paiva, Abida, Abreu, Vasco, Massinga Brasilino, Helder, Nadia during my stay in South Africa.

ABSTRACT

The influence of seed coat and cotyledon structure on cooking characteristics of cowpeas

by

Luisa Penicela

Promoter: Prof Amanda Minnaar

Co-supervisor: Dr Mohammad Naushad Emmambux

Department: Food Science

Degree: MSc (Agric) Food Science and Technology

Cowpea (*Vigna unguiculata* L. Walp) is an important legume mainly used for human consumption worldwide, particularly in developing countries. Cowpea legume is rich in protein (25%), carbohydrates (70%), dietary fibre, minerals and vitamins. Cowpea comprises a range of varieties that breeders release based primarily on agronomic characteristics, such as yield, early maturity and drought tolerance. However, consumers do not always adopt all the released cowpea varieties. Cooking characteristics such as cooking time and sensory properties (i.e. appearance, texture, flavour) of cooked cowpeas are believed to be quality characteristics for legume acceptability by consumers. Physicochemical characteristics are known to influence cooking characteristics of cowpeas. These characteristics may be influenced by seed coat and cotyledon structure. The present study focuses on the effect of seed coat and cotyledon structure on cooking and sensory characteristics of cowpeas and how this in turn influences consumer acceptability of cowpeas.

The influence of seed coat thickness and cotyledon compactness on cooking characteristics of four cowpea types (thick seed coat/compact cotyledon (Bechuana White), thick seed coat/porous cotyledon (IT82E 18), thin seed coat/compact cotyledon (Black Eye) and thin seed coat/porous cotyledon (California Black) was studied. Seed coat thickness was found to influence water absorption during soaking. Cowpeas with thin seed coats had higher rates of water absorption during soaking due

to its amorphous cell layer that rendered the seed coat more permeable compared to the palisade cell layer found in cowpeas with thick seed coats. Cotyledon compactness influenced cooking time of cowpeas. Cowpeas with porous cotyledons cooked faster compared to cowpeas with compact cotyledon probably because of the structural arrangement of porous cotyledon cells that provide more intercellular spaces for rapid water entry, cell expansion and separation favouring a faster cooking process compared to compact cotyledon.

Seed coat and cotyledon structures directly influenced very few of the cooking and sensory characteristics. Sensory attributes such as cooked cowpea flavour, degree of sweetness, degree of sweet aftertaste, and degree of mushiness positively contributed to consumers' liking of cowpeas. Raw cowpea flavour, bitter taste, degree of bitter aftertaste and degree of firmness contributed to consumers' disliking of cowpeas. Chemical composition of cowpeas probably influences sensory characteristics of cowpeas more than seed coat and cotyledon structures.

It is recommended that breeders work together with food scientists in order to release cowpeas types that are preferred by consumers (i.e. cowpeas with good appearance (low percentage of splitting), good flavour and soft texture upon cooking.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION AND PROBLEM STATEMENT

Cowpea *(Vigna unguiculata* L. Walp*)* constitutes an excellent source of high quality proteins, carbohydrates, minerals, vitamins and dietary fibre in the diet of populations, especially in the developing countries where they are readily available (Wu, 2002). The dry grain of cowpea, according to Taiwo, Akanbi & Ajibola (1997b), is the principal product used for human consumption. Leaves (mostly in eastern Africa), fresh peas (the southern US and Senegal) and fresh green pods (humid regions of Asia and the Caribbean), are also consumed. The whole grain is cooked and consumed, alone or with maize, rice or sorghum. It can also be soaked, dehulled and ground into a paste to produce akara or moin-moin (Uwaegbute, Iroegbu & Eke, 2000).

Cowpea is a widely adapted, drought tolerant grain legume (IITA, 2006). The total area grown for cowpea worldwide in 2003 was 9.8 million ha of which about 91% was in West Africa (Mahalakshmi, Lawson & Ortiz, 2007). Food and Agriculture Organization (FAO) estimated that 3.7 million tonnes of cowpea dry grains were produced worldwide in 2003 (Mahalakshmi *et al*., 2007). The world average yield was estimated as 378 kg/ha (Mahalakshmi *et al*., 2007). About ⅔ of the production and more than ¾ of the area of production is spread over the Sudan Savanna and Sahelian zones of sub-Saharan Africa from Senegal going east through Nigeria and Niger, from Angola across Botswana to Mozambique, Kenya and Tanzania (Ehlers & Hall, 1997).

Cowpea production for food uses comprises various varieties. Plant breeders are responsible for making new varieties available on the market. To release new varieties, breeders consider yield, early maturity, pest resistance, drought tolerance, nutritional value and consumer preferred-traits such as large seeds size and colour (IITA, 2006). However, consumers do not always adopt these new varieties. Consumers may have a completely different set of criteria than breeders, that include cooking and sensory characteristics (Taiwo, 1998). Thus, consumer preference information is essential to direct cowpea breeding research (Langyintuo, Ntoukam, Murdock, Lowenberg-DeBoer & Miller, 2004).

Various physicochemical and sensory characteristics may influence consumer preferences of whole cooked cowpeas. These are for example, seed size, seed coat colour (Langyintuo *et al.,* 2004**)** and cooking characteristics such as cooking time, mouth feel and texture (Taiwo, 1998). Physical (i.e. seed coat and cotyledon structure) and compositional (e.g. protein and starch) characteristics of cowpeas may influence cooking characteristics and ultimately consumer preferences of cowpea types.

The influence of seed coat and cotyledon structure on the water absorption (Sefa-Dedeh & Stanley, 1979c) and texture of soaked and cooked cowpeas (Sefa-Dedeh & Stanley, 1979b) has been briefly investigated. It was found that the seed coat and cotyledon structure play a significant role on cooking characteristics such as water absorption, cooking time and texture of cooked cowpeas. For example cowpeas with thin seed coats have shown rapid water absorption compared to cowpeas with thick seed coats (Sefa-Dedeh & Stanley, 1979c). The same authors reported that porous cotyledon of certain cowpeas may explain the rapid absorption of water compared to compact cotyledon. Porous cotyledon may allow for the rapid channelling of water in the cotyledon.

Seed coat has been reported to be the major barrier for seed softening, when cooking time was compared between whole and decorticated beans (Jackson & Varriano-Marston, 1981). However, it seems that there has been limited research done regarding the specific role and contribution of seed coat and cotyledon structure of cowpeas on cooking characteristics such as cooking time, splitting of cooked cowpeas, sensory characteristics (e.g. texture, taste and aroma) and ultimately consumer preferences.

2 LITERATURE REVIEW

This literature review discusses the influence of seed coat and cotyledon structure of cowpeas in cooking, sensory characteristics and consumer preference, and identifies the gaps in knowledge.

2.1 Structure and chemical composition of cowpea seed

It is important to understand the structure and chemical composition of cowpea seeds to explain the underlying physicochemical changes that occur during soaking and cooking, which in turn may eventually influence consumer preferences.

2.1.1 Structure of cowpea seed

The cowpea seed is composed of seed coat, cotyledon, hilum, micropyle and germ or embryo (Figure 2.1).

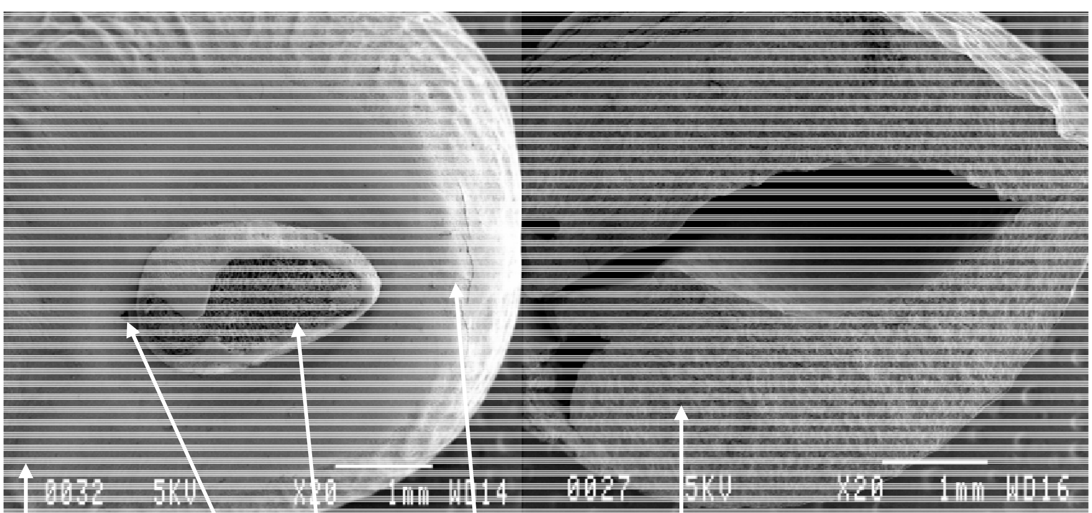


Figure 2.1 Scanning electron microscopy of California Black cowpea seed showing seed coat, micropyle, hilum, raphe and cotyledon

Cowpeas vary in terms of size (length, width and thickness) and seed weight, according to variety and origin of the seeds as reported by different authors (Table

2.1). The hilum has been reported to range in length from 2 to 3 mm (Sefa-Dedeh & Stanley, 1979c).

Table 2.1 Seed size (length, width and thickness) and 100 seed weight of cowpeas

Seed characteristic	Sefa-Dedeh & Stanley (1979c) (modified)	Demooy & Demooy (1990) (modified)	Giami (2005)
Length (mm)	6.1 (0.6)-8.8 (0.9)	5.0-8.8	6.3 (0.3)-8.8 (0.5)
Width (mm)	5.2 (0.3)-7.3 (0.6)	5.0-6.8	4.8 (0.3)-5.8 (0.4)
Thickness (mm)	3.9 (0.2)-5.1 (0.4)	4.0-5.3	a
100-seed weight (g)	a	7.5-19.2	12.5 (0.2)-18.6 (0.4)

[a] No reported value, Standard deviations in parentheses

2.1.1.1 The seed coat structure

The seed coat is a layer that provides physical protection to the cotyledons from the external environment of the cowpea seed. The percentage of seed coat in cowpeas has been reported to vary from between 9.3 and 33% (Ehlers & Hall, 1997). Cowpea seed coat consists of various colours ranging from white through various shades of buff, green, brown, red and purple to black; the predominant colours are brown and a combination of white and brown (Taiwo, 1998). The surface of the seed coat has been reported to vary: thick seed coated cowpeas showed a smooth surface while thin seed coated cowpeas showed a rough and a convoluted surface (Sefa-Dedeh & Stanley, 1979c).

According to Ma, Cholewa, Mohamed, Reterson & Gijzen (2004), a typical legume seed coat contains numerous specified areas, i.e. hilum, micropyle, raphe and the seed coat (Figure 2.1). The hilum, an elliptical area is a scar formed when the funiculus (the part of a pod that links to the seed) detaches from the seed at maturity (Ma *et al*., 2004). The micropyle is the pore through which the radicle emerges during seed germination (Ma *et al*., 2004). It is located just below the hilum. Micropyle may be a Y-shaped closed or can be a circular open micropyle depending upon cowpea type (Sefa-Dedeh & Stanley, 1979c**).** The raphe is a slightly depressed area on the opposite side of the micropyle beneath the hilum (Ma *et al*., 2004). Lush & Evans (1980) observed that in smooth-coated cowpeas the micropyle and raphe were closed while in rough seed coats the micropyle was open and the amorphous cell layer in the seed coat was relatively thin as compared to palisade cell layers in smooth seed coats.

The microstructure of the seed coat consists of an external layer known as cuticle or waxy layer (may be present or absent) followed by epidermis (palisade cell layer or amorphous cell layer, according to cowpea type), hypodermis or hour glass layer and parenchyma cell layer. Figure 2.2 shows the seed coat comprised of palisade cell layer and hourglass layer and the cotyledon storage parenchyma cell layer.

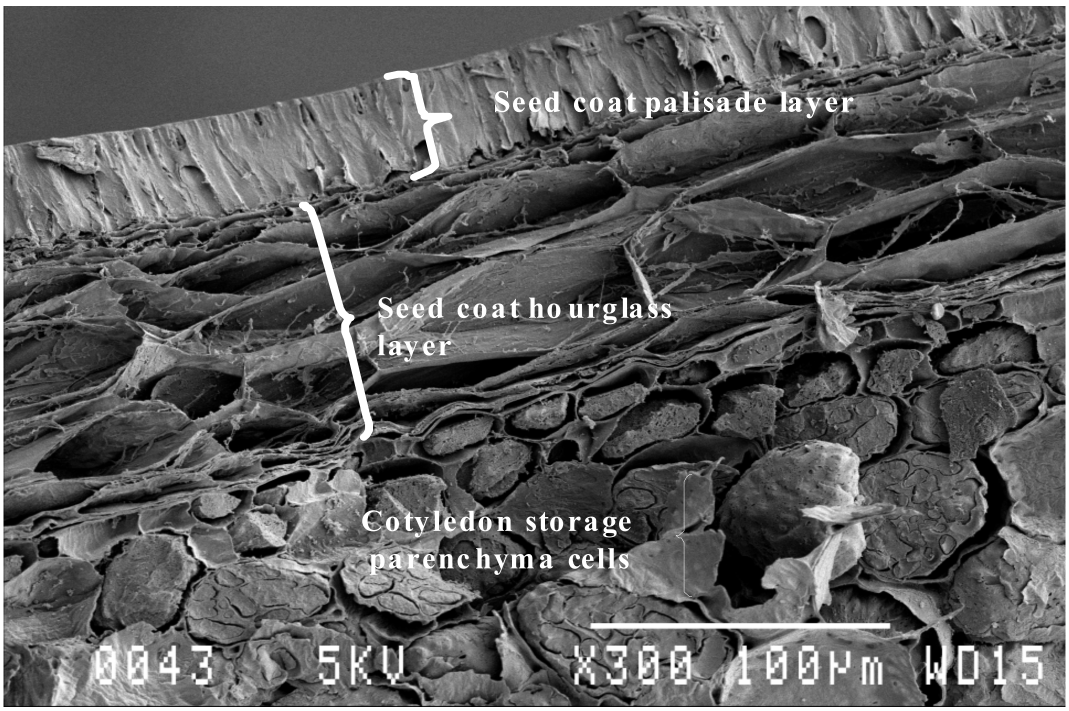


Figure 2.2 Scanning electron microscopy of a cross section of a conditioned Bechuana white cowpea seed (Phadi, 2004)

The epidermal layer of cowpeas may consist of a palisade layer made up of well organized palisade cells consisting of thick-walled, elongated cells with the long axis oriented perpendicularly to the surface (De Sousa & Marcos-Filho, 2001). Sefa-Dedeh & Stanley (1979c) reported that well organized palisade cells are associated with relatively thick seed coats ranging from 43 to 59 µm. In addition, the epidermal cell layer may consist of an amorphous layer (Sefa-Dedeh & Stanley 1979b; Agbo, Hosfield, Uebersax & Klomparens, 1987) which, according to Sefa-Dedeh & Stanley (1979b) comprises loosely packed cells where distinct palisade cells cannot be identified. Amorphous cells are associated with thin seed coats (Sefa-Dedeh & Stanley, 1979b), ranging from 5.8 to 9.9 µm (Sefa-Dedeh & Stanley, 1979c). The next layer of the seed coat is the hypodermis, also called hour glass layer, comprising pillar cells. They are larger than the adjacent cell layers and are separated by wide intercellular spaces, except under the hilum fissure where they are absent (De Sousa & Marcos-Filho, 2001). The internal structure of the seed coat is the parenchymateous layer formed by layers of thin-walled, tangentially elongated parenchyma cells (De Sousa & Marcos-Filho, 2001).

2.1.1.2 The cotyledon structure

Cowpea seed is composed of two cotyledons covered by a seed coat. The cotyledon forms a major part of the seed (Sefa-Dedeh & Stanley, 1979a). It comprises parenchyma cells which are known as storage sites of most nutrients (Sathe & Despande, 2002), for example carbohydrates and proteins as the main components (Sefa-Dedeh & Stanley, 1979c). The cotyledon parenchyma cells are reported to have intercellular spaces that may be in compact cotyledons (few intercellular spaces) or porous cotyledons (many intercellular spaces). The parenchyma cells range in length from 60 to 120 µm, with irregular shape, showing starch granules, protein bodies and a cytoplasmic matrix (Phadi, 2004) (Figure 2.3) and some lipid bodies mainly found along the cell wall (Saio & Monma, 1993).

2.1.2 Chemical composition of cowpea seed

Table 2.2 presents the proximate composition of the dry cowpea seeds, showing variations probably due to differences in terms of variety, growth location of the seeds, and agronomic practices (Hsieh, Pomeranz & Swanson, 1992).

The legume family of plants (plants producing pods) is not only an important source of proteins and carbohydrates, but also a good source of several B-complex vitamins, minerals and fibre (Wu, 2002). According to Prinyawiwatkul, McWatters, Beuchat & Phillips (1996) cowpeas are a good source of niacin, thiamine, and other water soluble vitamins, and essential minerals for example calcium, magnesium, potassium, and phosphorus (Table 2. 3).

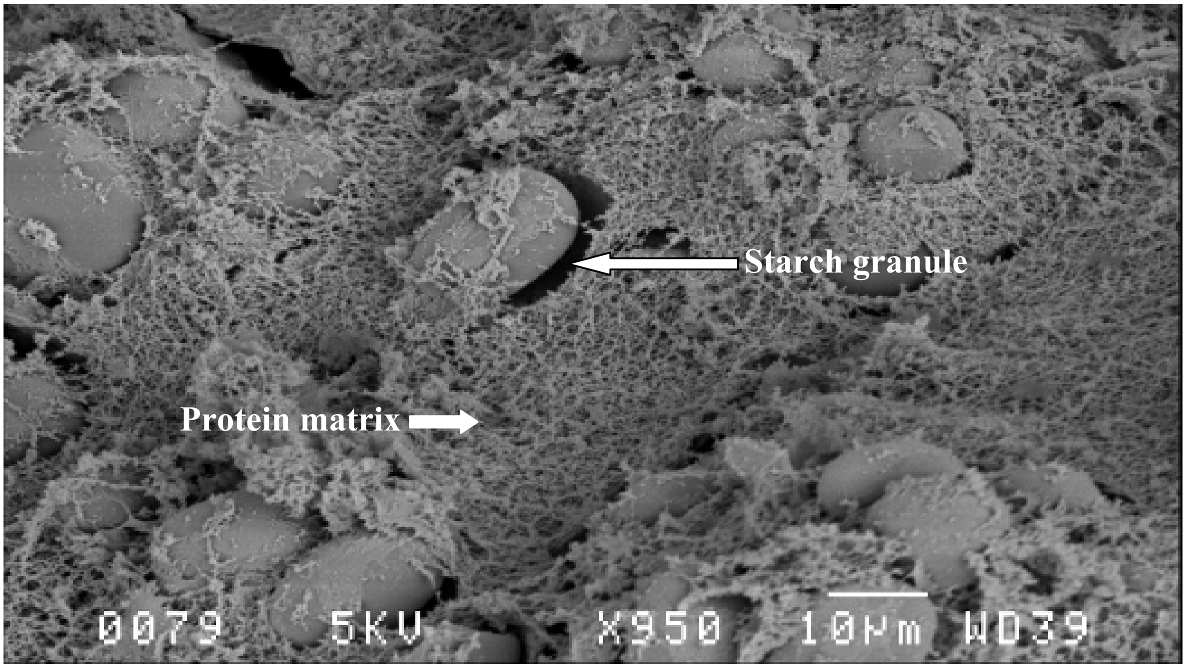


Figure 2.3 Scanning electron microscopy of the cotyledon cross section of a tempered raw Bechuana white cowpea (Phadi, 2004)

Table 2.2 Proximate composition of cowpeas

Parameter	Taiwo (1998) (modified)	Uwaegbute *et al.* (2000) (modified)	Phadi (2004) (modified)
Moisture (%)	9.8	15.6 (0.1)	8.6 ((0.1)
Fibre (%)	1.9	1.3 (2.0)	a
Ash (%)	3,4	1.3 (1.2)	3.5 (0.1)
Protein (%)	24.9	24.2 (0.4)	22.3 (0.4)
Lipid (%)	3.8	3.5 (0.1)	1.4 (0.02)
Carbohydrate (%)	56.4	50.3 (0.4)	64.2 (0.5)

[a] No reported values. Standard deviations of mean values are in parenthesis.

2.1.2.1 Proteins

Proteins are biological macromolecules made up of amino acids as monomeric units (Damodaran, 1996). The protein in cowpea seeds is rich in amino acids, aspartic acid, glutamic acid and lysine, but deficient in methionine and cystine, compared to cereal grain proteins which are poor in lysine but rich in these sulphur amino acids (Prinyawiwatkul *et al.*, 1996). Duranti (2006) reported that legume seeds accumulate large amounts of protein during their development. Most of them are devoid of metabolic activity and play no structural role in the cotyledonary tissue. They are stored in membrane bound organelles, protein bodies or in the cotyledonary parenchyma cells.

Table 2.3 Vitamins and mineral content of cowpeas at 12% moisture content (Prinyawiwatkul *et al.*, 1996)

Vitamins	mg/100g	Minerals	mg/100g
Niacin	2.0	Calcium	110.0
Thiamin	0.9	Copper	0.8
Riboflavin	0.2	Ion	8.3
Pyridoxin	0.4	Magnesium	184.0
Folacin	0.6	Phosphorus	125.0
Pantothenic acid	1.5	Potassium	110.0
Ascorbic acid	1.5	Selenium	84.5
		Sodium	16.2
		Zinc	3.4

Storage proteins are classified based on their solubility: albumins are soluble in water; globulins in dilute salt solutions, prolamins in dilute alcohol and glutelins are soluble in dilute acid or alkali solutions (Chan & Phillips, 1994; Shewry, Napier & Tatham, 1995). The globulin fractions are reported as the major cowpea seed proteins with 66.6% of the total, followed by albumins with 24.9% (Chan & Philips, 1994). Values such as 51% globulins of total proteins and 45% albumins of the total seed proteins were also reported by Freitas, Teixeira & Ferreira (2004). Differences in protein fractions may be related to the extraction method used (wet or dry basis). Duranti (2006) reported that globulins are generally classified as 7S or vicilin and 11S or legumins according to their sedimentation coefficients (S). Sathe (2002) reported that legumin-type proteins are typically hexameric, nonglycosylated, high molecular weight (~ 400 to 500 k) proteins, while vicilin-like proteins are usually trimeric glycosylated, ~150 to 180 k molecular weight proteins.

2.1.2.2 Starch

Starch is a biopolymer in which glucose is mainly polymerised into mylase and amylopectin. This polymerisation results in a densely packed semi crystalline structure in granules (Błaszczak, Valverde & Fornal, 2005). It is usually stored as microscopically small granules in the seeds and roots of plants (Sathe, Deshpande & Salunkhe, 1984). Starch provides the major source of physiological energy in human diet and accordingly it is classified, in general, as available carbohydrate (Tharanathan & Mahadevamma, 2003). It has been reported that starch is the most abundant single carbohydrate fraction in cowpea and its content was found ranging from 26% to 48% (Longe, 1980) and from 30 to 50% (Campechano-Correra, Corona-Cruz, Chel-Guerrero & Betancur-Ancona, 2007) according to variety and origin of the seeds. The ratio of mylase/amylopectin in cowpea has bean reported to be 25.8:23.8 db (Huang, Schols, Soest, Jin, Sulmann & Voragen, 2007). The properties of the starch components depend upon the type of starch, its maturity, agro-climatic conditions and the type of cultivar. Amylose is a linear polymer of α-(1-4) linkages of glucose units and amylopectin is a highly branched molecule consisting of a main chain of (1-4)-linked α-D-glucose with short chains of (1-6)-α-D-glucose-linked branches (Tharanathan & Mahadevamma, 2003). The native starch granules of cowpeas exhibit variations in terms of shape and size, being morphologically irregular, oval and kidney-shaped (Jacobs & Delcour, 1998; Agunbiade & Longe 1999). The size distribution of cowpea starch granules has been reported to range in length and width from 7.5 to 37.5 µm and 5 to 27.5 µm, respectively (Agunbiade & Longe, 1999).

2.1.2.3 Non starch polysaccharides

Non starch polysaccharides are generally cell wall substances in plants, also called dietary fibre. They represent a combination of chemically heterogeneous substances including pectin, cellulose, hemicellulose (Tharanathan & Muhadevamma, 2003). Pectic substances have been reported to be complex polysaccharides present in the primary cell wall and middle lamella where they play important roles such as hydrating agents and cementing materials for the cellulosic network (Muralikrishna & Tharanathan, 1994). Pectin molecule is a linear polymer composed of α-D-galacturonic acid linked through 1- and 4- positions, with a proportion of the carboxyl groups esterified with methanol (Coultate, 2002). Muralikrishna & Tharanathan (1994) characterised pectic polysaccharides from pulse husks and found that cowpea pectic substances contain sugar compositions of rhamnose, arabinose, xylose, mannose and glucose.

2.1.2.4. Phenolic compounds

Cowpeas also contain phenolic compounds which are mainly located in the seed coat (Bressani & Elias, 1980). Giami (2005) reported significant (p<0.05) differences between the values obtained for polyphenol contents of raw and heat-processed samples from unpigmented and pigmented cowpeas (Table 2.4).

Table 2.4 Phenolic contents of raw, cooked, raw pigmented and raw unpigmented cowpeas adopted from information in Giami (2005)

Sample	Phenolic compounds (mg/g)
Raw cowpeas	0.99 (0.02)-1.96 (0.02)
Cooked cowpeas	0.52 (0.03)-0.78 (0.04)
Raw pigmented cowpeas	1.92-1.96
Raw unpigmented cowpeas	0.99

2.2. Microstructural and compositional factors of cowpeas affecting soaking characteristics

Soaking consists of placing seeds in water for imbibition until saturation, prior to cooking. Bernal-Lugo, Parra, Portilla, Pena-Valdivia & Moreno (1997) reported that during soaking of beans, an enzymic breakdown within or between cell wall polymers takes place, initiating the degradation of pectin that lead to softening of the seeds and thus, reducing the cooking time (Taiwo, Akanbi & Ajibola, 1997a).

2.2.1 Water absorption and hydration capacity

It has been observed that structure and composition of the seed coat and cotyledon affect water absorption and hydration capacity during soaking (Agbo, Hosfield, Uebersax & Klomparens, 1987) leading to differences in softening of the soaked cowpeas. Water absorption is an essential first step towards the seed hydration required for initiation of changes that lead to cooked cowpeas (Asiedu, Powell & Stuchbery, 2000). This is because the seeds need to absorb water and swell for cellular expansion which is important for achieving soft cooked cowpeas.

2.2.1.1 Structure and composition of the seed coat

The seed coat is the first part of the cowpea seed in direct contact with water during soaking or cooking. It is one of the pathways for water to the cotyledon. Several structures have been reported as possible sites of entry of water: the hilum, the micropyle, the raphe (Swanson, Hughes & Rasmussen (1985) and the seed coat (Sefa-Dedeh & Stanley, 1979b). However, it is not exactly clear what the major site for entry of water into the seed is.

The hilum size as well as the nature and size of the micropyle have been reported to influence water absorption during soaking of cowpeas (Sefa-Dedeh & Stanley, 1979b). High hilum length and open and large opening of the micropyle have been reported to promote rapid water absorption during soaking (Sefa-Dedeh & Stanley, 1979b; Sefa-Dedeh & Stanley, 1979c).

Seed coat thickness has been reported to influence the water absorption during soaking (Sefa-Dedeh & Stanley, 1979b; Sefa-Dedeh & Stanley, 1979c). Thick seed coat comprises palisade cells (well organised) which are bound together and forming a layer that constitute a barrier to rapid water absorption on the first hours of soaking (Agbo *et al.*, 1987). The small intercellular spaces of the contracted palisade cell layer promote low permeability (Agbo *et al*., 1987)). A waxy layer on the top side of the palisade cell layer was reported to contribute to delayed hydration because of its hydrophobic characteristic (Sefa-Dedeh & Stanley, 1979b). Thin seed coats, characterised by amorphous cells (disorganised) form a layer that facilitate rapid water absorption during the first 6 h of soaking (Sefa-Dedeh & Stanley, 1979c). This is due to the structural arrangement of the amorphous cells which is characterised by large intercellular spaces (pores) allowing rapid water entry (Agbo *et al*., 1987). Some components such as lipids, cellulose, phenolic compounds, and lignin in the seed coat has been reported to favour low permeability to water in the legume *Rhynchosia minima* (Rangaswamy & Nandakumar, 1985).

2.2.1.2 Structure and composition of the cotyledon

Differences in the mode of seed coat attachment to the cotyledon have been described as affecting water absorption during soaking (Sefa-Dedeh & Stanley, 1979c; Lush & Evans, 1980). Olapade, Okafor, Ozumba & Olatunji (2002) postulated that cowpeas with a tightly attached seed coat absorbed water slowly during initial soaking while cowpeas with moderately attached seed coats showed rapid water absorption during initial soaking. However, there is no scientific evidence for this statement.

After entering the seed coat, water is transported to the cotyledon via parenchyma cells of the seed coat. Then the water enters the cotyledon through intercellular spaces of the epidermis and goes to the storage parenchyma cells of the cotyledon where it reaches the water absorbing components e.g. starch, proteins, pectin (Jackson & Varriano-Marston, 1981). However, differences in the seed cotyledon structure among cowpea types have been reported to affect hydration rate. Sefa-Dedeh & Stanley (1979c) suggested that cowpeas with porous cotyledons had higher rates of hydration than those with compact cotyledons.

The seed composition (proteins starch, pectin, hemicellulose/cellulose) has been reported to influence hydration capacity. Hydration capacity indicates the ability of proteins to absorb water and retain it through the formation of hydrogen linkages with the polar side chains (Sefa-Dedeh & Stanley, 1979c). Hydrated proteins in cowpeas were reported to facilitate the hydration process of the cotyledon cells (Mwangwela, 2006) since cowpea proteins are mainly composed of globulins (soluble in diluted salt solutions) and albumins (soluble in water) (Freitas *et al*., 2004) they have the ability to bind with water. Hydration capacity is an indication of the water holding capacity of the seeds. It was reported to range from 1.14 to 1.60 g/g seeds after soaking different cowpea types for 24 h at 30±2 ^{o}C (Olapade *et al*., 2002). Proteins also have the ability to retain water against gravitational forces within a protein matrix and other macromolecules (such as starch, pectic substances) (Sikorski, 1997). This is because cowpea proteins exhibit more hydrophilic properties than other macromolecules (e.g.

starch, pectic substances) favouring hydration (Horax, Hettiarachchy, Chen & Jalaluddin, 2004).

Hydration plays an important role in softening of the cowpeas. For instance, Bernal-Lugo *et al.* (1997) found that during soaking pectin which is mainly found in the middle lamella starts to degrade via enzymic breakdown contributing to softening of the soaked cowpeas.

2.2.1.3 Other factors

Temperature of soaking water has been reported to increase the rate of water uptake and to decrease the time required to attain maximum absorption (Patane, Iacoponi & Raccuia (2004). Soaking cowpeas at high temperature (up to 75 ^{o}C) started softening the seed texture thereby reducing cooking time from four to one hour (Taiwo, Akanbi & Ajibola, 1997a).

2.3 Changes in structural and physicochemical characteristics of cowpeas during cooking

Cowpea seeds are cooked to obtain a soft texture and develop a desirable flavour for consumption (Aremu, 1991). These characteristics are the result of some structural and compositional changes of the seed during cooking (Taiwo *et al.*, 1997a). The cooking properties of grain legumes are dependent on factors such as seed structure and composition (Bishnoi & Khetarpaul, 1993).

Tester & Karkalas (1996) reported that during the heating, hydrogen bonds responsible for stability of the double helices in crystallites of starch granules are broken and hydrogen bonds with water are formed. As a result, the starch granules absorb water and swell, increasing its volume. The starch granules lose their birefringence contributing to the softening of the cowpea seeds (Tester & Karkalas, 1996). Due to their more hydrophilic characteristic, proteins have been reported to be the main water absorption components (Sefa-Dedeh & Stanley, 1979c) helping the hydration process of the cotyledon cells. Akinyele Onigbinde, Hussain & Omololu (1986) found that the cooking time of cowpea seeds increased with an increase in protein content. Protein denaturation, the change in its molecular structure, also contributes to softening of the cowpea seeds in the cooking process. Poor hydration of the seeds may result in incomplete cellular expansion and separation of the cells and in limited starch gelatinisation resulting in grainy mouth feel (Mwangwela, 2006).

Cooking time is one of the major criteria involved in the evaluation of pulse quality (Proctor & Watts, 1987) and thus, it is considered a critical limitation to consumption of whole cowpeas as food (Giami, 2005). Cooking brings about numerous changes in physical characteristics and chemical composition of food legumes (Rehinan, Rashid & Shah, 2003). The main changes taking place during cooking cowpeas to attain a soft texture are as follows. As the seeds absorb water they hydrate during cooking, the glycosidic bonds linking middle lamellae pectin polymers break down (Golonka, Drizek & Klusa, 2002) thereby softening the seeds. The cells expand and separate, starch gelatinises and protein denatures. These two processes are reported to play an important role in the cooking process (Golonka *et al*., 2002). Gelatinisation of cowpea starch has been reported as the main structural and physicochemical change in the cotyledon cells contributing to softening of cowpea seeds (Sefa-Dedeh, Stanley & Voisey, 1979).

Cooking time has been defined as the time necessary for cowpeas to reach a soft cooked texture acceptable to consumers. Cooking time has been reported to vary from 31 to 160 minutes (Akinyele *et al*., 1986). Demooy & Demooy (1990), found a range of cooking times of 36 to 56 min. Cooking time has been reported to significantly reduce when cowpeas are dehulled prior to cooking, from 62 to 24 min (Jackson & Varriano-Marston, 1981) probably because the seed coat water absorption barrier has been removed encouraging relatively faster water absorption and consequently resulting in short cooking times.

2.3.1 Changes in sensory characteristics of cowpeas during cooking

2.3.1.1 Splitting

Splits are described as all seeds with cracks greater than 1/5 of the small circumference of the seeds (Taiwo e*t al*., 1997a). Splitting is generally considered to be an undesirable characteristic for consumers (Afoakwa, Yenyi & Sakyi-Dawson, 2006). Depending on the cultivar, seeds may split transversally below the hilum maintaining the two cotyledons in two portions. Each piece of the split has a piece of the two cotyledons held together by a portion of the seed coat. Splitting may also occur at the ends in a longitudinal manner (Taiwo *et al.*, 1997a). Percentage of splitting of cowpea seeds has been reported to range from 63 to 92% (Taiwo *et al.*, 1997a) and from 41 to 92% and to be strongly influenced by differences in seed variety in terms of physicochemical characteristics (Taiwo, Akanbi & Ajibola, 1998). Splitting during cooking may be due to compactness of the seed cotyledon that does not facilitate easy water entry and heat transfer. Heat and vapour pressure during cooking force the compact structural arrangement of some cowpeas to split up.

Occasionally, the cotyledon may disintegrate in the cooking water resulting in empty pieces of seed coat (Taiwo *et al.*, 1997a) or the seed coat may split separating from the cotyledon. Splitting of the seeds has been reported to be also affected by calcium content of the cowpea seed and starch gelatinisation. Low levels of calcium favour pectin solubilisation increasing softening of the seeds which may lead to splitting (Lu, Chang, Grafton & Schwarz, 1996).

High water absorption of cowpea seeds during cooking has been associated with increased splitting (Taiwo *et al.,* 1998; Mwangwela, 2006). Splitting of cowpea seeds depends upon variety, pre-treatment such as soaking, and water absorption, and has shown to increase with cooking time. A positive correlation between drained weight, texture (penetration depth) and splitting tendency has been observed (Taiwo *et al*., 1998).

2.3.1.2 Texture

Texture has been described as the sensory and functional manifestation of the structural, mechanical and surface properties of foods detected through the senses of vision, hearing, touch and kinesthetics (Szczesniak, 2002). The texture of cooked cowpeas is an important quality characteristic. Soft texture seems to be more preferred by consumers (Proctor & Watts, 1987). Textural characteristics of legumes may be dependent upon both microstructure and chemical and/or physicochemical changes occurring during cooking (Sefa-Dedeh & Stanley, 1979b; Bernal-Lugo *et al*., 1997).

Studying two cowpea types, Sefa-Dedeh & Stanley (1979b) found that softening of cowpeas increased with cooking time due to the gelatinisation of starch (Taiwo *et al*, 1997a), protein denaturation, and solubilisation of the middle lamella and separation of parenchyma cells during cooking leading to a desired soft texture of cooked cowpeas (Sefa-Dedeh *et al*., 1978; Sefa-Dedeh & Stanley, 1979b). The separation of cells was explained as a result of the heat-catalysed depolymerisation of the middle lamella pectin polymers. The depolymerisation involves beta-eliminative reaction (Figure 2.4) of the middle lamella pectin in which pectin is degraded to lower molecular weight products. Degradation of middle lamella pectin occurs via breakage of glycosidic bonds adjacent to carboxymethyl groups, through pectin lyases which break the glycosidic links between methylated galacturonate residues (Liu, Phillips & McWatters, 1993; Bernal-Lugo *et al*., 1997).

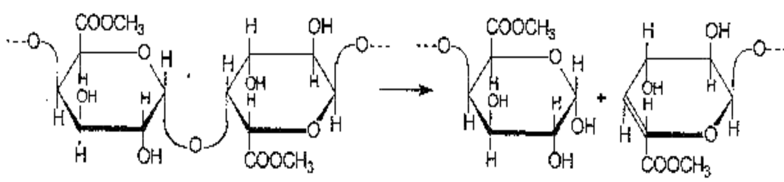


Figure 2.4 Part of β-elimination reaction: breakage of the glycosidic links to low molecule weight products (Coultate, 2002)

In addition, Bernal-Lugo *et al.* (1997) found that solubilisation of pectin resulted from enzymatic degradation of pectin during soaking, followed by thermal dissociation of hydrogen bonding of the pectin polymers in beans during cooking. These mechanisms allow the thermal extension of cell walls that help further cell separation, and the loss of the adhesive forces that cement the cells all together. Therefore, the differences in cooking quality of beans might be related to the thermal solubility properties of pectic substances. Thermal solubility of pectic substances may control the rate of dissolution of the middle lamella and cell wall expansion and rapid water diffusion are required for cell swelling, starch gelatinization and protein denaturation (Bernal-Lugo *et al*., 1997).

2.3.1.3. Flavour

Flavour is described as an overall integrated perception of all the contributing senses that include, smell, taste, sight, feeling and sound during eating (Lawless & Lee, 1993). Taste and aroma are components of flavour perceived during eating food, through the mouth and the nose respectively. Flavour is considered as one of the most important attributes determining food acceptability by consumers (Guichard, 2002). Aroma is considered as a key factor for the acceptance of food by consumer (Buetner & Schieberle, 2000).

There is no available information for cowpeas regarding their sensory characteristics. Relating consumer preferences to physicochemical properties of dry beans (*Phaseolus vulgaris* L), Mkanda (2007) found that consumers had higher preference for some bean varieties because of their sweet, soft and cooked bean flavour compared to the varieties that were described as having bitter taste.

When beans were grown in different locations, some varieties revealed differences in flavour of cooked beans which demonstrated to influence consumer preferences (Mkanda, 2007).

Food matrix components that affect flavour in cooked legumes have been considered to be the major components which interact with flavour compounds and they include proteins, lipids, and phenolic acids (Van Ruth, Dings, Buhr & Posthumus, 2004).

Proteins generally bind with flavour compounds. This binding may influence the flavour of a food. For example, proteins are known to bind with phenolic compounds forming complexes that may influence the flavour of cooked cowpeas. Heng, Van Koningsveld, Gruppen, Van Boekel, Vincken, Roozen & Voragen, (2004) reported that proteins bind with flavour compounds such as saponins contributing to bitterness in food. Mkanda (2007) postulated that saponins encountered in some bean varieties influenced the flavour of cooked beans. However, information regarding influence of seed coat and cotyledon structure on flavour of cooked cowpeas is not available.

2.4 Gaps in knowledge

Cowpeas with thin seed coats have been reported to favour rapid water absorption during soaking (Sefa-Dedeh & Stanley, 1979c; Agbo *et al*., 1987). Differences in seed coat thickness may therefore lead to differences in water absorption characteristics (Sefa-Dedeh *et al*., 1978), cooking time and sensory characteristics (texture and appearance (splitting) of cooked cowpeas) (Taiwo *et al*., 1997a) of cowpeas. However, there is limited information on the influence of the seed coat thickness and cotyledon compactness on cooking and sensory characteristics as well as consumer preferences of cooked cowpeas.

Textural characteristics of legumes may be dependent upon both microstructure and chemical and/or physicochemical changes of the seed samples occurring during cooking (Sefa-Dedeh & Stanley, 1979b; Bernal-Lugo *et al*., 1997). However, there is limited information on what consumers regard to be important factors for cowpea preference. Specific contribution of seed coat and cotyledon structure on cooking and sensory characteristics as well as consumer preferences is lacking. Additionally, there are no conducted studies regarding descriptive sensory characteristics and consumer preference in relation to cowpeas with different seed coat and cotyledon structures.

2.5 Hypotheses

1. Thick seed coat palisade cell layers may create a barrier to rapid water absorption during soaking (Sefa-Dedeh & Stanley, 1979c) and cooking because of lower water permeability compared to thin seed coat amorphous cell layers. This will lead to incomplete starch gelatinisation/pasting, resulting in a relatively hard texture (firmness) of cooked cowpeas.

2. Thick seed coat and compact cotyledons will be more prone to splitting because its intercellular spaces are smaller and therefore they will absorb less water during soaking and cooking compared to thin seed coat and porous cotyledon. The limited cellular expansion plus vapour pressure will lead to splitting of the cowpeas.

3. Thick seed coat cooked cowpeas with hard texture will be found to be less acceptable by consumers because texture is an important cooking quality as soft texture seems to be more preferred by consumers (Proctor & Watts, 1987). Thick seed coat/compact cotyledon cowpeas with high percentage of splitting will have low acceptance because splitting is generally considered to be an undesirable characteristic for consumers (Afoakwa *et al*., 2006).

2.6 Objectives

The overall objective of this study is to determine the influence of seed coat and cotyledon structure of cowpeas on cooking and sensory characteristics as well as consumer preference.

The specific objectives are:

a) To characterise different cowpea types in terms of seed coat thickness and cotyledon compactness;
b) To determine the influence of seed coat thickness and cotyledon compactness on cooking characteristics such as cooking time, water absorption, percentage of splitting during cooking and the texture of cooked cowpeas
c) To determine the influence of seed coat thickness and cotyledon compactness of cowpeas on sensory characteristics and consumer preferences of cooked cowpeas.

3. RESEARCH

The research work comprised three sections. The first section characterised ten cowpea types in terms of seed coat thickness and cotyledon compactness as well as selected physicochemical characteristics (i.e. seed coat thickness, seed size, pH, moisture content, bulk density and cooking time). The second section evaluated the role of seed coat and cotyledon structure on cooking characteristics (i.e. water absorption during soaking and cooking, cooking time, splitting during cooking and texture of cooked cowpeas) of four selected cowpea types [thick seed coat/compact cotyledon (Bechuana White), thick seed coat/porous cotyledon (IT82E 18), thin seed coat/compact cotyledon (Black Eye) and thin seed coat/porous cotyledon (California Black)]. The third section focused on the role of seed coat thickness and cotyledon compactness on sensory characteristics (appearance, aroma, taste and texture) and consumer preferences.

3.1. Characterisation of cowpea types regarding seed coat and cotyledon structure and physicochemical characteristics

3.1.1 Abstract

Ten cowpea (*Vigna unguiculata* L Walp) types were characterised in order to select four cowpea types representing different combinations of seed coat thickness and cotyledon compactness. The characterisation was based on the seed coat and cotyledon structure as determined by Scanning Electron Microscopy (SEM) and bulk density (to confirm cotyledon compactness) of the seeds as well as some physicochemical characteristics (seed size, moisture content, pH and cooking time). The characterisation of the ten cowpea types resulted in grouping the cowpea types as follows: (i) Thin seed coat/porous cotyledon (27 Climber and California Black); (ii) Thin seed coat/compact cotyledon (Black Eye and 8 Dwarf); (iii) Thick seed coat/porous cotyledon (223/1 Climber, IT82e 18 and IT82E 16); and (iv) Thick seed coat/compact cotyledon (Bechuana White, INIA 36 and 418 Warf). Bechuana White, Black Eye, California Black and IT82E 18 were selected for further research work based on the availability of raw material and physicochemical characteristics (i.e. cooking time).

3.1.2 Introduction

Cowpea varieties differ in microstructure in terms of seed coat thickness and cotyledon compactness. De Sousa & Marcos-Filho (2001) reported that cowpea seed coats may be thick comprising well organized palisade cell layer. Palisade cell layer in the seed coats has thickness ranging from 43 to 59 µm (Sefa-Dedeh & Stanley, 1979c). Alternatively, the seed coats may be thin containing amorphous cell layer (Sefa-Dedeh & Stanley 1979b; Agbo *et al*., 1987). These amorphous cell layers are loosely packed cells where distinct palisade cells cannot be identified. The thickness of amorphous cell layers range from 5.8 to 9.9 µm (Sefa-Dedeh & Stanley, 1979c). The present research chapter aims to characterise ten cowpea types in terms of physicochemical qualities in order to select four cowpea types for further research work.

3.1.3 Material and methods

3.1.3.1 Cowpea samples

The set of ten cowpea types initially used as raw material comprised: 27 Climber, 223/1 Climber, 8 Dwarf and 418 Dwarf from Malawi (Lilongwe, Bunda College); INIA 36, IT82E 16 and IT82E 18 from Mozambique (Chókwè Agricultural Research Station); California Black from USA; Bechuana White and Black Eye from South Africa. Samples were received, cleaned to remove chaffs, packed in plastic containers and then stored in a cold room at 4 ^{o}C.

3.1.3.2 Seed coat and cotyledon structure: Scanning Electron Microscopy

Seed coat and cotyledon structures of the cowpea samples were examined using Scanning Electron Microscopy (SEM) model JSM-840® JEOL (Tokyo, Japan). The samples were sliced with a razor blade cutting the seeds transversally and mounted on specimen stubs and coated with a 30 nm thick layer of gold using a Sputter coater, model Polaron E5200C® (Watford, England). Seed coat thickness of the micrograph was measured with Image Tool Software Version 7.0.

3.1.3.3. Bulk density

Bulk density was determined according to the method of Fasina, Tyler, Pickard & Zheng (1999) with modifications. Cowpea seeds were placed in a metal funnel and allowed to flow from 15.5 cm height into a 60 ml metal cup. Without pressing, the seeds were levelled with a metal scraper and then weighed. The bulk density was then calculated as the ratio of the weight of the sample in the metal cup to the volume of the cup and expressed as g per cm^3 in dry basis.

3.1.3.4 Moisture content

Moisture content was determined according to the method described by AACC (1995). Whole cowpeas were milled using a Falling Number Mill 3100® (Falling Number, Huddinge, Sweden). Moisture tins were dried in an oven at 103 ºC for one hour and cooled in desiccators for about 10 min. The dried and cooled tins were weighed, and then about 5 g of flour samples of each cowpea type were weighed into the tins. The samples were covered with foil and oven dried for four hours at 103 ºC (±2 ºC). After cooling in desiccators the samples were weighed and the moisture content was calculated as the ratio of weight of the sample before drying to the weight of the sample after drying.

3.1.3.5 pH

The pH of the cowpeas was calculated as described by Liu, Phillips, Hung, Shewfelt & McWatters (1992) using a pH meter. About 5 g of cowpea flour was mixed with 100 ml of deionised water and stirred for 45 min at ambient temperature. The pH value of the mixture was recorded as cowpea tissue pH.

3.1.3.6 Seed size

The size of cowpea seeds was determined as the weight of 100 seeds and expressed as grams per 100 seeds.

3.1.3.7 Cooking time

The cooking time was determined using a modified method by Jackson & Varriano-Marston (1981) with a Mattson cooking device (Mattson, 1946). The apparatus (Figure 3.1.1) has a cooking rack (Mattson cooker) with 25 rods (49.8 g each) and 25 cylindrical holes (9 mm diameter) where seeds were placed. The piercing tip of each rod was placed in contact with the surface of the seed. The Mattson cooker was then placed into a stainless steel pot containing about 1500 ml of boiling deionised water. When a cowpea seed was sufficiently tender, the piercing tip penetrated the cooked seed and the rods dropped through the hole in the saddle (Jackson & Varriano-Marston, 1981). The cooking time was recorded when 20 rods (80%) had fallen through the cooked seeds.

3.1.3.8 Statistical analysis

The experiment was repeated three times. All physicochemical analyses were done in duplicate. ANOVA was performed using Statistica version 7.0 (Stat Soft Inc, Tulsa, USA). Means were compared using Fisher's Least Significant Difference (LSD) at 5% significance level.

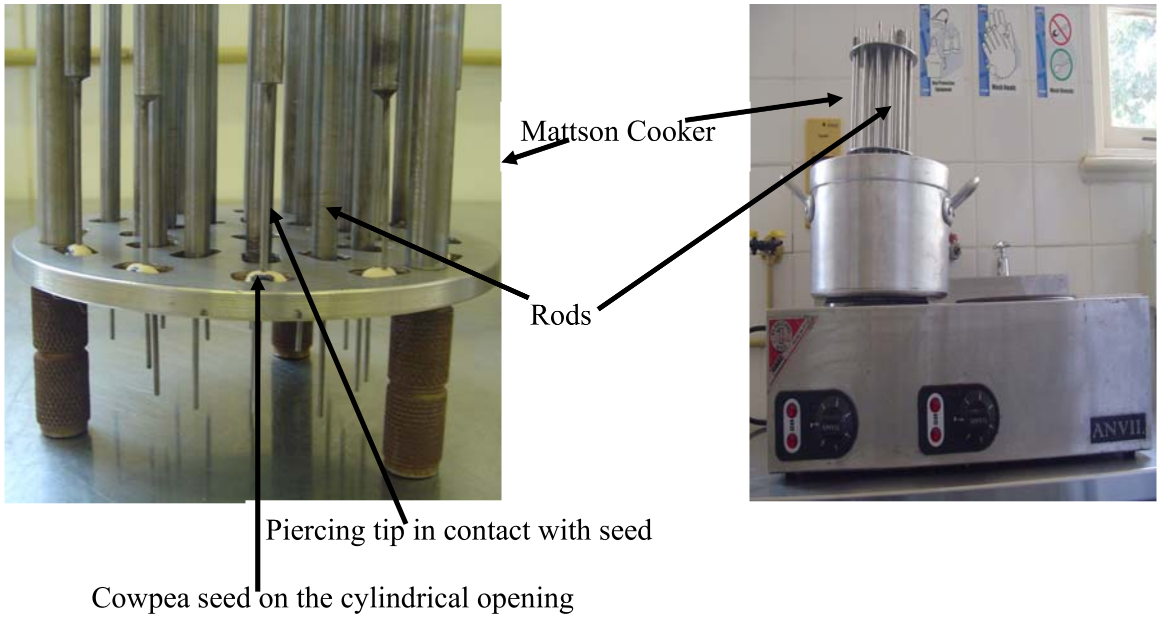


Figure 3.1.1 Mattson cooker with rods, cylindrical holes with seeds

3.1.4 Results and discussion

The SEM of a cross section of seeds of ten cowpea types showed variation in seed coat and cotyledon cell structural arrangement (Figures 3.1.2 to 3.1.11).

Cowpea types IT82E 18, INIA 36, Bechuana White, IT82E 16, 418 Dwarf and 223/1 Climber showed seed coats with palisade cell layers comprising well organized palisade cells (Figures 3.1.3, 4, 5, 7, 8, and 10, respectively). As a result of the dense and structured arrangements, the palisade cell layers form a thick seed coat (Agbo *et al*., 1987) with thickness of the palisade cell layers ranging from 38.3 to 50.6 µm (Table 3.1.1). In contrast, the cowpea types California Black, 27 Climber, Black Eye and 8 Dwarf (Figures 3.1.2, 6, 9 and 11, respectively) showed thin seed coats consisting of amorphous cell layers with thickness ranging from 10.6 to 25.2 µm.

The measured thickness of seed coat palisade cell layer and amorphous cell layer was significantly ($p<0.001$) different among the cowpea types (Table 3.1.1). IT82E 16 and 223/1 Climber did not differ from each other; California Black was similar to 27 Climber, and Bechuana White was similar to IT82E 18. In a study done by Sefa-Dedeh & Stanley (1979c), the seed coat thickness ranged from 5.8 to 9.9 µm for thin seed coats, and 43.3 to 59.3 µm for thick seed coated cowpeas. Cowpea types with thinner seed coats were relatively larger in size as compared to cowpeas with thicker seed coats. Cowpea type Black Eye which had the thickest seed coat value was the smallest in size.

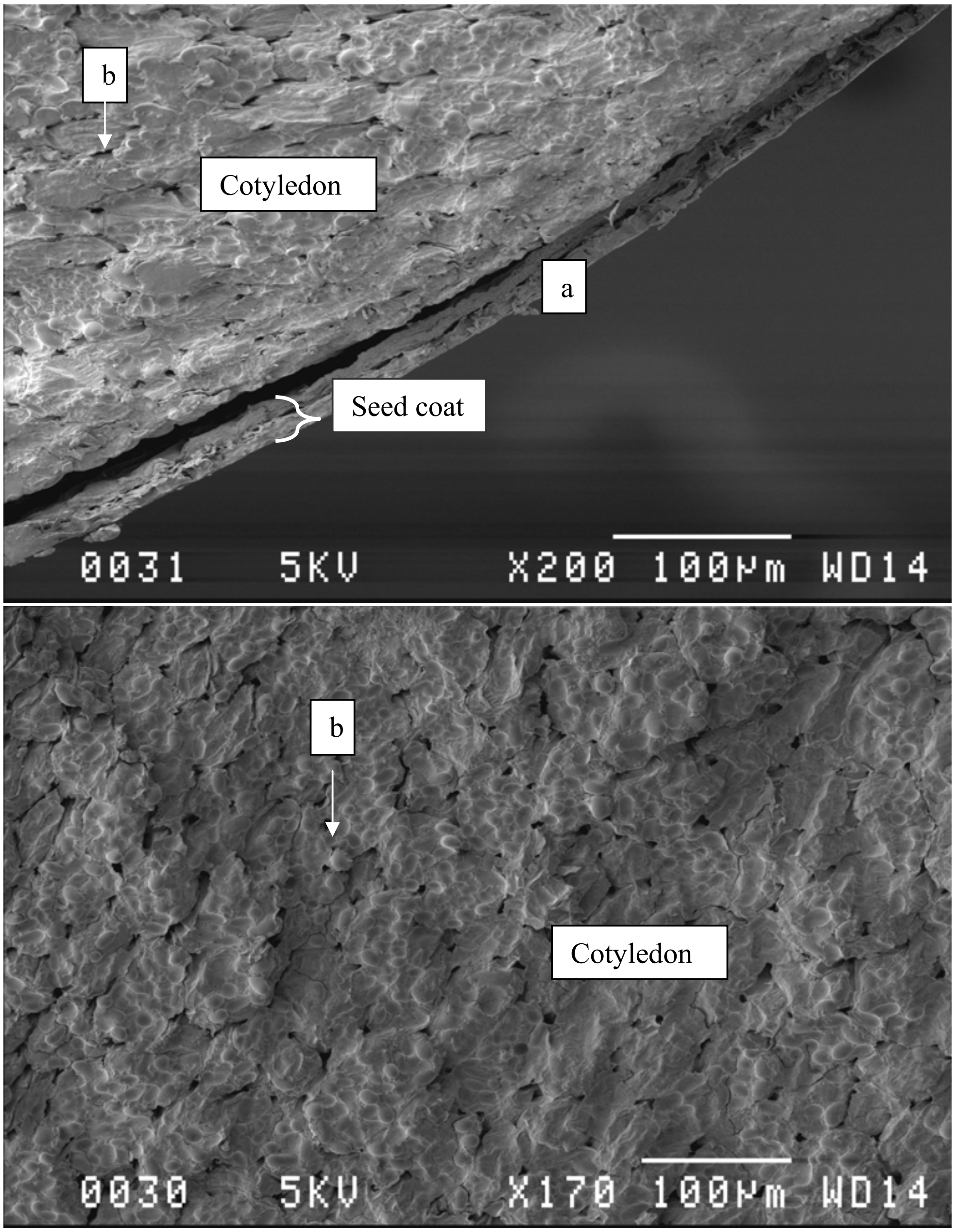


Figure 3.1.2 Scanning Electron Microscopy (SEM) of the seed cross section of California black cowpea type: a- Amorphous cell layer in the seed coat and b- many intercellular spaces in the cotyledon (Cowpea type: Thin seed coat / Porous cotyledon)

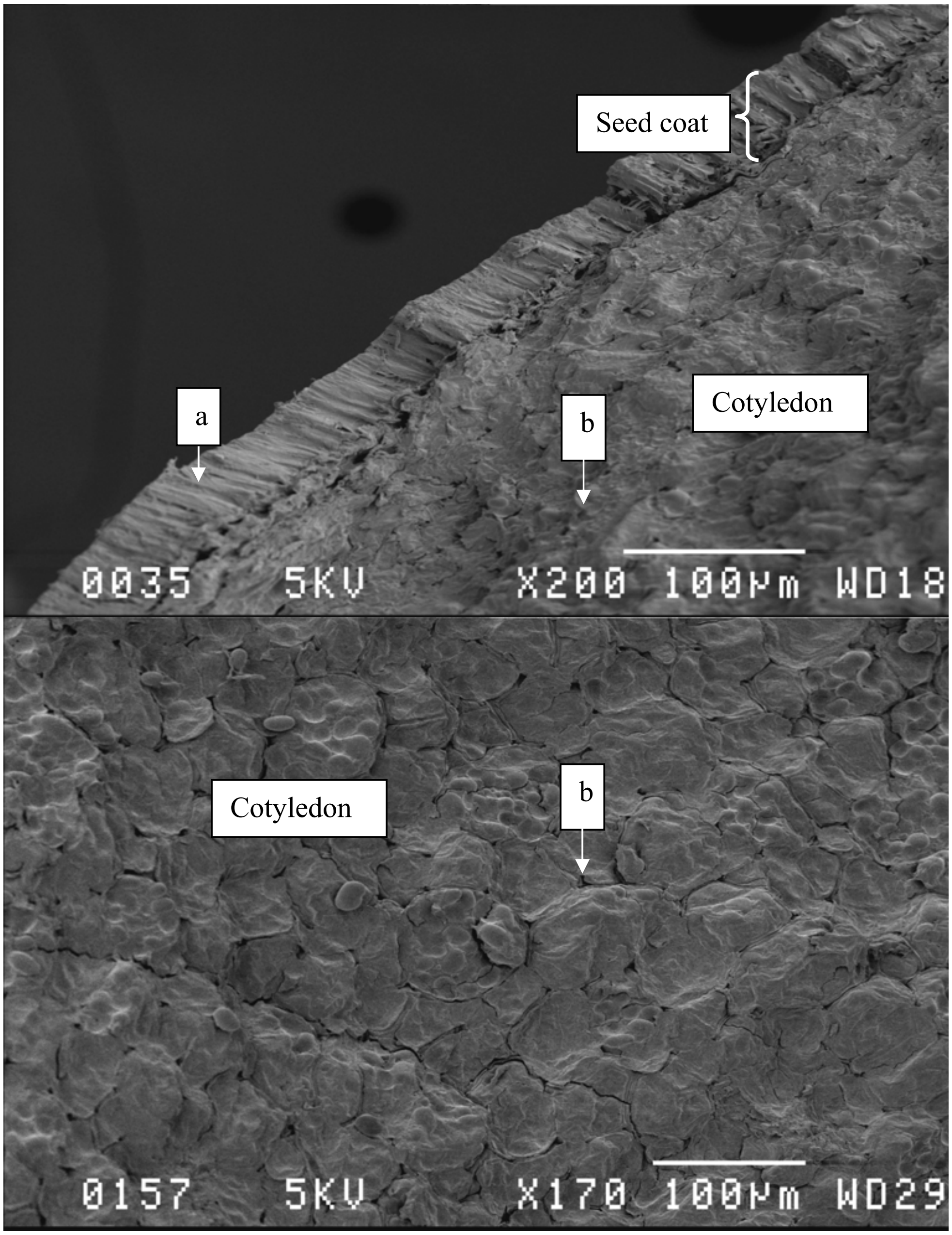


Figure 3.1.3 Scanning Electron Microscopy (SEM) of the seed cross section of IT82E 18 cowpea type: a- well organised palisade cell layer in the seed coat and b- many intercellular spaces in the cotyledon (Cowpea type: Thick seed coat/Porous cotyledon)

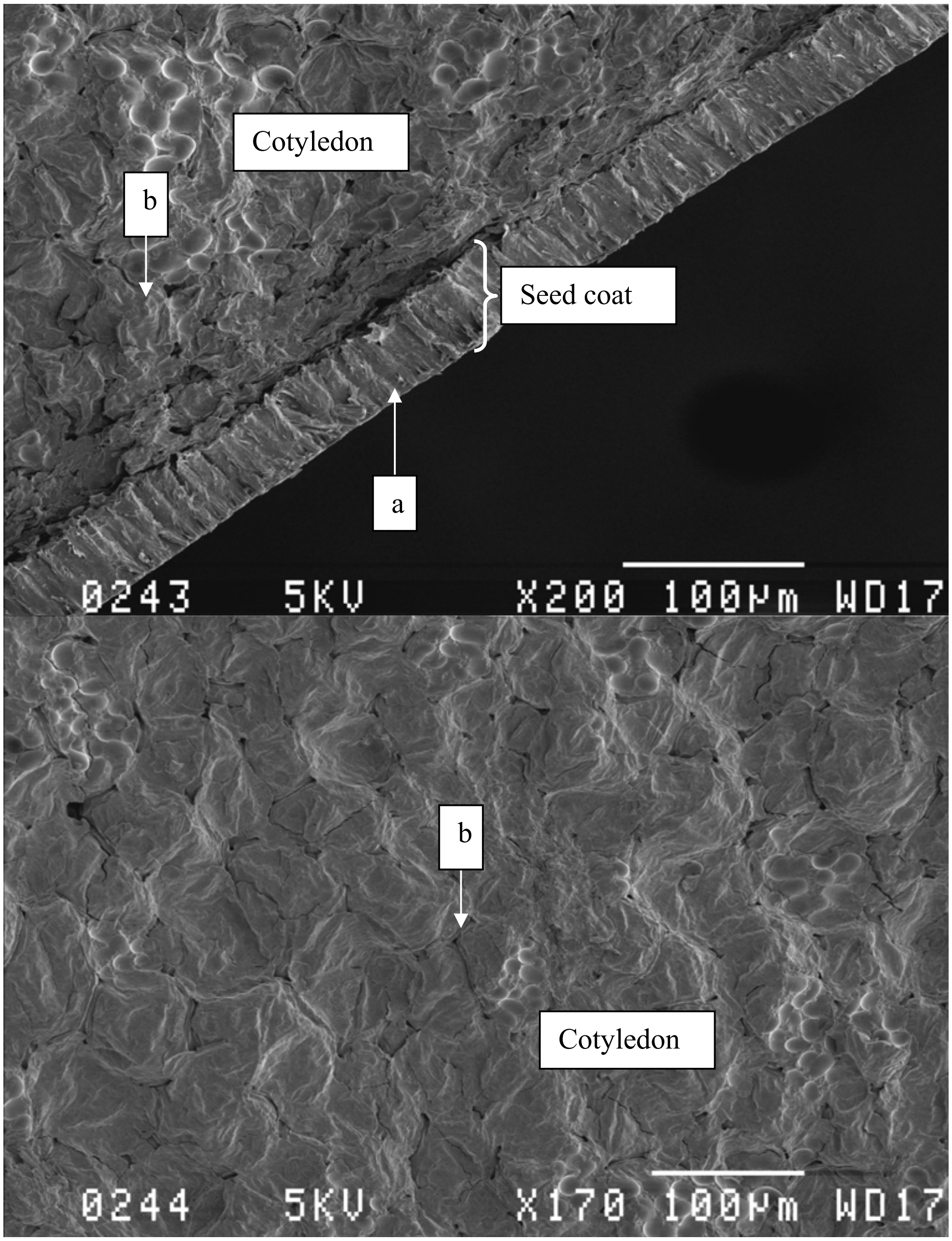


Figure 3.1.4 Scanning Electron Microscopy (SEM) of the seed cross section of INIA 36 cowpea type: a- well organised palisade cell layer in the seed coat and b- few intercellular spaces in the cotyledon (Cowpea type: Thick seed coat/Compact cotyledon)

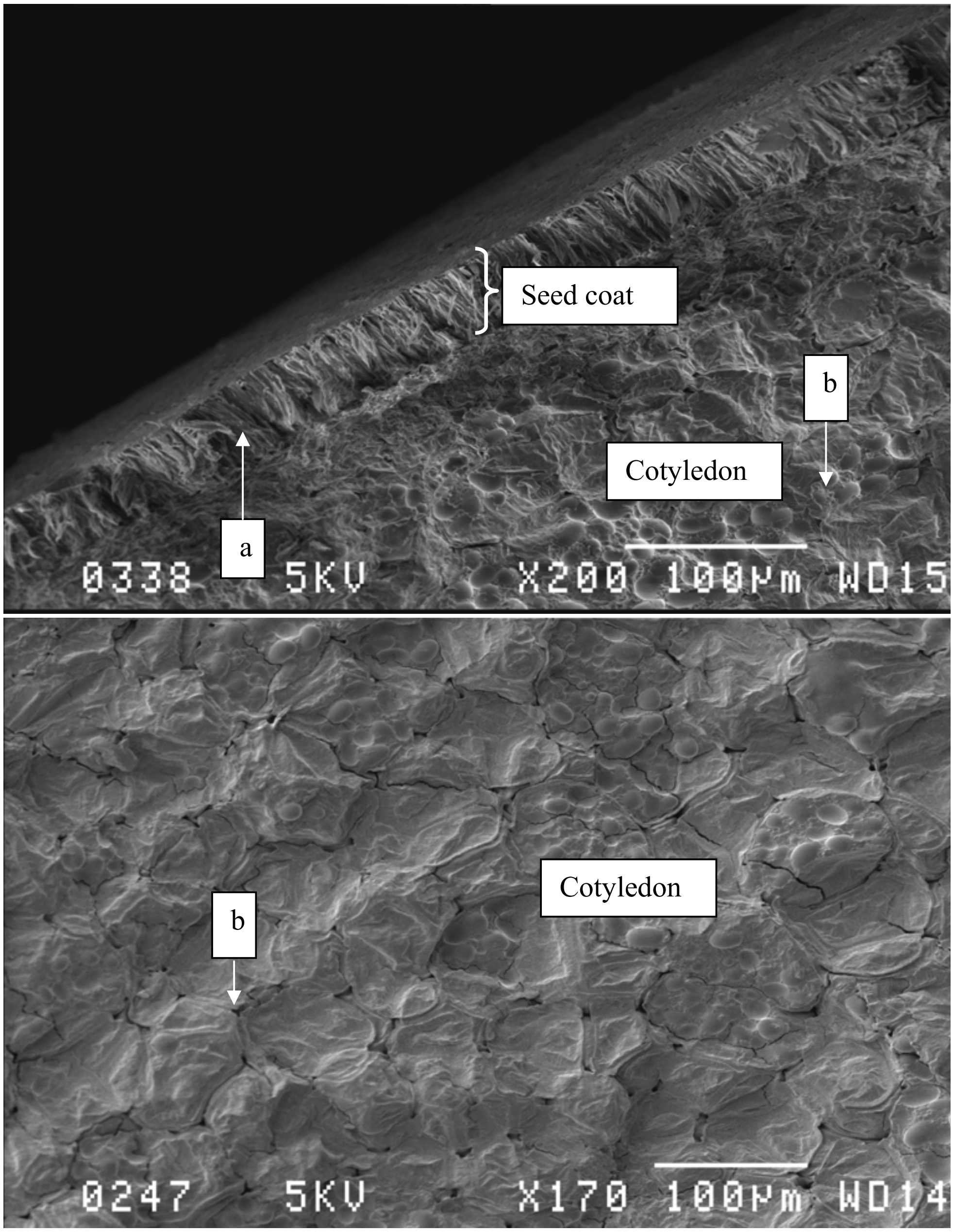


Figure 3.1.5 Scanning Electron Microscopy (SEM) of the seed cross section of Bechuana White cowpea type: a- well organised palisade cell layer in the seed coat and b- few intercellular spaces in the cotyledon (Cowpea type: Thick seed coat/Compact cotyledon)

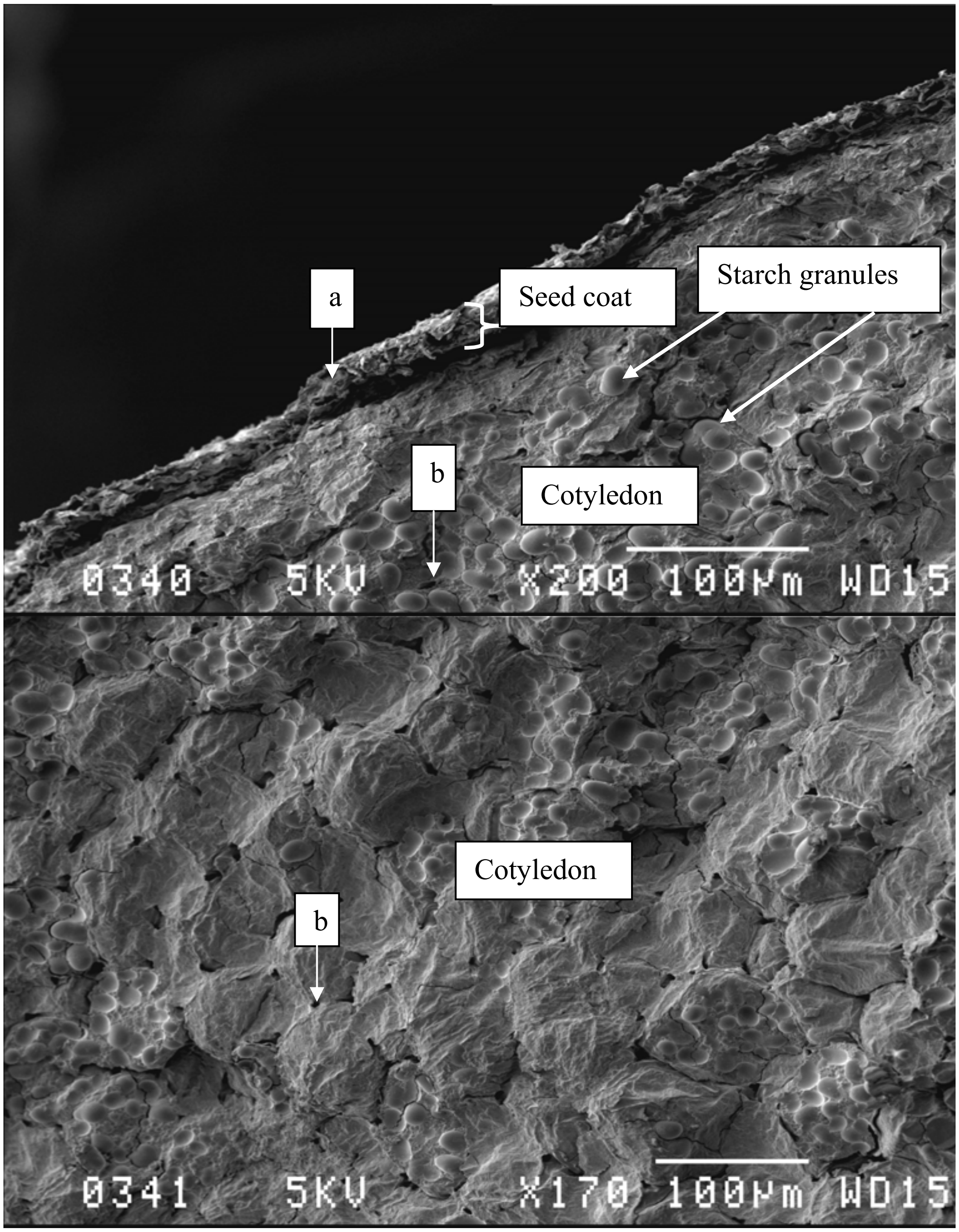


Figure 3.1.6 Scanning Electron Microscopy (SEM) of the seed cross section of 27 Climber cowpea type: a- Amorphous cell layer in the seed coat and b- many intercellular spaces in the cotyledon (Cowpea type: Thin seed coat/Porous cotyledon)

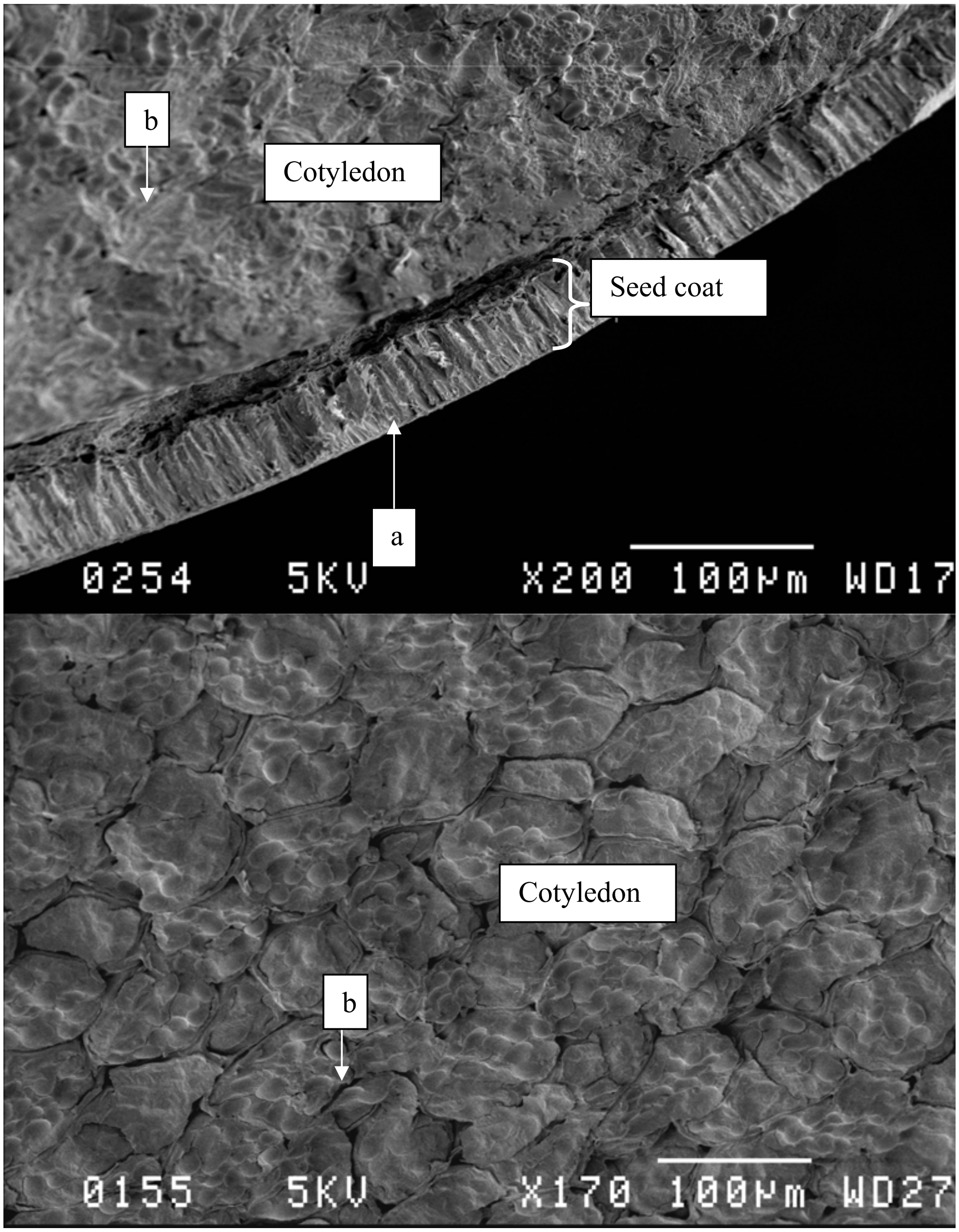


Figure 3.1.7 Scanning Electron Microscopy (SEM) of the seed cross section of IT82E 16 cowpea type: a- well organised palisade cell layer in the seed coat and b- many intercellular spaces in the cotyledon (Cowpea type: Thick seed coat/Porous cotyledon)

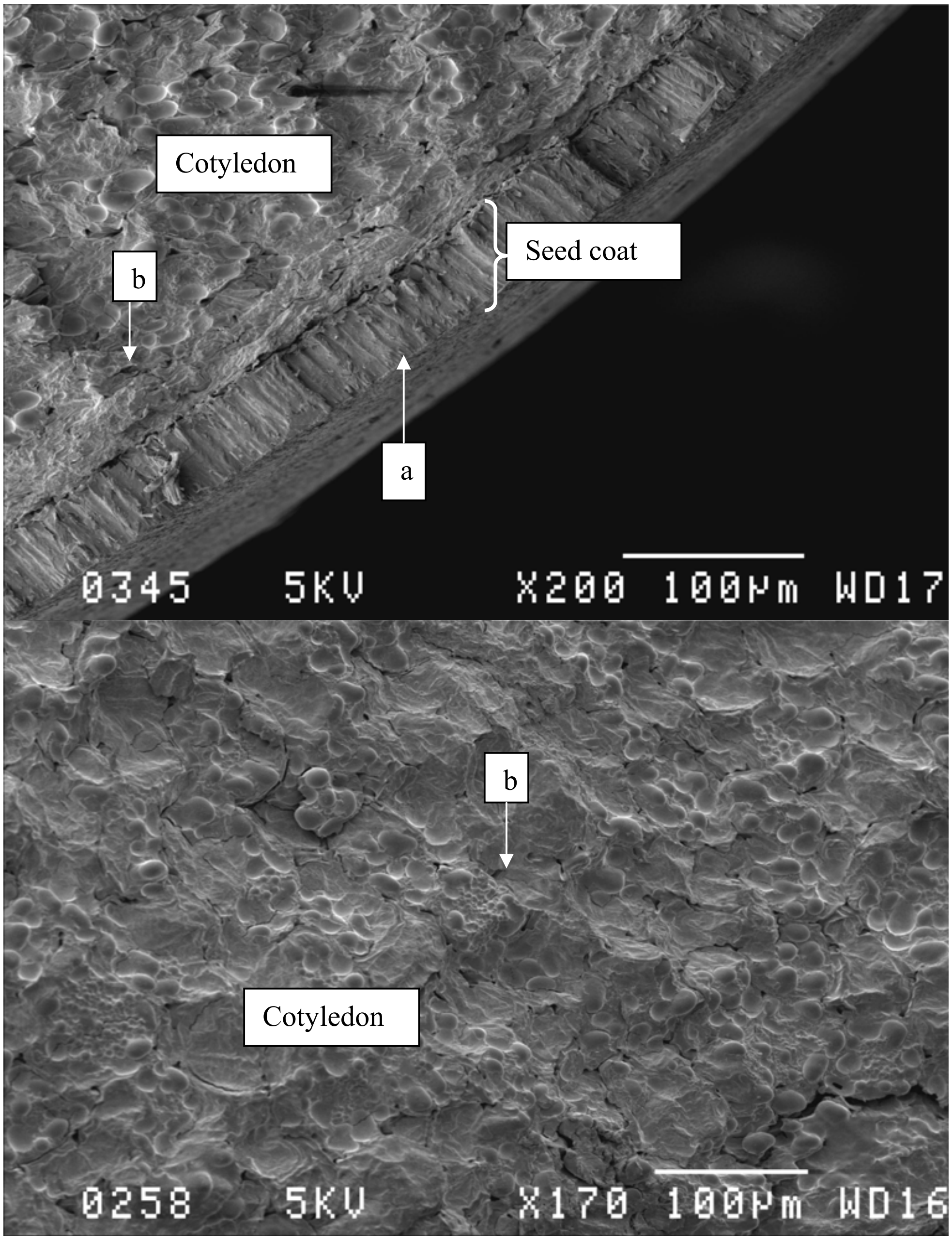


Figure 3.1.8 Scanning Electron Microscopy (SEM) of the seed cross section of 418 Dwarf cowpea type: a- well organised palisade cell layer in the seed coat and b- few intercellular spaces in the cotyledon (Cowpea type: Thick seed coat/Compact cotyledon)

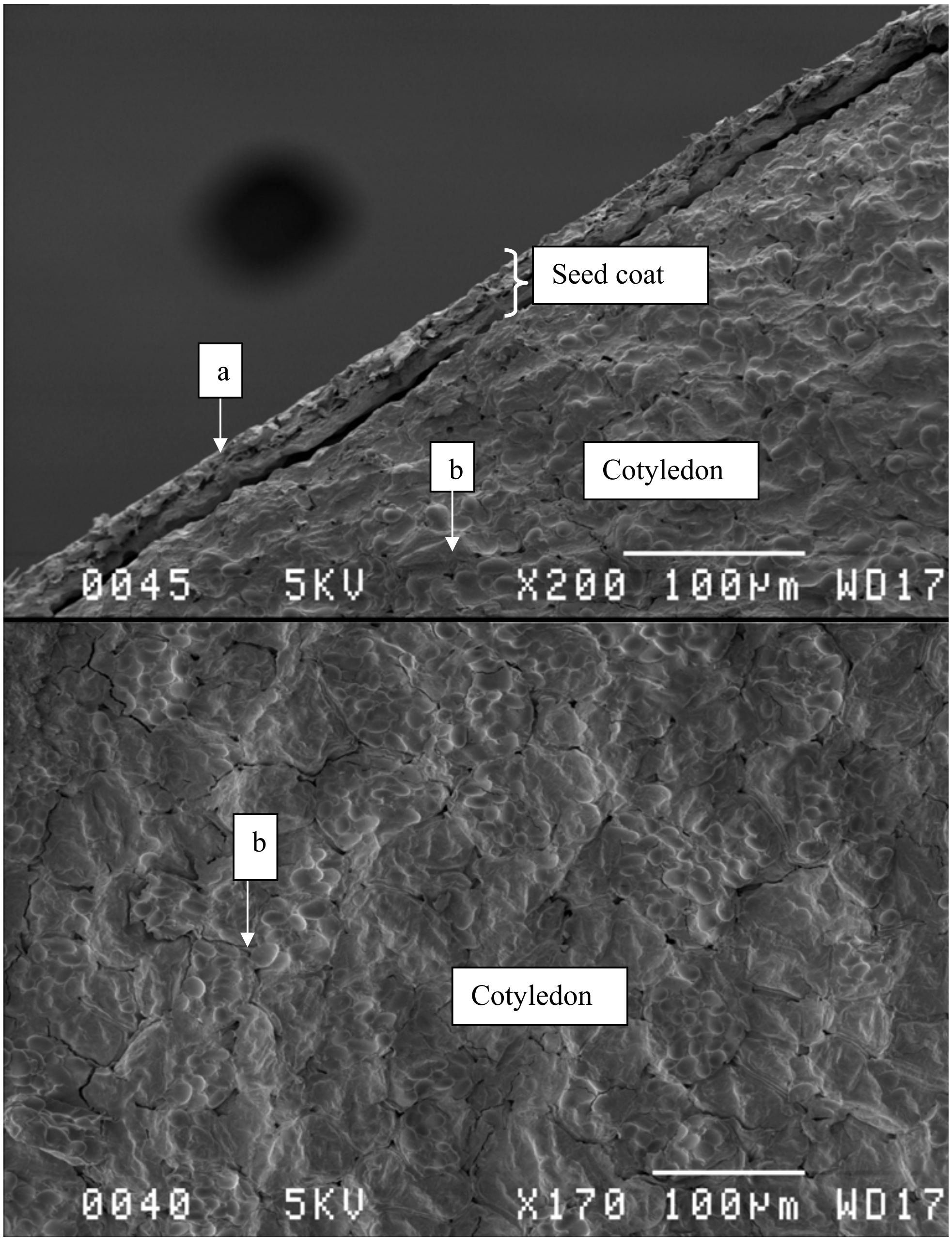


Figure 3.1.9 Scanning Electron Microscopy (SEM) of the seed cross section of Black Eye cowpea type: a- Amorphous cell layer in the seed coat and b- few intercellular spaces in the cotyledon (Cowpea type: Thin seed coat/compact cotyledon)

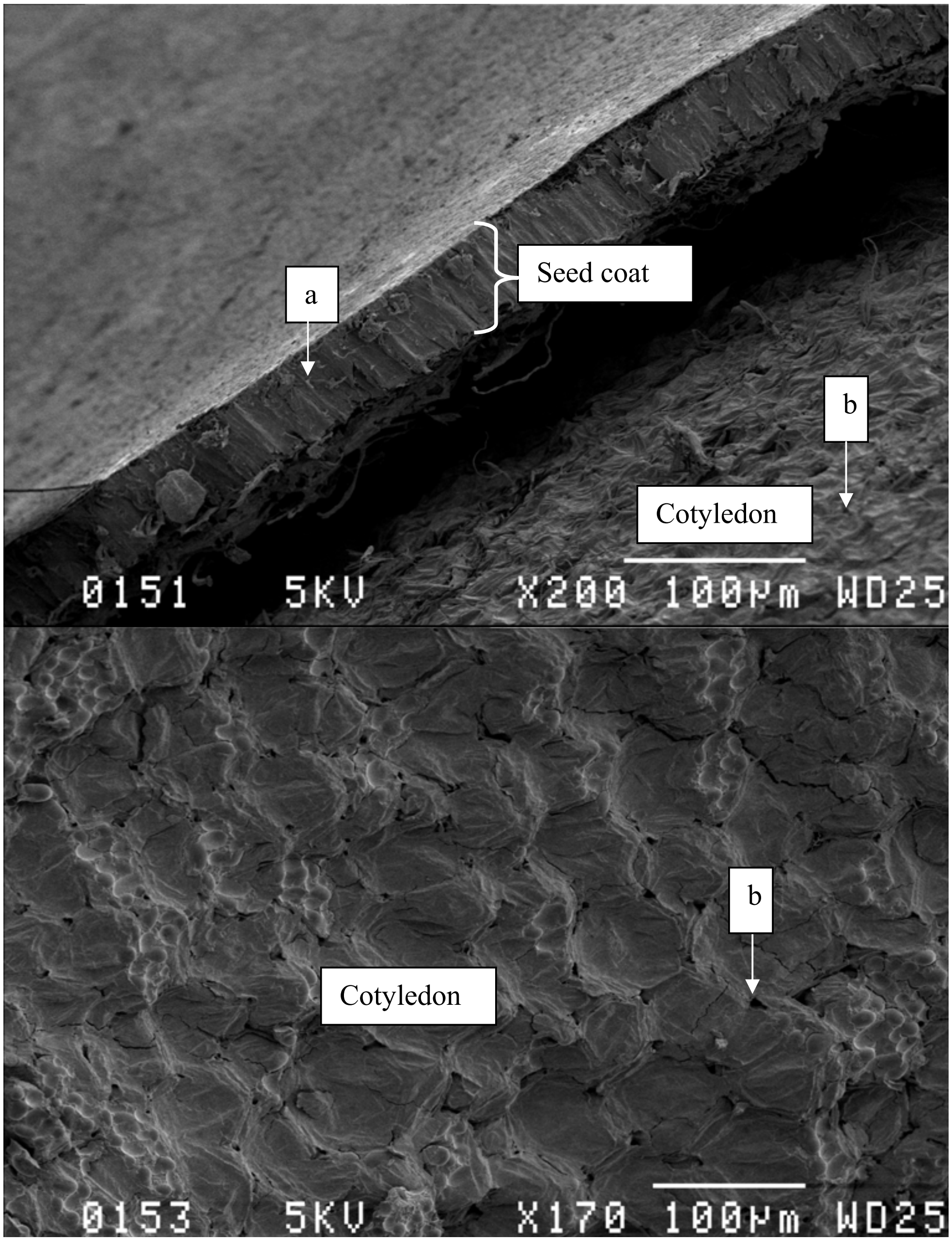


Figure 3.1.10 Scanning Electron Microscopy (SEM) of the seed cross section of 223/1 Climber cowpea type: a- well organised palisade cell layer in the seed coat and b- many intercellular spaces in the cotyledon (Cowpea type: Thick seed coat/Porous cotyledon)

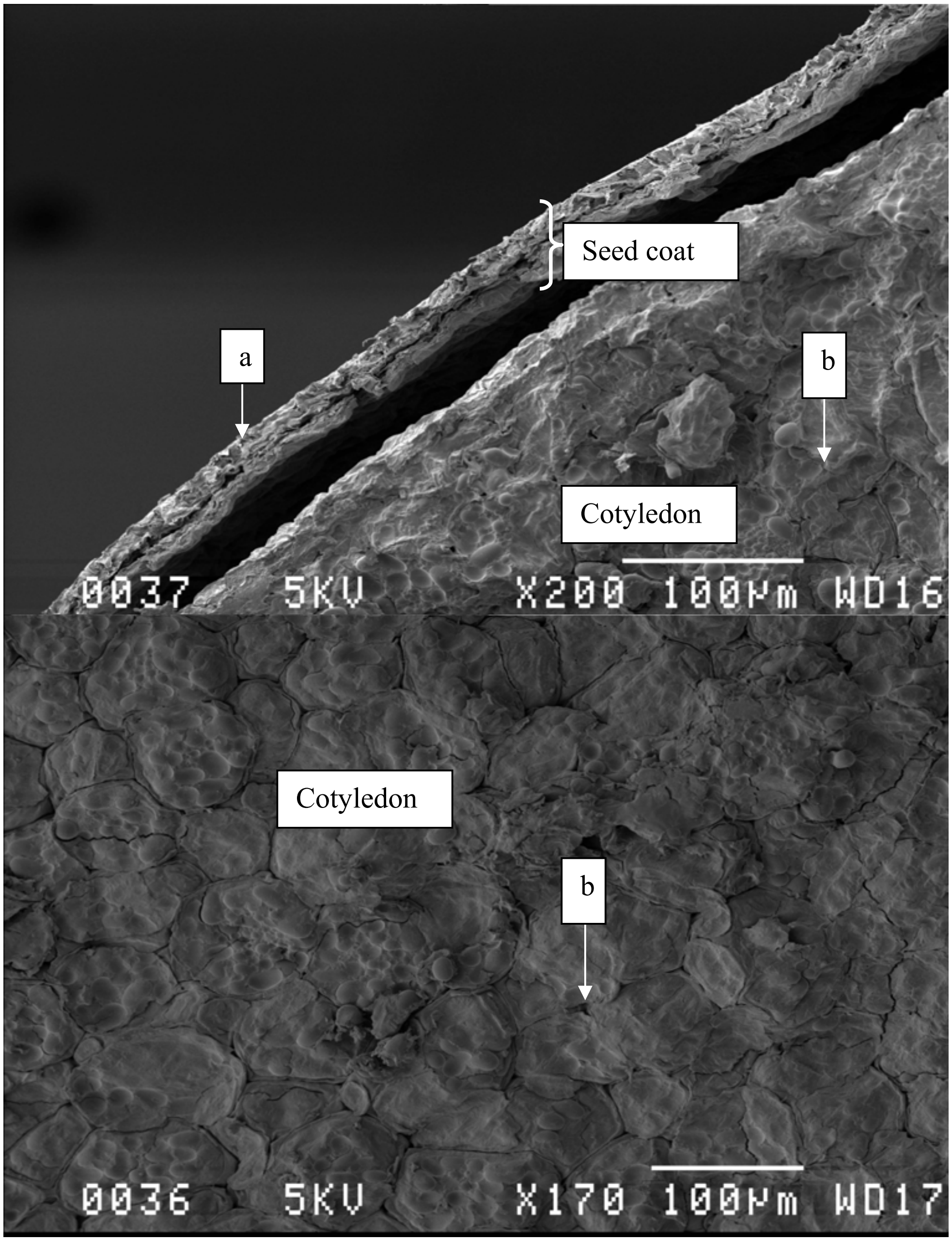


Figure 3.1.11 Scanning Electron Microscopy (SEM) of the seed cross section of 8 Dwarf cowpea types: a- amorphous cell layer in the seed coat and b- few intercellular spaces in the cotyledon (Cowpea type: Thin seed coat/compact cotyledon)

The SEM results also showed that cowpeas with palisade cells forming thick seed coats were tightly attached to the cotyledon compared to cowpeas with amorphous cells forming thin seed coats which are separated from the cotyledon.

Regarding cotyledon compactness the cowpea types were relatively different as confirmed by significant (p<0.001) differences in bulk density. The cowpeas, 27 Climber and 223/1 Climber showed many intercellular spaces which are confirmed by their low values of bulk density (0.88 and 0.89 g/ cm^3 respectively) (Table 3.1.1), followed by California Black (0.93 g/cm^3), IT82E 16 (0.94 g/cm^3) and IT82E 18 (0.96 g/cm^3) which did not differ from each other. Although 27 Climber and 223/1 Climber presented relatively more intercellular spaces than the other three cowpea types (California Black, IT82E 16 and IT82E 18), all fell in the same group of having porous cotyledon. The Bechuana White, Black Eye, INIA 36 and 418 Dwarf with similar bulk density (0.98 g/cm^3 for each) and the 8 Dwarf with 1.01 g/cm^3 showed few intercellular spaces resulting in compact cotyledon structure.

The bulk density values seemed to be lighter than those reported by Olapade *et al*. (2002), which ranged from 0.61 to 0.7 g/ cm^3. The moisture content which ranged from 8.9 to 11.3% in this study and 11.40 to 12.6% in the moisture reported by Olapade *et al*. (2002) may have contributed to the relatively high bulk density values for this study.

The colour of the seed coat varied among cowpea types. Visual observations suggest that the seed coat colour seemed to be related to the structure of the seed coat (Table 3.1.2). Cowpea types characterised by amorphous cell layers and thin seed coats were white in colour (California Black, Black Eye, 27 Climber and 8 Dwarf) while cowpeas with palisade cell layers and thick seed coats were cream (Bechuana White and INIA 36, brown (IT82E 18, IT82E 16, 223/1 Climber) and maroon (418 Dwarf**)**.

The weight of 100 seeds of the cowpea types varied significantly (p<0.001) and ranged from 9.1 to 26.1 g/100 seeds (Table 3.1.2). 27 Climber cowpea type which had the highest weight (26 g/100 seeds) visually appeared bigger in size compared to the other cowpea types. Black Eye which looked the smallest in size among the ten cowpea types had the lowest weight (9 g/100 seeds). California Black cowpea type did not differ from 8 Dwarf whilst Bechuana White, 418 Dwarf and INIA 36 wee similar. Far the most these results are within the range of seed size reported by Olapade *et al*. (2002) (i.e. 1.92 to 24.4 g/100 seeds).

Table 3.1.1 Characterisation of ten cowpea types in terms of moisture, seed coat thickness and seed coat and cotyledon structure

Type	Source of cowpeas	Seed coat thickness (µm)	Moisture content (%)	Bulk density (g/cm^3 db)	Seed coat structure	Cotyledon structure
California Black	USA	$10.6^{a}(1.7)$	$8.9^{a}(0.5)$	$0.93^{c}(0.02)$	Amorphous layer	1- Porous cotyledon
IT82E 18	Mozambique	$38.3^{d}(3.5)$	$10.7^{c}(0.1)$	$0.96^{d}(0.01)$	Palisade layer	1- Porous cotyledon
INIA 36	Mozambique	$45.9^{e}(1.6)$	$10.2^{b}(0.1)$	$0.98^{e}(0.01)$	Palisade layer	2- Compact cotyledon
Bechuana White	South Africa	$41.2^{d}(2.5)$	$9.1^{a}(0.1)$	0. $98^{e}(0.01)$	Palisade layer	2- Compact cotyledon
27 Climber	Malawi	$11.0^{a}(0.8)$	$10.6^{c}(0.7)$	$0.88^{a}(0.01)$	Amorphous layer	1- Porous cotyledon
IT82E 16	Mozambique	$47.0^{ef}(2.8)$	$10.2^{b}(0.2)$	$0.94^{cd}(0.02)$	Palisade layer	1- Porous cotyledon
418 Dwarf	Malawi	$45.5^{e}(2.3)$	$10.8^{c}(0.2)$	$0.98^{e}(0.01)$	Palisade layer	2- Compact cotyledon
Black Eye	South Africa	$25.2^{c}(0.5)$	$9.1^{a}(0.2)$	0. $98^{e}(0.01)$	Amorphous layer	2- Compact cotyledon
223/1 Climber	Malawi	$50.6^{f}(3.4)$	$10.2^{b}(0.2)$	$0.89^{b}(0.01)$	Palisade layer	1- Porous cotyledon
8 Dwarf	Malawi	$15.1^{b}(2.1)$	$11.3^{d}(0.1)$	$1.01^{f}(0.01)$	Amorphous layer	2- Compact cotyledon

Means followed by different superscripts in a column are significantly different at $p \leq 0.001$. Standard Deviations of the means are in parenthesis. Amorphous layer= thin seed coat; palisade cell layer= thick seed coat. 1 = there are many intercellular spaces and 2= there are few intercellular spaces

Based on their 100 seed weights, the ten cowpea types may be classified in extra large seed size of 27 Climber cowpea type; large seed size of California Black and 8 Dwarf cowpea types, medium seed size of IT82E 16, 223/1 Climber, 418 Dwarf, Bechuana White, INIA 36 and IT82E 18 and small seed size of Black Eye. The difference in size of cowpea seeds has been attributed to the differences in genetic and agronomic ecological conditions (Demooy & Demooy, 1990).

Cooking time ranged from 83.0 to 216.0 min (Table 3.1.2) and differed significantly ($p<0.001$) between cowpea types. The shortest cooking time was attained by IT82E 18 while the longest was observed in 223/1 Climber. The two cowpea types (IT82E 18 and 223/1 Climber have thick seed coat and porous cotyledon. The difference in cooking time may be explained by the differences in the thickness of their seed coats as 223/1 Climber had a relatively thicker seed coat (50.6 µm) and more porous cotyledon (more intercellular spaces) compared to IT82E 18 which had seed coat thickness of 38.3 µm and relatively less porous cotyledon (less intercellular spaces). The highest cooking time attained by 223/3 Climber cowpea type may also be explained by development of hard to cook defect for this cowpea type although the pH values did not indicate development of hard to cook defect for all cowpea types.

Table 3.1.2 Characterisation of ten cowpea types in terms of some physicochemical properties

Type	Seed coat colour	Seed size (g /100 seeds)	pH	Cooking time (min)
California Black	White	18.7^{g}(0.4)	6.4^{a}(0.01)	90.3^{b}(2.7)
IT82E 18	Light brown	11.6^{b}(0.1)	6.5^{b}(0.01)	83.0^{a}(5.1)
INIA 36	Cream	13.5^{c}(0.3)	6.6^{c}(0.00)	89.5^{b}(0.5)
Bechuana White	Cream	13.8^{d}(0.6)	6.6^{c}(0.00)	112.4^{d}(1.0)
27 Climber	White	26.1^{h}(0.5)	6.5^{b}(0.01)	105.7^{c}(0.4)
IT82E 16	Brown	15.0^{f}(0.1)	6.6^{c}(0.00)	106.2^{c}(0.5)
418 Dwarf	Maroon	13.7^{cd}(0.1)	6.5^{b}(0.00)	90.1^{b}(0.4)
Black Eye	White	9.1^{a}(0.2)	6.6^{c}(0.00)	125.7^{e}(2.3)
223/1 Climber	Brown	14.4^{e}(0.2)	6.6^{c}(0.00)	216.3^{f}(1.8)
8 Dwarf	White	18.7^{g}(0.1)	6.6^{c}(0.01)	92.0^{b}(0.4)

Means followed by different superscripts in a column are significantly different at $p\leq0.001$. Standard Deviations of the means in parentheses

The pH values of the ten cowpea types varied significantly ($p<0.001$) (Table 3.1.2). California Black had the lowest pH, followed by IT82E 18, 27 Climber and 418 Dwarf. The highest pH values were observed in cowpea types INIA 36, Bechuana White, IT82E 16, Black Eye, 223/1 Climber and 8 Dwarf. Overall, the measured pH values confirmed that the seeds were fresh, indicating that the hard to cook phenomena was not developed. Salvador (2007) found pH values of 6.5 in fresh seeds and 6.3 in hard to cook cowpeas.

3.1.5 Conclusions

Based on the microstructure and physicochemical characteristics of the cowpeas, the cowpea types were grouped as follow:
i) Thin seed coat/porous cotyledon (27 Climber and California Black); ii) Thin seed coat/compact cotyledon (Black Eye and 8 Dwarf); iii) Thick seed coat/porous cotyledon (223/1 Climber, IT82e 18 and IT82E 16); and iv) Thick seed coat/compact cotyledon (Bechuana White, INIA 36 and 418 Warf).

From the identified groups, four cowpea types were selected for further research work namely, Bechuana White (thick seed coat and compact cotyledon), Black Eye (thin seed coat and compact cotyledon), California Black (thin seed coat/porous cotyledon) and IT82E 18 (thick seed coat/porous cotyledon). The selection of the four cowpea types was based on more evident differences in terms of seed coat and cotyledon structure, sample availability, fresh seed colour, cooking time and pH.

3.2 The influence of seed coat thickness and cotyledon compactness on cooking characteristics of cowpeas

3.2.1 Abstract

The influence of seed coat thickness and cotyledon compactness on cooking characteristics of cowpeas was studied. Seed coat thickness influenced water absorption during soaking; Cowpeas with thin seed coats, comprising amorphous cells showed rapid water absorption during soaking of whole cowpea seeds compared to thick seed coats formed of palisade cells. The arrangement of amorphous cells lead to large intercellular spaces that favoured permeability in water while the arrangement of palisade cells lead to small intercellular spaces resulting in low permeability. Splitting of the cowpeas seemed to be influenced by seed coat thickness and by other factors that may be amounts of some chemical components (calcium). Seed coat plays a significant role on cooking characteristics. Once the seed coat was removed, water easily entered into cotyledon, cooking time was reduced and the seed had no defence to maintain its integrity becoming much softer after cooking. Cotyledon compactness influenced cooking time of cowpea samples; Whole cowpeas with compact cotyledon took longer time to cook compared to cowpeas with porous cotyledon probably due to the complex arrangement of cells in compact cotyledon than in cowpeas with porous cotyledon.

3.2.2 Introduction

Food legumes like cowpeas are considered as an important protein source in the diet, particularly of people in the developing countries. Prior to consumption, cowpea grains need to be cooked in water to mainly improve their texture and palatability (Bakr & Gowish, 1991). When the cowpea grains are placed in water during cooking, the water diffuses from the seed coat to the cotyledon and then the seeds hydrate and heat up. Middle lamella pectin depolymerises through β-eliminations of methyl esterified polygalacturonic acids. This increases cell separation and soften the tissues (Bernal-Lugo *et al*., 1997). Additionally, the starch granules gelatinise and proteins denature, contributing to the softening process (Golonka *et al*., 2002).

Factors such as cultivars, seed structure and composition (e.g. protein) have been reported to play an important role on the cooking process (Bishnoi & Khetarpaul, 1993). In terms of structure, cowpeas with thin seed coats (Sefa-Dedeh & Stanley, 1979b) and porous cotyledons (Agbo *et al*., 1987) had higher rate of water absorption compared to cowpeas with thick seed coats and compact cotyledons. Sefa-Dedeh & Stanley (1979b) has examined the relationship between texture and microstructure by Scanning Electron Microscopy of soaked and cooked whole cowpeas. It was found that the cell wall separates out during cooking of legume seeds. This was due to breakdown of the pectin polymeric material in the middle lamella. However, the authors did not consider the use of cowpeas with different seed coat thickness and cotyledon compactness as well as the use of dehulled cowpeas. Jackson & Varriano-Mattson (1981) found that whole cowpeas cooked longer compared to dehulled cowpeas due the influence of seed coat. However, research on cooking characteristics such as water absorption during soaking and cooking and texture of cooked cowpeas using whole and dehulled cowpeas of different seed coat thickness (in case of whole) and cotyledon compactness is lacking.

Splitting of cowpeas has been reported to be a quality characteristic for consumer preferences (Wu, 2002). During cooking, as cowpea cells hydrate, expand and heat up, water is transformed into vapour which creates a pressure in the seeds. Since expansion of seed cells is limited, the seeds split up. Splitting of cowpeas during cooking was associated with high water absorption (Mwangwela, 2006) and the texture of cooked cowpeas (determined using texture analyser) (Taiwo *et al*., 1998). Research regarding the influence of seed coat thickness and cotyledon compactness on splitting of cooked cowpeas is not available. Thus, this section aims to determine the influence of seed coat thickness and cotyledon compactness on cooking characteristics such as cooking time, water absorption, percentage of splitting during cooking and the texture of cooked cowpeas using objective measurements.

3.2.3 Materials and methods

3.2.3.1 Experimental design

Figure 3.2.1 shows the experimental design used during evaluation of the role of seed coat and cotyledon structure on cooking characteristics using whole, seed coat and dehulled cowpeas. Seed coat thickness and cotyledon compactness of cowpea samples were independent variables while the analysed cooking characteristics were dependent variables.

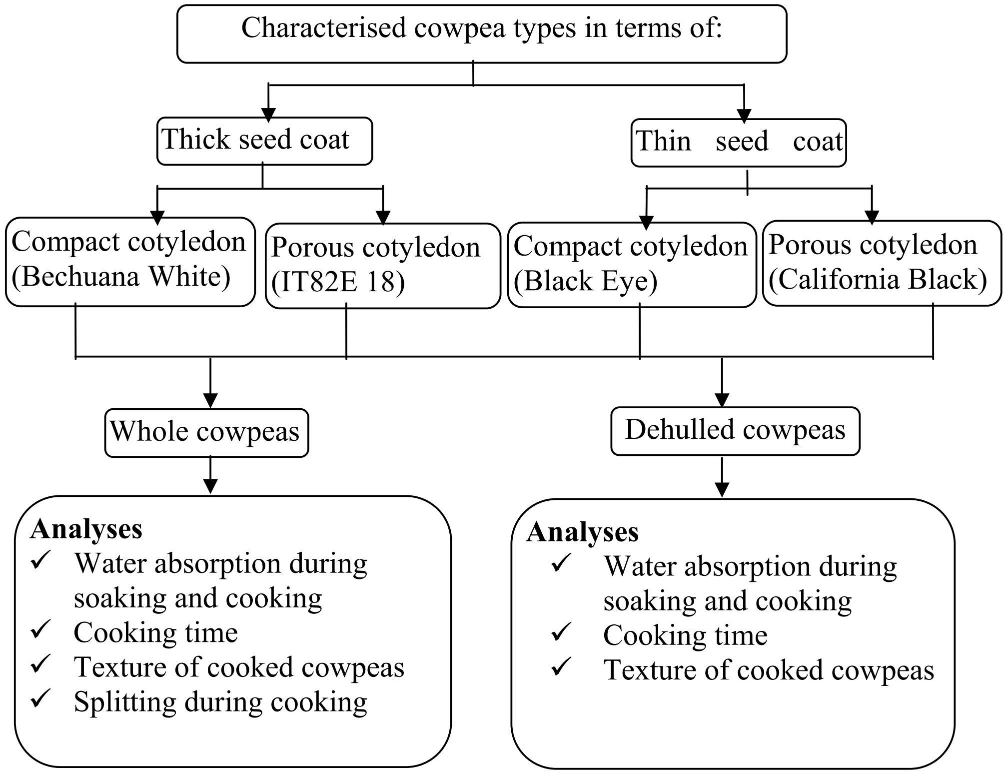


Figure 3.2.1 Experimental design for the determination of the role of seed coat and cotyledon structure on cooking characteristics of cowpeas

3.2.3.2 Cowpea samples

Based on the preliminary results from section 3.1, four cowpea types were identified according to specific physicochemical characteristics. The selected cowpea types representing different seed coat and cotyledon structure were: thick seed coat/compact cotyledon (Bechuana White) obtained from South Africa, thin seed coat/compact cotyledon (Black Eye) and thin seed coat/porous cotyledon (California Black) from USA, and thick seed coat/porous cotyledon (IT82E 18) from Chokwe-Agricultural Research Institute of Mozambique. The seeds were cleaned to remove chaff using sieves of different sizes and stored at 4°C.

3.2.3.3 Dehulling of cowpeas

The removal of the seed coat of the cowpea seeds was done using an abrasive laboratory grain dehuller TADD Model 4E-220 (Venables Machine Works Ltd, Saskatoon, Saskatchewan, Canada) with a no. 36 grit disk (3 M Minneapolis, Minnesota, USA). 50 g cowpea seeds were placed into each of the eight cups (diameter of 5.5 cm) of the TADD and abraded for 5 min for thin seed coated cowpeas and 10 min for thick seed coated cowpeas. The flour produced during dehulling was separated from the seed coat using a sieve (2.5 mm) and the breakage was hand sorted from dehulled grains.

3.2.3.4 Determination of water absorption during soaking

The water absorption of whole and dehulled cowpea seeds during soaking was determined following a modified method of Agbo *et al*. (1987). 10 g of seeds of each cowpea type was placed in 100 ml Erlenmeyer flasks containing 50 ml (for whole and dehulled cowpeas) and 5 ml (for seed coat) deionised water and then placed in an incubator at about 22 °C for 1, 2, 3, 4, 5 and 6 h. After soaking at each interval, the excess water was drained using a metal sieve (2.5 mm) and the cowpeas were then blotted dry with absorbent paper to remove excess water and afterwards weighed. Three replicates each done in duplicate were used. The mean of gain in weight of the soaked samples was expressed as grams of water per kg sample (g/kg), corresponding to water absorbed (WAS) according to the following formula.

$$WAS = \frac{Weight\ of\ the\ sample\ after\ soaking - Weigth\ of\ the\ sample\ before\ soaking}{Weight\ of\ the\ sample\ before\ soaking}$$

(3.2.1)

3.2.3.5 Determination of cooking time

Cooking time was determined according to Jackson & Varriano-Marston (1981) modified method using the Bean Mattson Cooker device (Mattson, 1946) as described in section 3.1.3.7.

3.2.3.6 Determination of water absorption during cooking

The amount of water absorbed during cooking was determined using the Cenkowski & Sosulski (1997) method with some modifications. Erlenmeyer flasks (100 ml) containing 60 ml of deionised water were placed in a covered pot with boiling water and brought to boil. 10 g cowpea seeds sample were poured into the flasks and then covered with aluminium foil. The samples were then cooked in boiling water for 25, 50, 75, 100, and 125 min for whole seeds and 5, 10, 15, 20, 25, and 30 min for dehulled seeds. After cooking, the water was drained using a metal sieve (2.5 mm) and the cowpeas cooled to room temperature (±22 ºC), blotted dry with absorbent paper to remove excess water and then weighed. The gain in weight (g) was expressed as water absorption (WAC) in g water per kg cowpea seeds (g/kg) according to the following equation:

$$WAC = \frac{Weight\ of\ the\ sample\ after\ cooking - Weight\ of\ sample\ before\ cooking}{Weight\ of\ the\ sample\ before\ cooking}$$

(3.2.2)

3.2.3.7 Determination of percentage of splitting during cooking

Whole seeds with splits greater than 1/5 of the small circumference of the cowpeas were considered split seeds (Taiwo *et al*., 1997a). The cowpeas with splits were counted after cooking at different intervals (0, 25, 50, 75, 100 and 125 min) and expressed as a percentage of the total number of seeds in the sample (%) according to the following equation:

$$Percentage\ Splitting = \frac{Number\ of\ split\ seeds}{Total\ number\ of\ seeds} * 100 \qquad (3.2.3)$$

3.2.3.8 Determination of texture of cooked cowpeas

Texture of cooked cowpeas (whole and dehulled) was determined using a TA-XT® Plus Texture Analyser (Stable Micro System, Godalming, UK) with attachments of the Ottawa Texture Measuring System (OTMS) cells with an eight-bar extrusion grid. About 15 cooked cowpea seeds of a known weight were loaded on a sample holder of the OTMS in a single layer. The seeds were placed perpendicularly to the wires and compressed with a compressing plate to 90% strain at a speed of 1.67 mm/s. The compressing plate was attached to a load cell of 25 kg. The firmness, i.e. maximum compression force was recorded and expressed as the maximum force per g of cooked cowpeas (N/g).

3.2.3.9 Statistical analysis

The experiment was a completely randomized design (CRD) and repeated three times. ANOVA was used to test for differences between the effects of the cowpea types in terms of seed coat thickness and cotyledon compactness. Treatment means were separated using Fishers' Least Significant Difference (LSD) at the 5% level of significance (Snedecor & Cochran, 1980). Regression analysis was done for water absorption during soaking and cooking and for percentage of splitting during cooking. Data were analysed using the statistical program GENSTAT (2003).

3.2.4 Results and discussion

3.2.4.1 Dehulling of the cowpeas

The different fractions obtained after dehulling are presented in Figure 3.2.2 and their corresponding percentages are illustrated in Table 3.2.1. Thin seed coat/porous cotyledon cowpea type (California Black) did not have breakage and almost all its dehulled seeds had the hilum attached to the cotyledon. The presence of hilum in dehulled cowpeas may be the reason for absence of broken seeds. Because during seed coat removal process, the hilum is also removed allowing the two cotyledons to separate from one another. After detachment of the cotyledons, broken grains are easily produced. Once the hilum of California Black remained attached to the cotyledon, the two cotyledons did not separate and no broken cowpeas were produced.

The optimal dehulling times were 5 and 10 min for thin and thick seed coats respectively. The amount of cowpea seeds for each cup of TADD mill was fixed at 50 g. Dehulling time differed among cowpeas with thick and thin seed coats. Cowpeas with thick seed coats seemed to be tightly attached to the cotyledon resulting in longer dehulling time (10 min) compared to cowpeas with thin seed coats. Cowpeas with thin seed coats seemed to be loosely attached to the cotyledon, as observed by SEM (Figure 3.2.3) thus; the seed coats were easily separated from the cotyledon only requiring 5 min to dehull.

1 2 3 4

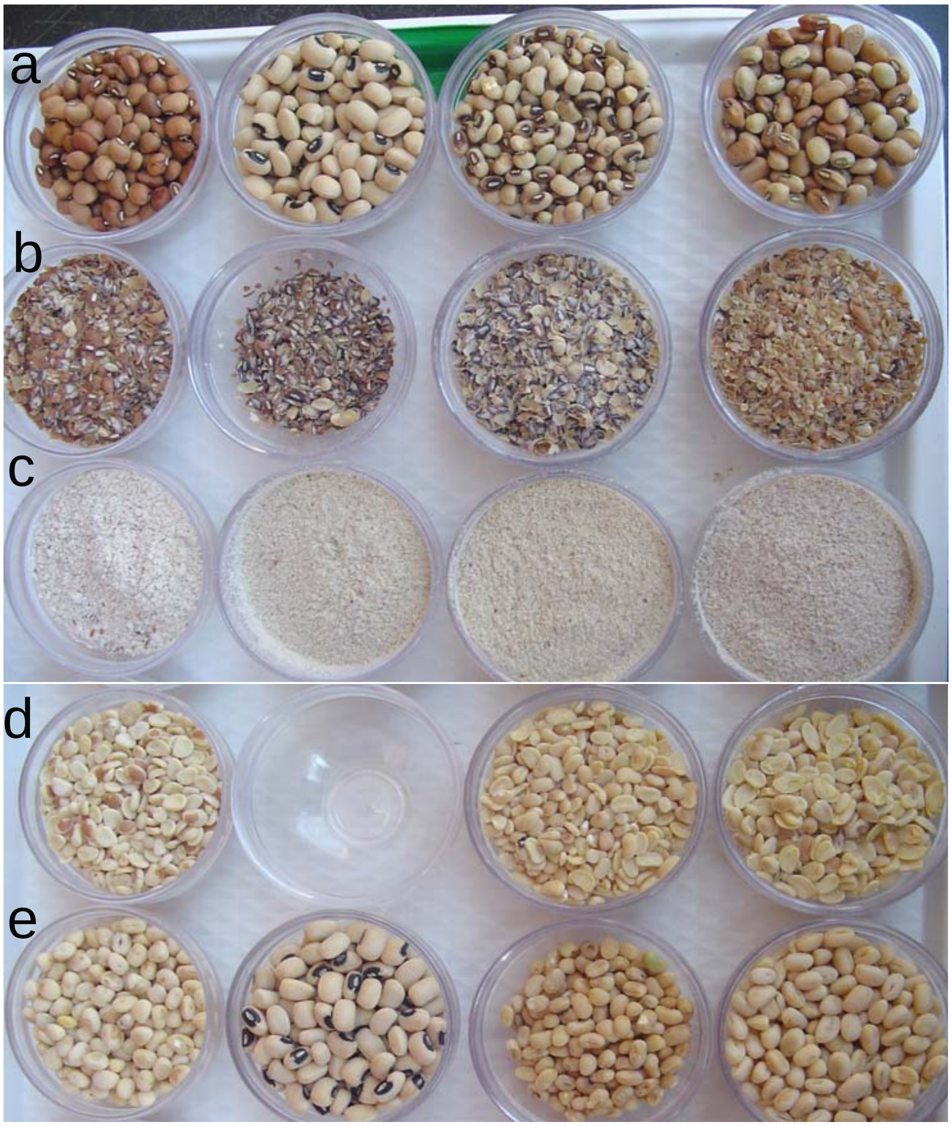


Figure 3.2.2 Photograph showing: columns: 1- Thick seed coat/porous cotyledon (IT82E 18), 2- Thin seed coat/porous cotyledon (California Black), 3- Thin seed coat/compact cotyledon (Black Eye) and 4- Thick seed coat/compact cotyledon (Bechuana White). Rows: a- whole cowpea seeds; b-seed coat; c-flour (from seed coat, breakage and dehulled seeds); d- breakage and e- dehulled seeds

These results are in agreement with Sefa-Dedeh & Stanley (1979c) who reported that cowpeas with thick seed coats were hard to dehull probably because the seed coats were tightly attached to the cotyledon.

Table 3.2.1 Different fractions obtained after dehulling 400 g of each cowpea sample for 5 min (thin cowpea seed coats) and for 10 min (thick cowpea seed coats)

Fraction (%)	Thick seed coat		Thin seed coat	
	Compact cotyledon (Bechuana White)	Porous cotyledon (IT82E 18)	Compact cotyledon (Black Eye)	Porous cotyledon (California Black)
Seed coat	5.6^{d}(0.1)	5.3^{c}(0.1)	2.5^{b}(0.2)	2.0^{a}(0.1)
Flour	14.6^{c}(0.2)	20.9^{d}(0.2)	7.6^{b}(0.2)	3.8^{a}(0.2)
Breakage	12.1^{b}(0.2)	20.0^{c}(0.1)	30.6^{d}(0.3)	0.0^{a}(0.0)
Dehulled seeds	67.7^{c}(0.3)	53.8^{a}(0.1)	59.3^{b}(0.4)	94.2^{d}(0.1)

Means followed by different superscripts in a row are significantly different at p≤0.001; Standard Deviations of the means in parenthesis.

Figure 3.2.3 Scanning Electron Microscopy of two cowpea types. Thick seed coat tightly attached to the cotyledon; thin seed coat loosely attached to the cotyledon

3.2.4.2 Water absorption during soaking

The results of the amount of water absorbed during soaking for the whole and dehulled cowpeas are presented in Figure 3.2.4 (whole) and Figure 3.2.5 (dehulled). As expected the amount of water absorbed by each cowpea type increased with soaking time. Whole and dehulled cowpeas differed (p<0.001) in amount of water absorbed after six hours of soaking. Whole cowpeas absorbed over 1000 g of water / kg of cowpea sample with exception of thin seed coat/compact cotyledon (Bechuana White) while dehulled cowpeas absorbed less than 1000 g/kg.

In whole cowpeas, the amount of water absorbed by all cowpea types increased and tended to plateau after about four hours, except for thick seed coat/compact cotyledon (Bechuana White) (Figure 3.2.4). In dehulled cowpeas, the amount of water absorbed increased and tended to plateau for all cowpea types after about two to three hours (Figure 3.2.5). Plateau of water absorption during soaking may indicate the saturation of intercellular spaces by water and absorption of water by hydrophilic biomolecule for example proteins, starch, pectic substances (Sefa-Dedeh & Stanley, 1979c).

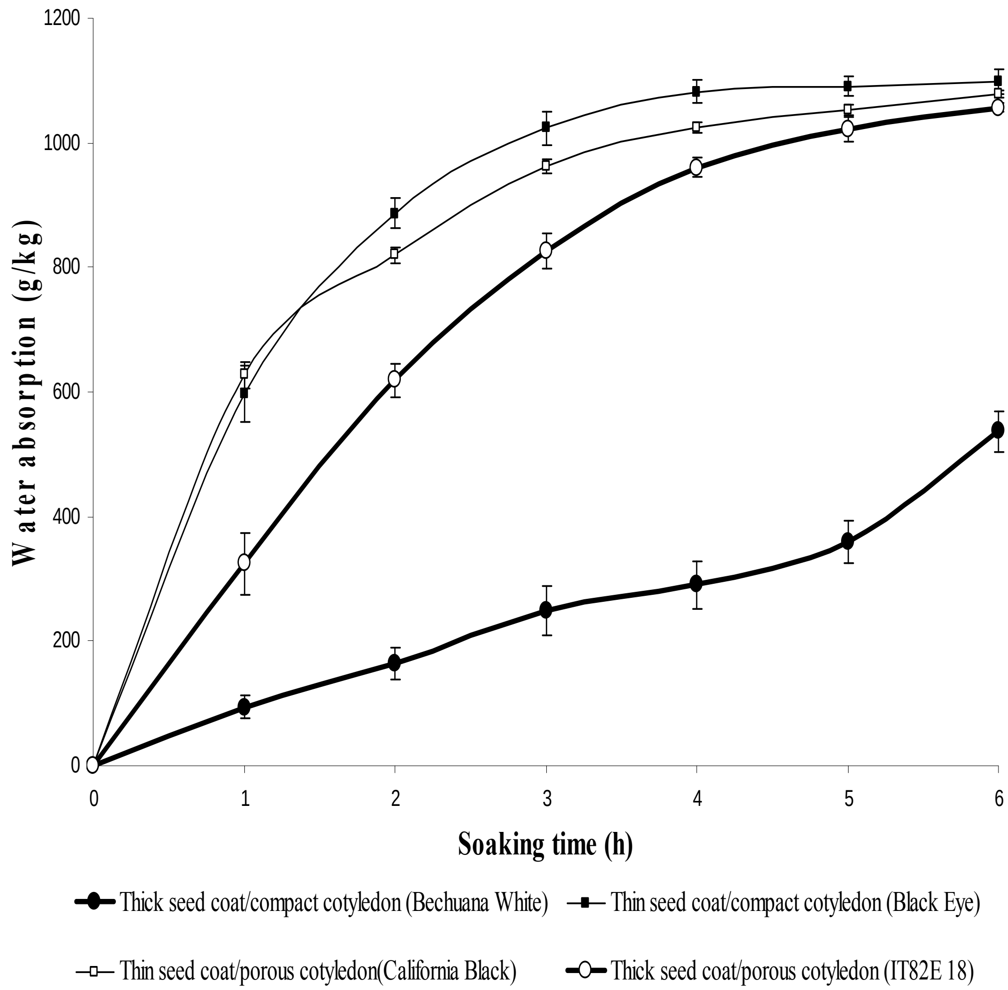


Figure 3.2.4 Water absorption during soaking of whole cowpeas

The initial increase of water absorption with soaking time for whole (Figure 3.2.4) and dehulled cowpeas (Figure 3.2.5) was significantly different ($p<0.001$) between the cowpea types and interaction cowpea type and soaking time. To better understand these differences, data were fit into a polynomial regression model as given in Equation 3.2.4 and Table 3.2.2.

$$Y = b_0 + b_1 x + b_2 x^2 + \ldots + b_k x^k \qquad (3.2.4)$$

Where: Y= predicted outcome value of water absorption in grams of water per kilogram of sample for the polynomial model with regression coefficient r^2 and b_1 to b_k are the slope (tangent lines to the curve of the distribution) values of water absorption for each order term of X^1 to X^k soaking time and b_0 is the predicted value of Y where X equals zero (intercept).

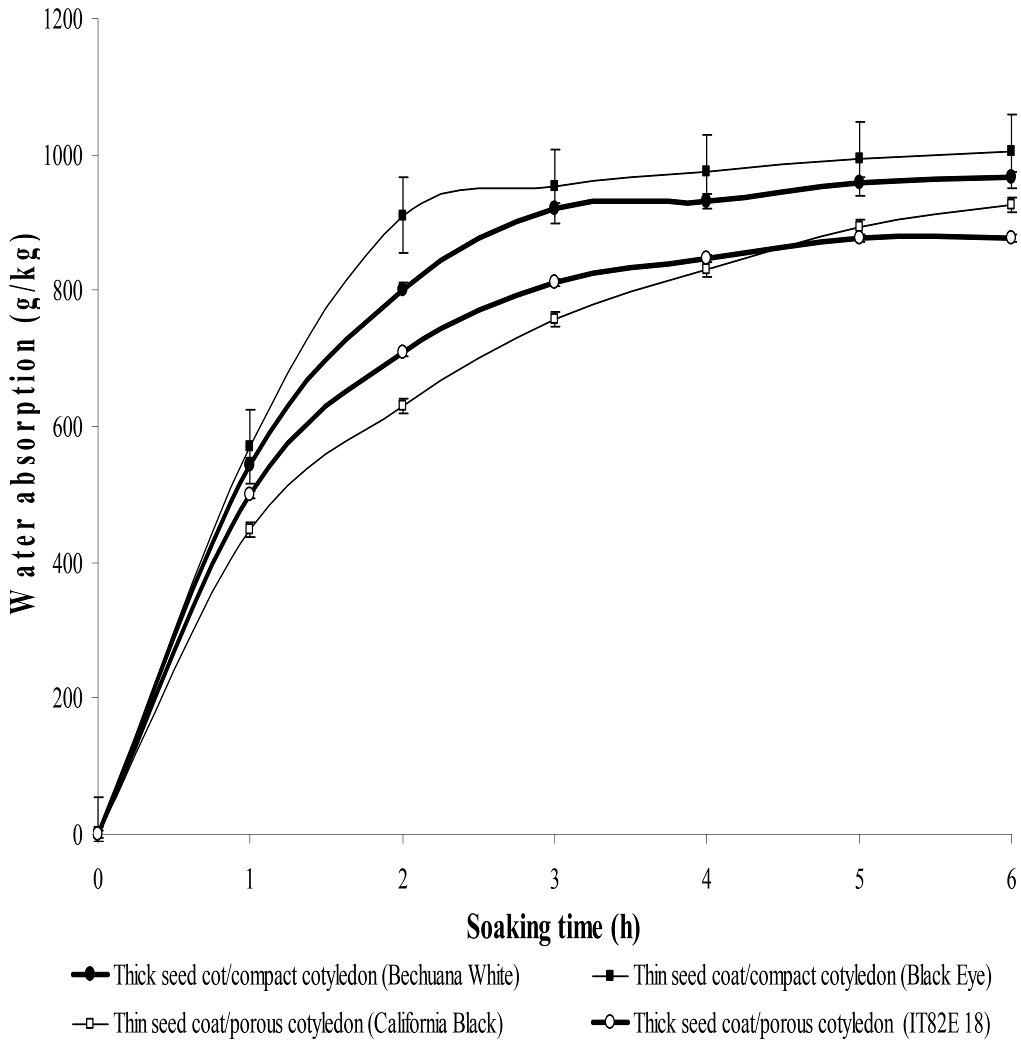


Figure 3.2.5 Water absorption during soaking of dehulled cowpeas

The rate of water absorption was higher for whole cowpeas with thin seed coats compared to thick seed coats. This was shown by higher slope b_1 values of 1053 and 787 for the thin seed coats compared to 375 and 81 for the thick seed coats (Table 3.2.2). The b_1 value is an indication of the rate of water absorption in a linear part of the polynomial regression. Agbo *et al.* (1987) attributed the low rate of water absorption for the cowpeas with thick seed coats to the dense and structured arrangement of palisade cells. This makes the seed coat less permeable to water compared to amorphous cells of cowpeas with thin seed coats.

Table 3.2.2 Regression analysis of water absorption of whole and dehulled cowpeas during soaking

	Thick seed coat		Thin seed coat	
	Compact cotyledon (Bechuana White)	Porous cotyledon (IT82E 18)	Compact cotyledon (Black Eye)	Porous cotyledon (California Black)
Water absorption during soaking cowpeas				
Whole				
b_0	-0.57	-3.01	1.20	0.61
b_1	80.87	372.44	786.98	1053.00
b_2	3.80	-32.88	-224.01	-588.15
b_3	-	-	29.73	184.62
b_4	-	-	-1.53	-28.49
b_5	-	-	-	1.67
r^2	0.99	0.99	0.99	0.99
Dehulled				
b_0	0.00	1.13	-5.27	0.43
b_1	731.78	688.93	809.50	682.47
b_2	-215.53	-229.46	-238.62	-310.52
b_3	28.42	36.30	29.54	85.06
b_4	-1.39	-2.19	-1.26	-11.77
b_5	-	-	-	0.63
r^2	0.97	0.99	0.99	0.99

Not applicable

Removal of seed coat increased the rate of water absorption for all cowpea types as shown by high b_1 values (Table 3.2.2), with exception of thin seed coat/porous cotyledon California Black). The increase of the rate of water absorption on dehulled cowpeas may indicate that the seed coat, regardless of its structure (thick/thin) influenced the water absorption.

The rate of water absorption was higher for dehulled compact cotyledon cowpea types when compared to porous cotyledon. This is indicated by higher b_1 values of 810 and

731 for compact cotyledon and 689 and 682 for porous cotyledon (Table 3.2.2). High rate of water absorption by compact cotyledon was unexpected since they have few intercellular spaces for water entry. This suggests that the cotyledon compactness may not have played a main role in water absorption during soaking of dehulled cowpeas. Other factors beyond cotyledon structure, such as, starch and protein matrix of the cowpea cotyledons may have contributed to water absorption during soaking (Sefa-Dedeh & Stanley, 1979c).

Whole Bechuana White seeds had unusual water absorption behaviour compared to other cowpea types. This is indicated by the lower b_1 value of 81 compared to other cowpea types (Table 3.2.2). Thick seed coat/compact cotyledon (Bechuana White) seemed to have almost a linear b_1 value of water absorption because of a very low b_2. This unusual trend of low rate of water absorption during soaking whole cowpeas was observed by Mwangwela (2006). Thus, to understand this unusual behaviour, Bechuana White was compared to two other thick seed coat/compact cotyledon cowpea cultivars (INIA 36 and 418 Dwarf). The two cowpea types showed more rapid water absorption than Bechuana White initially (Figure 3.2.6).

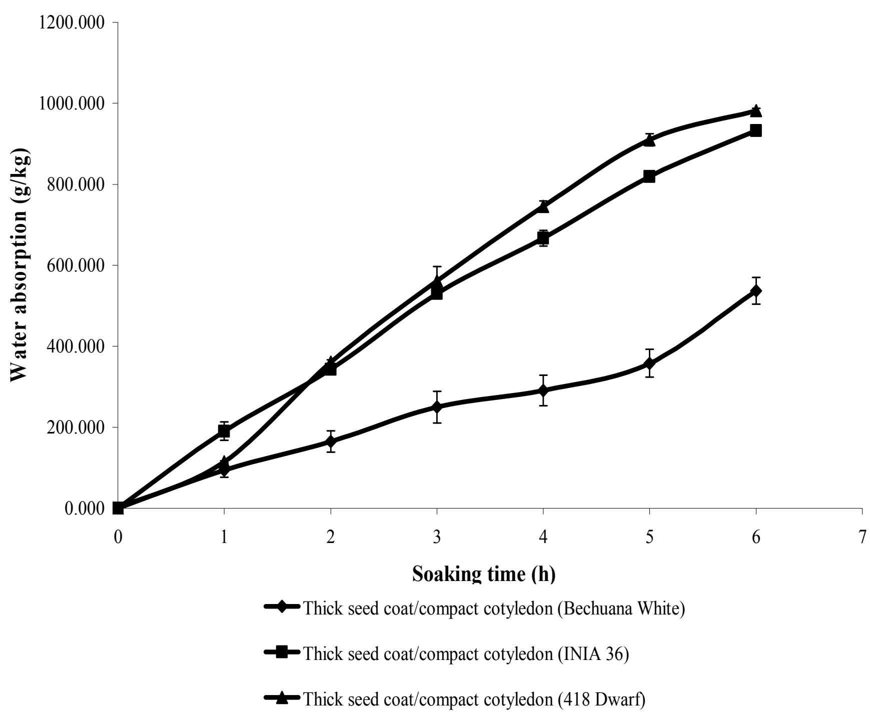


Figure 3.2.6 Water absorption during soaking of cowpeas with thick seed coats

The different behaviour of thick seed coat/compact cotyledon (Bechuana White), could indicate that this cowpea type needed more time of soaking to reach saturation. Thick seed coat compact cotyledon (Bechuana White) was soaked for 24 h and started to plateau after about 10 h of soaking (data not presented). Bechuana White's behaviour in water absorption during soaking could be possibly explained by some seed coat components as observed by Rangaswamy & Nandakumar (1985) who found that high levels of lignin, cellulose present in the seed coat of *Rhynchosia Minima* legume constituted a barrier to rapid water absorption during soaking as these components have reduced water binding capacity that results in low permeability.

3.2.4.3 Water absorption during cooking

The results of water absorption during cooking of whole and dehulled cowpeas are presented in Figure 3.2.7 (whole) and Figure 3.2.8 (dehulled). As expected, the amount of water absorbed by each cowpea type increased with cooking time. The amount of water absorbed after the cooking time differed significantly ($p<0.001$) among whole and dehulled cowpeas. Whole cowpeas absorbed over 1500 g / kg while dehulled cowpeas absorbed less than 1500 g of water /kg of cowpea sample.

For all cowpea types, in both whole and dehulled samples, the amount of water absorbed increased and tended to plateau during cooking (Figures 3.2.7 and 3.2.8). Probably water diffused from the seed coat to the cotyledon and filled the intercellular spaces during cooking. As the intercellular spaces hydrated, the amount of water absorbed increased. The increase in water absorption with cooking time of whole cowpeas has been observed (Taiwo *et al*., 1997a; Taiwo *et al*., 1998 and Mwangwela, 2006). In addition, this trend was attributed to absorption of water by gelatinised starch and denatured protein (Mwangwela, 2006) during the cooking period. The plateau could be due to fully hydration of the water absorbing components in the cotyledon.

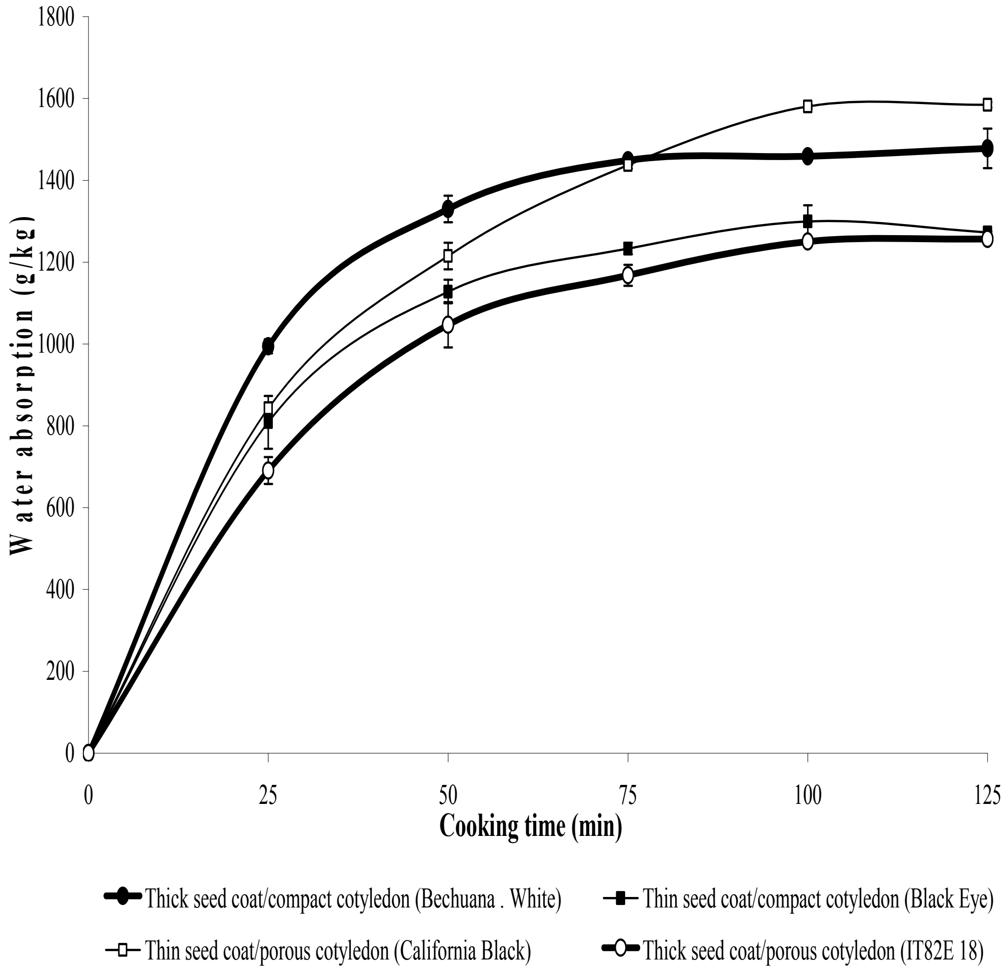


Figure 3.2.7 Water absorption during cooking of whole cowpeas

The initial increase of water absorption with cooking time for whole (Figure 3.2.7) and dehulled (Figure 3.2.8) cowpeas differed significantly ($p<0.001$) among cowpea types and there was a significant interaction between the cowpea type and cooking time. To better understand these differences, data were fit into a polynomial regression model (equation 3.2.5) and Table 3.2.3.

$$Y = b_0 + b_1 x + b_2 x^2 + \ldots + b_k x^k \qquad (3.2.5)$$

Where: Y= predicted outcome value of water absorption for the polynomial model with regression coefficient r^2 and b_1 to b_k are the slope (tangent lines to the curve of the distribution) values of water absorption for each order term of X^1 to X^k soaking time and b_0 is the predicted value of Y where X equals zero (intercept).

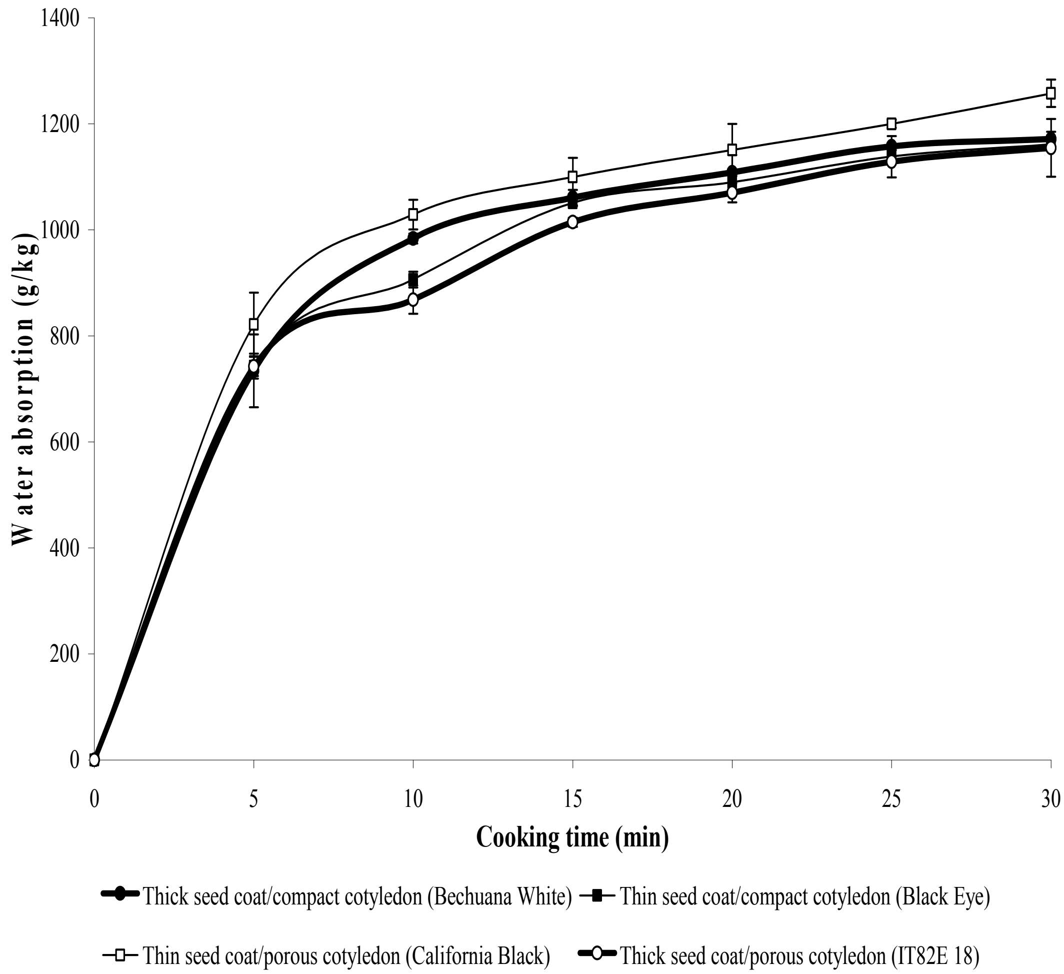


Figure 3.2.8 Water absorption during cooking of dehulled cowpeas

The rate of water absorption during cooking was higher in dehulled cowpeas compared to whole cowpeas (Table 3.2.3). Whole cowpeas with thin seed coats had similar rate of water absorption while cowpeas with thick seed coats had different rates of water absorption. Thick seed coat/compact cotyledon cowpea type (Bechuana White) had higher rate of water absorption compared to the other cowpea types. This was indicated by higher b_1 values of 51 for thick seed coat/compact cotyledon (Bechuana White) and 40, 35 and 40 for the other cowpea types. The higher rate for Bechuana White may be related to factors associated to some Bechuana White seed components that favour rapid water absorption compared to the other cowpea type.

Table 3.2.3 Regression analysis of water absorption of whole and dehulled cowpeas during cooking

	Thick seed coat		Thin seed coat	
	Compact cotyledon (Bechuana White)	Porous cotyledon (IT82E 18)	Compact cotyledon (Black Eye)	Porous cotyledon (California Black)
Water absorption during cooking of cowpeas				
Whole				
b_0	12.91	3.61	11.24	14.00
b_1	50.84	34.92	40.34	39.58
b_2	-0.58	-0.34	-0.43	-0.35
b_3	0.002	0.001	0.002	0.001
r^2	0.99	0.99	0.99	0.99
Dehulled				
b_0	1.22	8.74	7.23	4.37
b_1	216.61	214.88	212.24	245.19
b_2	-17.01	-18.45	-17.23	-20.57
b_3	0.60	0.71	0.63	0.75
b_4	-0.01	-0.01	-0.01	-0.01
r^2	0.99	0.99	0.99	0.99

The rate of water absorption of all cowpea types increased when the seed coat was removed (Table 3.2.3). In dehulled cowpeas the cotyledon did not seem to be important in water absorption during cooking. This might be an indication of the important role of the seed coat acting as a barrier for water to diffuse into the cotyledon during cooking. The rate of water absorption was similar for all dehulled cowpeas except for thin seed coat/porous cotyledon (California Black). This may be related to relatively bigger size of its seeds compared to the size of other cowpeas.

3.2.4.4 Splitting of cowpea seeds during cooking

The results of the percentage of splitting of the cowpeas during cooking are presented in Figure 3.2.9. For all cowpea types, percentage of splitting increased significantly ($p<0.001$) with cooking time. All cowpea types (thick and thin seed coats) differed significantly ($p<0.001$) in percentage of splitting during cooking for 125 min. However, these significant differences in percentage of splitting in all cowpea types were observed after 50 min of cooking. Similar trends were observed by Mwangwela (2006).

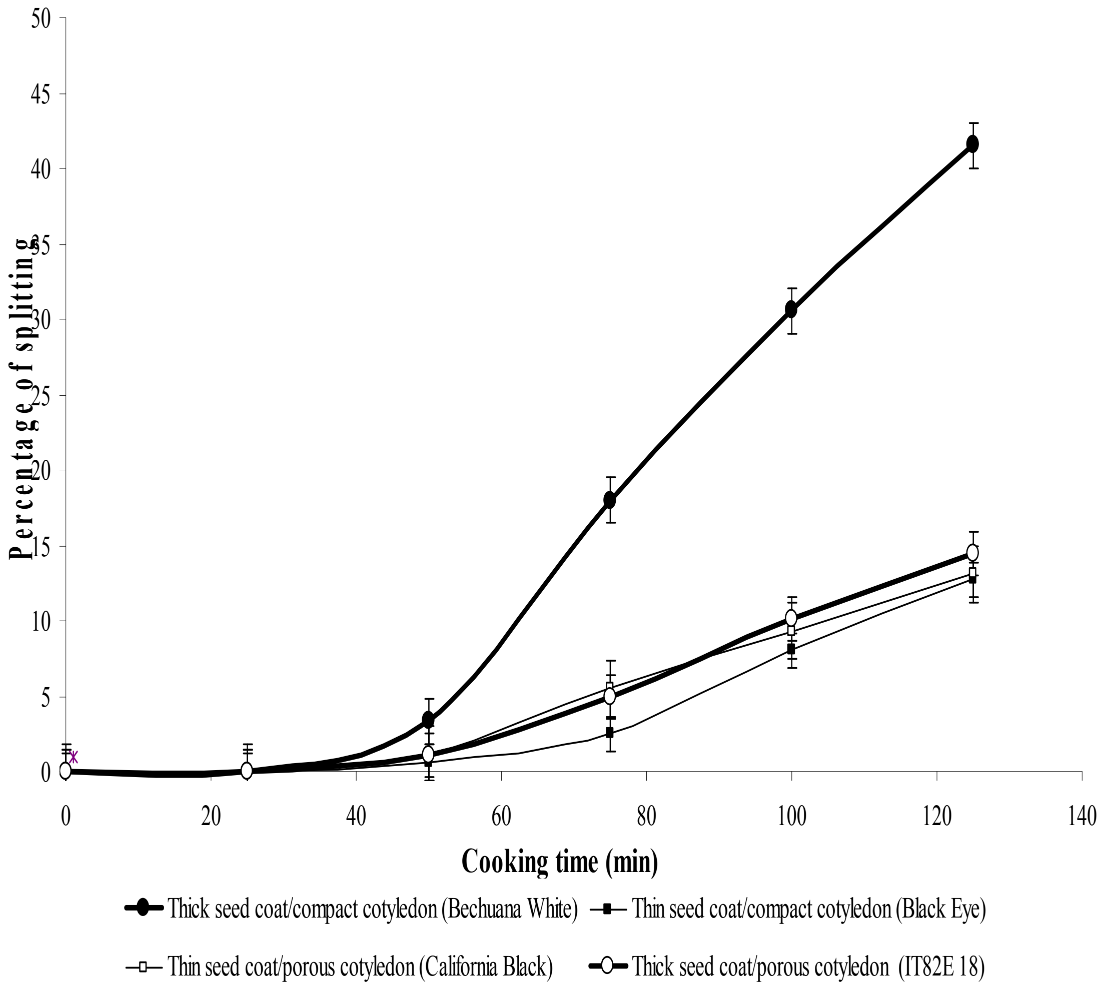


Figure 3.2.9 Effect of seed coat thickness and cotyledon compactness on splitting of the cowpea seeds during cooking whole cowpeas

Cowpeas with thick seed coats showed higher percentage of splitting compared to cowpeas with thin seed coats ((Figure 3.2.9) probably due to their dense arrangement of the seed coat palisade cells and limited cotyledon intercellular spaces that restrict the space for cellular expansion and heat transfer during cooking. Vapour pressure forces cellular expansion resulting in splitting of the cowpeas. The dense arrangement of the palisade cells and the limited intercellular spaces were observed by SEM and supported by the bulk density results (section 3.1.4). Bechuana White exhibited higher percentage of splitting compared to IT82E 18. Higher percentage of splitting for thick seed coat/compact cotyledon (Bechuana White) compared to another cowpea type was also observed by Mwangwela (2006).

The higher percentage of splitting of the thick seed coat/compact cotyledon (Bechuana White) compared to thick seed coat/porous cotyledon (IT82E 18) might be due to other factors that may have contributed to high percentage of splitting of Bechuana White. Cooking time and differences in legume variety was reported to constitute the major factors influencing percentage of splitting of cowpeas during cooking (Taiwo, 1998). In this study, cooking time did not seem to have influenced splitting since for measurement of percentage of splitting, all the samples were cooked for the same time. Wu (2002) reported that cowpeas with low levels of calcium and magnesium are prone to splitting. Taiwo *et al*. (1998) found a positive correlation between percentage of splitting, drained weight and softening during cooking.

3.2.4.5 Cooking time

The results of cooking time of whole and dehulled cowpeas are shown in Table 3.2.4. Whole and dehulled cowpeas differed significantly ($p<0.001$) in cooking time. As expected, whole cowpeas had longer cooking times (>100 min) compared to dehulled cowpeas (<100 min).

Table 3.2.4 Effect of seed coat thickness and cotyledon compactness on cooking time of whole and dehulled cowpeas

	Thick seed coat		**Thin seed coat**	
	Compact cotyledon (Bechuana White)	**Porous cotyledon (IT82E 18)**	**Compact cotyledon (Black Eye)**	**Porous cotyledon (California Black)**
Whole	112.4^{c}(1.0)	83.0^{a}(5.1)	125.7^{d}(2.3)	90.3^{b}(2.8)
Dehulled	25.7^{a}(0.5)	25.7^{a}(0.4)	30.6^{b}(0.4)	31.6^{c}(0.4)

Means followed by different superscripts in a row are significantly different at $p\leq0.001$; Standard deviations of the means are in parenthesis

Whole cowpeas with compact cotyledons had higher cooking time (112 and 126 min) compared to cowpeas with porous cotyledon (83 and 90 min). This may be explained by the structural arrangement of cotyledon cells (few intercellular spaces) which did not allow easy and rapid diffusion of water and heat transfer. Water is necessary for break down of middle lamellae and cellular expansion resulting in softening. Water is also important for starch gelatinisation and protein denaturation, which are important processes contributing to softening of the tissues. This suggests that the cotyledon compactness could play an important role in cooking time compared to seed coat thickness. However, after seed coat removal, the time necessary to soften the cowpeas was reduced for all cowpeas. The reduction of cooking time after seed coat removal may be explained by the increase in the rate of water absorption during cooking of dehulled cowpeas (Table 3.2.3).

3.2.4.6 Texture (firmness) of cooked cowpeas

The results of the texture of cooked whole and dehulled cowpeas are shown in Table 3.2.7. Overall, whole and dehulled cowpeas differed significantly (0.001) in texture after cooking according to Mattson cooking time for each cowpea type as well as when whole cowpea samples were cooked for 125 min and dehulled cowpeas were cooked for 30 min (the highest cooking time obtained when cooked according to Mattson Cooker). The texture of cowpeas cooked according to the Mattson Cooker ranged from 22 to 42 N/g for whole samples and from 12 to 33.7 N/g for dehulled samples. The texture of cowpeas cooked for 125 min ranged from 21.7 to 33.7 N/g for whole and from 11.6 to 33.7 N/g for dehulled cowpeas.

Whole cowpeas had harder texture compared to dehulled cowpeas cooked either for different or same cooking times (Table 3.2.6). This shows the important role of the seed coat in maintaining the firmness of the cowpeas during cooking. Thick seed coat/compact cotyledon (Bechuana White) had softer textures of cooked cowpeas probably because of high percentage splitting during cooking compared to the other cowpeas. Among cowpeas with thick seed coats, Bechuana White had softer texture than IT82E 18 in both cooking times. This may probably be because Bechuana White absorbed more water during cooking and had a high percentage of splitting, which increased the softening of the cowpea seeds.

Cooked dehulled cowpeas were softer compared to cooked whole cowpeas (Table 3.2.5). Thin seed coat/compact cotyledon) (Black Eye) cowpea had the hardest texture while the thick seed coat/compact cotyledon (Bechuana White) and thick seed coat/porous cotyledon (IT82E 18) had the softest texture. Hard texture of cooked cowpeas of Black Eye may be explained by differences in seed composition, for example starch, proteins, pectin). In beans, hard texture of cooked beans has been attributed to low total soluble pectin (Bernal-Lugo *et al.*, 1997).

Table 3.2.5 Effect of seed coat thickness and cotyledon compactness on the texture (N/g) of cooked whole and dehulled cowpeas

	Thick seed coat		Thin seed coat	
	Compact cotyledon (Bechuana White)	Porous cotyledon (IT82E 18)	Compact cotyledon (Black Eye)	Porous cotyledon (California Black)
	Texture of cooked cowpeas (N/g)			
Whole cooked according to Mattson Cooker (times given below)	22.0^{a}(0.8) (112.4^{c}(1.0))	35.9^{b}(1.2) (83.0^{a}(5.1))	42.4^{c}(1.7) (125.7^{d}(2.3))	22.8^{a}(0.8) (90.3^{b}(2.8))
Whole cooked for 125 min	21.7^{b}(0.8)	32.7^{c}(1.2)	41.7^{d}(1.7)	17.6^{a}(0.8)
Dehulled cooked according to Mattson Cooker (times given below)	12.1^{a}(0.3) (25.7^{a}(0.5))	12.3^{a}(0.6) (25.7^{a}(0.4))	33.7^{c}(1.5) (30.6^{b}(0.4))	17.4^{b}(0.7) (31.6^{c}(0.4))
Dehulled cooked for 30 min	11.6^{a}(0.3)	11.8^{a}(0.7)	33.7^{c}(1.5)	17.4^{b}(0.7)

Means followed by different superscripts in a row are significantly different at $p \leq 0.001$; Standard Deviations of the means in parenthesis

The texture of thin seed coat/porous cotyledon cowpea type (California Black) was comparable to the texture of whole cowpeas cooked for 125 min. A similar softer texture of dehulled samples of California Black, dehulled samples of Bechuana White and IT82E 18 was expected. But, California Black had relatively harder texture than the other samples probably because of the presence of hilum in its dehulled samples. Hillum is a firm feature on the seeds providing harder cooked samples during compression compared to seed samples whose hillum was removed during dehulling.

3.2.5 Conclusions

Seed coat thickness influences water absorption during soaking. Due to their structural arrangement of amorphous cells that facilitate rapid water entry, cowpeas with thin seed coats have higher rates of water absorption during soaking than cowpeas with thick seed coats which have palisade cells less permeable to water.

Cotyledon compactness influences the time required to cook and attain a soft texture necessary for consumption of cowpeas. Cowpeas with compact cotyledon need more time to soften compared to cowpeas with porous cotyledon.

Seed coat thickness and other factors related to some chemical components like calcium seem to influence the percentage of splitting during cooking cowpeas. Cowpeas with thick seed coats have higher percentage of splitting compared to cowpeas with thin seed coats due to its dense palisade cell layer as well as factors like chemical components (e.g. calcium content) that need to be investigated.

Cowpea type Bechuana White seems to perform differently from other cowpea types in water absorption, percentage of splitting during cooking and texture of cooked cowpeas. A study of Bechuana White concerning chemical composition in comparison to other types with similar thick seed coat/compact cotyledon is recommended.

In dehulled cowpeas the studied cooking characteristics do not seem to be related to cotyledon compactness. Other factors (which need further research such as arrangement of protein and starch granule in the cotyledon and total soluble pectin may be responsible for differences in cooking characteristics of the four cowpeas. Seed coat removal increased the rate of water absorption, reduced the cooking time and resulted in softer texture of cooked dehulled cowpeas than whole cowpeas.

3.3 The influence of seed coat and cotyledon structure of cowpeas on sensory characteristics and consumer preferences

3.3.1 Abstract

The influence of seed coat and cotyledon structure of cowpeas on sensory characteristics and consumer preferences was studied to understand the contribution of seed coat and cotyledon structure on sensory characteristics and consumer preferences. The study was based on a descriptive sensory evaluation using a trained panel and on a consumer sensory evaluation. Seed coat thickness influenced the colour of cowpeas. Cowpea types with thick seed coats had higher brown colour intensity than cowpeas with thin seed coats probably as a result of higher levels of seed components in the thick seed coats than in the thin seed coats. The influence of seed coat thickness and cotyledon compactness on degrees of firmness appeared to be limited. Other factors such as some seed chemical components such as minerals, pectin, phenolic compounds may play major influence. High degree of firmness (harder texture) was described as undesirable sensory characteristics and cowpea type with this attribute was less preferred by consumers. The attributes cooked cowpea flavour, degree of sweetness, degree of sweet aftertaste were described with high ratings and the correspondent cowpea types were more preferred by consumers.Generally, whole cowpea samples were described as having higher intensity of cooked cowpea aroma, spicy aroma and lower degree of bitter aftertaste compared to dehulled cowpeas probably as a result of high levels of phenolic compounds in the seed coats (known as responsible for bitterness) of whole cowpeas. Whole cowpea samples were also described as having higher degree of firmness and higher intensity of chewiness/rubberiness than dehulled samples because the seed coats maintained the integrity of the cooked seeds.

3.3.2 Introduction

Various factors influence consumer preferences and acceptability of cooked legumes such as cowpeas. The texture of cooked legumes (measured using a texture analyser) is usually used as a measure of cooking time (Sefa-Dedeh & Stanley, 1979c) and is believed to be an important cooking characteristic that influence consumer preferences and acceptability of cooked cowpeas. Texture of cooked cowpeas may be affected by amount of water absorbed during cooking, cooking time (Taiwo *et al*., 1998) as well as percentage of splitting (Taiwo *et al*., 1997a). Sefa-Dedeh & Stanley (1979b) have studied textural characteristics of cowpeas by doing Scanning Electron Microscopy and describing the changes in the texture of soaked and cooked cowpeas using cultivars with similar seed coat structure. They found that the texture of cowpeas was softened by cooking as a result of breakdown of the middle lamella leading to easy separation of cells and softening of seed tissues.

There is a lack of information regarding sensory characteristics as it relates to consumer preferences of cooked cowpeas. In beans (*Phaseolus vulgaris*), Mkanda (2007) found that physicochemical (e.g. seed size) and sensory attributes such as sweet taste, cooked bean aroma, cooked bean flavour and softness positively influenced consumer preferences of some bean varieties. It is expected that similar results will be found in cowpeas.

This chapter aims to study the influence of seed coat and cotyledon structure of cowpeas on sensory characteristics and consumer preferences. Considering that the available information on sensory analysis is related to texture only, information about the influence of seed coat thickness and cotyledon compactness of cowpeas on other sensory characteristics and ultimately consumer preferences is lacking.

3.3.3 Materials and methods

3.3.3.1 Experimental design

Figure 3.3.1 shows the experimental design used to study the role of seed coat and cotyledon structure on sensory characteristics and consumer preferences.

3.3.3.2 Cowpea samples

Based on section 3.1, the following cowpea types were used for descriptive sensory evaluation and consumer acceptability and preference:

- Bechuana White from South Africa – thick seed coat and compact cotyledon
- Black Eye from South Africa – thin seed coat and compact cotyledon
- California Black from USA – thin seed coat and porous cotyledon and

- IT82E 18 from Chókwé Agraricultural Research Institute, Mozambique – thick seed coat and porous cotyledon.

All cowpeas were packed in plastic containers and then stored at 4 ^{o}C.

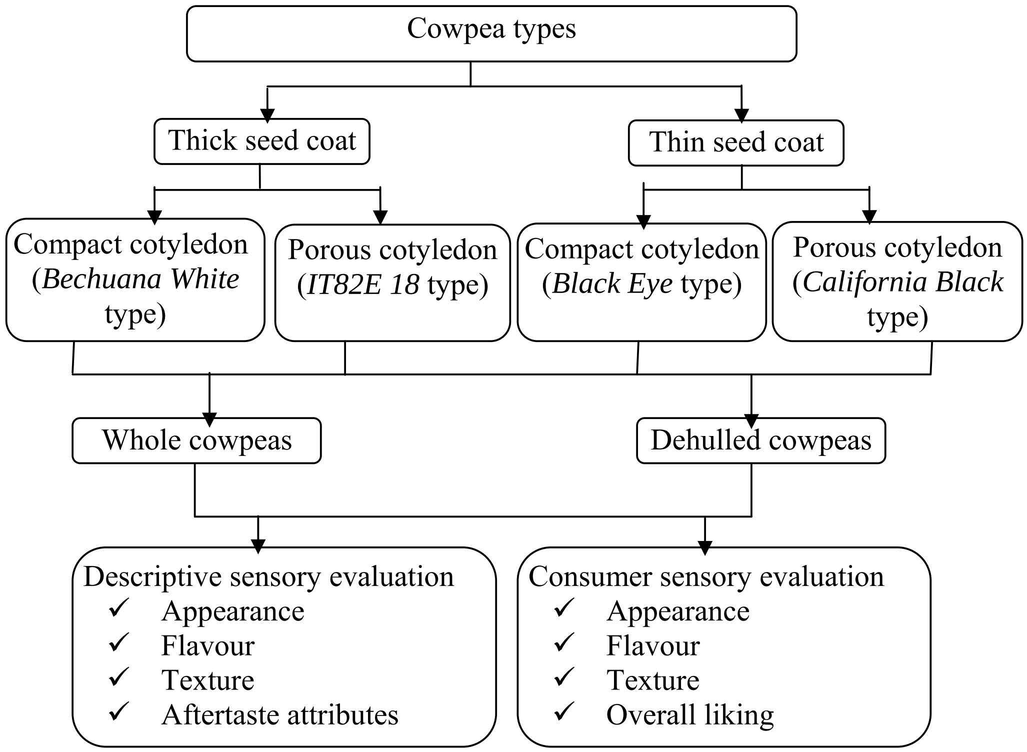


Figure 3.3.1 Experimental design of role of seed coat and cotyledon structure on sensory characteristics and consumer preference

3.3.3.3 Dehulling of the cowpeas

Dehulling of the cowpea samples was performed as indicated in section 3.2.3.3.

3.3.3.4 Descriptive sensory evaluation

Recruitment and screening of panel

Fifteen individuals (students and University of Pretoria employees) who had experience in descriptive sensory evaluation were recruited to participate in the descriptive sensory panel. The 15 individuals were screened for assessor's interest and availability (available to participate in all sessions) and 10 panellists were selected for further training.

Sample preparation

Samples (50 g of whole and dehulled cowpeas) were placed in BB4L 300 mm x 450 mm plastic bags (Cryovac, Johannesburg, South Africa) containing 200 ml deionised water. The bags were placed in 6 l cooking pots (four bags per pot) containing boiling deionised water on a two-plate industrial stove (Anvil, Johannesburg, South Africa, 220-240 V, ~50 Hz and 3200 W). To cook the cowpeas, the bags were supported with steel rods (30 cm long) that were placed on the cooking pots. Samples were cooked following the predetermined cooking times using the Mattson Cooker for each cowpea type (Bechuana White whole cowpeas – 112 min and dehulled cowpeas – 25 min; Black Eye whole cowpeas – 126 min and dehulled cowpeas – 30 min; California Black whole cowpeas – 90 min and dehulled cowpeas – 30 min and IT82E 18 whole cowpeas – 83 min and dehulled cowpeas – 30 min). Cooked cowpeas samples (10 g) were served in preheated (50 ^{o}C) glass ramekins covered with aluminium foil and coded with three random digit numbers for sample identification.

Training of the panel and sample evaluation

Training of panellists was done over five days, one hour per day. Training was conducted to familiarise panellists with the cowpea samples and for descriptive terms development using the Generic Descriptive Analysis technique described by Einstein (1991). Panellists were asked to individually describe the differences between the samples (both whole and dehulled cooked cowpea samples) on different occasions, in terms of appearance, texture, and flavour (taste and aroma).

During training, discussion sessions were carried out under supervision of a panel leader. A lexicon developed by Mkanda (2007) was used during these sessions to help panellists to generate descriptive terms that differentiated between samples and also to develop definitions for the sensory descriptors. Discussions were carried out to reach consensus on descriptive terms and definitions.

The sensory evaluation took place at the University of Pretoria's sensory laboratory containing individual cubicles equipped with computers for direct data entry using Compusense Five® release 4.6 (Compusense Inc, Guelph, ON, Canada). The evaluation was done on three separate occasions. Each time comprised two sessions separated by ten minutes interval to avoid fatigue of panellists. In each session for each day the panellists evaluated four completely randomised whole and dehulled cowpea samples, making eight samples (four whole and four dehulled) in total per day. The four random samples (whole and dehulled cowpeas) were placed in a numbered white tray, alongside four stainless steel tea spoons, a serviette, a glass tumbler with sliced carrots and a glass tumbler with deionised water, and given to each panellist. Carrots and water were used to cleanse the mouth before and in between tasting each sample. The evaluation was done using 21 descriptive terms concerning appearance, flavour and texture attributes. Table 3.3.1 shows the descriptive terms and the respective definitions of the lexicon developed by the descriptive sensory panel. The nine-point intensity scale (1 = not intense and 9 = very intense) was used by the panellists to assess the characteristics of the cowpea samples.

Statistical analysis

Descriptive sensory evaluation to determine the role of seed coat and cotyledon structure on sensory characteristics was conducted in triplicate. The effect of seed coat thickness and cotyledon compactness on sensory attributes was evaluated using analysis of variance (ANOVA) using a statistical programme GENSTAT. The means were compared using Fischer's Least Significant Difference (LSD) test at 5% level of significance. Principal component analysis (PCA) for sensory characteristics of cowpeas was conducted using Statistica version 7.0 (Stat Soft Inc, Tulsa, USA).

3.3.3.5 Consumer sensory evaluation

Consumer sensory evaluation of cowpeas was carried out in the sensory laboratory on two days using a total of 53 consumers on the first day and the same people on the second day. On the first day the assessors tasted whole cowpea samples while on the second day the same consumers tasted dehulled cowpea samples. The consumers were University of Pretoria students. The panel consisted of 73.6% females and 26.4% males. In the panel, 86.8% were between 18 to 30 years, 11.3% between 31 and 39 years, and 1.9% between 40 and 49 years of age. Consumers were selected based on the regular consumption of cowpeas/beans after an advertisement poster was placed all over the university inviting cowpeas/beans consumers to participate in consumer sensory evaluation.

Table 3.3.1 Terms developed by descriptive panel for cooked whole and dehulled cowpeas

Descriptive terms	Definitions
Grassy aroma	Aromatic attribute of cooked cowpeas similar to the smell of grass.
Cooked cowpea aroma	Characteristic aromatic attribute of cooked cowpeas.
Raw cowpea aroma	Aromatic attribute of cooked cowpeas associated with the smell of raw cowpeas.
Meaty aroma	Aromatic attribute of cooked cowpeas associated with the smell of cooked meat.
Earthy aroma	Aromatic attribute of cooked cowpeas associated with the smell of soil.
Nutty aroma	Aromatic attribute of cooked cowpeas associated with the smell of nut.
Spicy aroma	Aromatic attribute of cooked cowpeas associated with the smell of a spice.
Dry cooked maize aroma	Aromatic attribute of cooked cowpeas associated with the smell of dry cooked maize
Cooked cowpea flavour	Taste intensity of cooked cowpeas perceived during eating.
Raw peanut flavour	Taste similar to that perceived when eating raw peanuts.
Raw cowpea flavour	Taste intensity of raw cowpeas perceived when eating cowpeas.
Dry cooked maize flavour	Taste of cooked cowpeas similar to that perceived when eating dry cooked maize.
Bitter taste	Feeling in the tongue stimulated by caffeine, quinine or alkaloids when eating cowpeas.
Earthy flavour	Taste of cooked cowpeas similar to that perceived when eating soil.
Degree of sweet taste	The intensity of the taste of cooked cowpeas in the mouth stimulated by sugars.
Boiled egg yolk flavour	Taste of cooked cowpeas similar to that perceived when eating cooked egg yolk.
Degree of firmness	The extent to which the texture of cowpeas resist deformation during chewing
Degree of mushiness	The extent to which the texture of cowpeas allows for deformation during chewing giving a sensation of overcooked cowpeas.
Chewy/rubbery	Characteristic hard texture of cooked cowpeas perceived during masticating.
Degree of sweet aftertaste	The extent to which sweet taste is perceived after swallowing
Degree of bitter aftertaste	The extent to which bitter taste is perceived after swallowing

Whole and dehulled cowpea samples (350 g of each cowpea type) were cooked as described in section 3.3.2.2. Additionally, 3.5 g salt was added 10 min before the end of cooking time according to the method developed by Calvo & Del Rey (1999) since consumers would find it abnormal to evaluate unsalted cowpeas. The cooked cowpeas (10 g) were served in preheated (50 ^{o}C) glass ramekins covered with aluminium foil and coded with three-digit random numbers for sample identification.

Each consumer received four randomly ordered samples of cowpeas on a numbered white tray, four stainless steel tea spoons, a serviette and a glass tumbler with deionised water for rinsing the mouth between tasting samples. During the evaluation (Figure 3.3.2), consumers were required to express their liking of each cooked cowpea samples in terms of appearance, flavour, texture and overall preference using a nine-point hedonic scale (1 – dislike extremely and 9 – like extremely).

The questions (e.g. how much do you like the flavour of cooked cowpeas?) and scales were prepared in an understandable way and displayed using Compusense Five® release 4.6 (Compusense INC, Guelph, ON, Canada).

Figure 3.3.2 Consumers evaluating cowpea samples

Statistical analysis

The role of seed coat and cotyledon structure on the consumer preferences of cowpeas was determined using a generalised linear model two-way ANOVA (Statistica version 7.1 Stat Soft, Inc., Tulsa, UK) with samples treated as fixed and consumers as random independent effects. Fischer's LSD test at 5% level of significance was used to compare means.

3.3.4 Results and discussion

3.3.4.1 Descriptive sensory evaluation

Table 3.3.2 shows the p values of the analysis of variance of the sensory attributes regarding the test of overall effect of seed coat thickness, cotyledon compactness, structure of the seeds (in terms of whole or dehulled seeds) and their interactions.

Tables 3.3.3 and 3.3.4 show the influence of seed coat and cotyledon structure on appearance and aroma attributes of cooked whole and dehulled cowpeas and on flavour as well as aftertaste attributes, respectively.

Appearance

Significant seed coat, cotyledon, seed structure and seed coat x structure interaction effects were observed for brown colour intensity of cooked cowpeas (Table 3.3.2). The seed structure (whole or dehulled cowpeas) had the major effect. 77% of the variation in brown colour intensity between samples may be explained by difference in structure (whole/dehulled). Whole cowpea samples (Table 3.3.3) were significantly browner compared to dehulled samples. Presence of seed coat increased the intensity of brown colour of cowpeas. Preet & Punia (2000) reported higher levels of phenolic compounds in the seed coats than in the cotyledon which may contribute to colour intensity. Asiedu *et al*. (2000) reported that compounds such as flavonoids (including colour pigments, anthocyanins) and lignins that may be present in seed coats contribute to colour formation. Whole cowpea samples with thick seed coats were perceived to have higher brown colour intensity than cowpeas with thin seed coats probably because thick seed coats have higher levels of anthocyanins and phenolic compounds and other seed components compared to thin seed coats which were whitish in colour. Without referring to the seed coat thickness, it has been observed that brown coloured beans contained significantly higher amounts of phenolic compounds than white beans (Bressani & Elias, 1980; Giami & Ukwechime, 1993).

Table 3.3.2 P-values to test the overall effect of cowpea types in terms of seed coat thickness and cotyledon compactness and sensory attributes for whole and dehulled cowpeas

Sensory characteristic	Seed coat	Cotyledon	Structure (whole or dehulled)	Seed coat x Cotyledon	Seed coat x Structure	Cotyledon x Structure
			Appearance			
Brown colour	<0.001	<0.002	<0.001	0.851	<0.001	0.495
			Aroma attributes			
Grassy aroma	0.265	1.000	*0.046*	0.144	0.529	0.320
Cooked cowpea	0.130	0.070	***<0.001***	0.130	0.487	0.175
Raw cowpea	0.259	0.838	0.383	0.209	0.838	0.168
Meaty aroma	0.613	0.430	0.182	0.286	0.828	0.613
Earthy aroma	0.159	0.207	0.159	0.338	0.267	1.000
Nutty aroma	0.061	0.824	***0.003***	***0.026***	0.196	0.196
Spicy aroma	0.560	0.560	***0.007***	***0.022***	0.439	0.439
Dry cooked maize	0.408	0.304	0.532	0.408	0.110	0.157
			Flavour and aftertaste attributes			
Cooked Cowpea	***0.032***	0.059	0.401	***<0.001***	0.346	0.401
Raw peanut	0.662	0.073	***0.007***	***0.024***	0.315	***0.042***
Raw Cowpea	***0.045***	0.055	0.214	***<0.001***	0.544	0.179
Dry cooked maize	0.243	0.477	0.477	0.477	0.936	0.300
Bitter taste	***0.005***	0.105	0.366	*<0.001*	***0.040***	0.366
Earthy flavour	0.909	0.731	0.102	0.731	***0.007***	0.220
Degree of sweetness	***0.036***	0.474	0.680	***0.011***	0.066	0.311
Boiled egg Yolk	***0.005***	0.542	0.343	***0.001***	0.202	0.202
Sweet aftertaste	0.052	0.677	0.275	***<0.001***	***0.030***	0.337
Bitter aftertaste	***0.004***	***0.024***	***0.024***	***<0.001***	0.315	0.315
			Texture attributes			
Degree of firmness	***<0.001***	***<0.001***	***<0.001***	***<0.001***	***<0.001***	***<0.001***
Degree of mushiness	***<0.001***	***0.002***	***<0.001***	***<0.001***	***0.003***	0.260
Chewy/ rubbery	***0.032***	0.502	***<0.001***	***0.007***	***0.007***	0.168

Table 3.3.3 Influence of seed coat and cotyledon structure on appearance and aroma attributes of cooked whole and dehulled cowpeas

Sensory characteristics	Thick seed coat		Thin seed coat	
	Compact cotyledon (Bechuana White)	Porous cotyledon (IT82E 18)	Compact cotyledon (Black Eye)	Porous cotyledon (California Black)
Appearance				
Brown colour				
Whole	4.8^{d}(1.1)	5.6^{e}(1.1)	3.2^{c}(0.9)	3.6^{c}(1.0)
Dehulled	1.3^{a}(0.5)	1.6^{ab}(1.3)	1.4^{a}(0.8)	2.0^{b}(0.9)
Aroma attributes				
Grassy aroma				
Whole	2.2^{a}(0.8)	2.4^{ab}(0.9)	2.5^{abc}(1.1)	2.5^{abc}(0.9)
Dehulled	2.6^{abc}(1.0)	2.7^{bc}(1.1)	2.9^{c}(1.3)	2.5^{abc}(1.0)
Cooked cowpea aroma				
Whole	4.1^{b}(1.4)	4.1^{b}(1.4)	3.8^{ab}(1.4)	3.9^{ab}(1.3)
Dehulled	3.5^{ab} (1.5)	3.6^{ab}(1.6)	3.2^{a}(1.3)	3.8^{ab}(1.5)
Raw cowpea aroma				
Whole	2.3^{a}(1.2)	2.5^{a}(1.3)	2.4^{a}(1.1)	2.5^{a}(0.9)
Dehulled	2.2^{a}(1.1)	2.3^{a}(0.7)	2.6^{a}(1.2)	2.2^{a}(1.1)
Meaty aroma				
Whole	2.2^{a}(1.1)	2.4^{a}(1.0)	2.4^{a}(1.1)	2.2^{a}(0.9)
Dehulled	2.3^{a}(1.0)	2.1^{a}(1.1)	2.2^{a}(1.3)	2.0^{a}(1.1)
Earthy aroma				
Whole	1.8^{ab}(0.9)	2.2^{b}(0.9)	2.1^{ab}(0.9)	2.0^{a}(0.9)
Dehulled	1.7^{a}(0.9)	1.8^{ab}(0.9)	1.9^{ab}(1.0)	2.1^{ab}(1.1)
Nutty aroma				
Whole	1.8^{a}(0.8)	1.9^{ab}(1.1)	1.8^{a}(1.0)	1.8^{a}(1.0)
Dehulled	2.1^{ab}(1.0)	2.3^{b}(1.0)	2.2^{ab}(1.0)	1.8^{a}(1.2)
Spicy aroma				
Whole	2.1^{ab}(1.0)	2.2^{ab}(1.2)	2.5^{b}(1.2)	2.1^{ab}(1.0)
Dehulled	1.9^{a}(0.9)	2.1^{ab}(1.1)	2.0^{ab}(1.1)	1.9^{a}(0.9)
Dry cooked maize aroma				
Whole	2.3^{a}(1.2)	2.2^{a}(1.0)	2.3^{a}(1.0)	2.3^{a}(1.1)
Dehulled	2.3^{a}(1.1)	2.5^{a}(1.1)	2.1^{a}(0.9)	2.3^{a}(1.1)

Scale 1-9: 1 not intense; 9 Very intense. Means followed by different superscripts for a specific attribute (whole and dehulled samples) are significantly different at $p<0.05$. Standard Deviations in parentheses

Table 3.3.4 Influence of seed coat thickness and cotyledon compactness on flavour, texture and aftertaste attributes

Sensory characteristics	Thick seed coat		Thin seed coat	
	Compact cotyledon (Bechuana White)	Porous cotyledon (IT82E 18)	Compact cotyledon (Black Eye)	Porous cotyledon (California Black)
		Flavour and aftertaste attributes		
Cooked cowpea flavour				
Whole	4.2^{c}(1.6)	3.8^{bc}(1.3)	3.4^{ab}(1.7)	4.1^{bc}(1.5)
Dehulled	4.2^{c}(1.3)	3.8^{bc}(1.5)	2.8^{a}(1.4)	4.2^{c}(1.7)
Raw peanut flavour				
Whole	1.7^{a}(0.7)	2.0^{abc}(0.7)	2.2^{abcd}(1.2)	1.9^{ab}(1.0)
Dehulled	2.4^{cd}(1.1)	2.3^{bcd}(0.9)	2.7^{d}(1.2)	1.9^{ab}(0.9)
Raw cowpea flavour				
Whole	2.1^{a}(1.0)	2.8^{b}(1.1)	3.1^{b}(1.2)	2.2^{a}(1.0)
Dehulled	2.1^{a}(1.1)	2.2^{a}(0.9)	3.1^{b}(1.2)	2.0^{a}(0.9)
Dry cooked maize flavour				
Whole	2.7^{a}(1.1)	2.4^{a}(1.0)	2.3^{a}(1.1)	2.5^{a}(1.1)
Dehulled	2,5^{a}(1.1)	2.7^{a}(1.2)	2.4^{a}(1.1)	2.6^{a}(1.2)
Bitter taste				
Whole	1.3^{ab}(0.6)	1.6^{ab}(0.8)	1.8^{c}(1.0)	1.2^{a}(0.5)
Dehulled	1.2^{a}(0.6)	1.3^{ab}(0.8)	1.7^{c}(1.0)	1.5^{abc}(0.7)
Earthy flavour				
Whole	2.1^{b}(0.9)	2.0^{ab}(0.9)	1.8^{ab}(0.9)	1.8^{ab}(0.9)
Dehulled	1.6^{a}(0.9)	1.8^{ab}(0.9)	1.9^{ab}(0.8)	1.9^{ab}(0.8)
Degree of sweetness				
Whole	2.2^{bc}(1.2)	1.9^{ab}(1.0)	1.6^{a}(0.9)	2.5^{bc}(1.3)
Dehulled	2.7^{c}(1.0)	2.3^{bc}(1.2)	1.6^{a}(0.6)	1.9^{ab}(1.1)
Boiled egg yolk flavour				
Whole	2.4^{ab}(1.2)	2.**2**^{ab}(1.1)	1.8^{a}(0.9)	2.4^{ab}(1.3)
Dehulled	2.7^{b}(1.2)	2.3^{ab}(1.3)	1.9^{a}(1.1)	2.2^{ab}(1.1)
Degree of sweet aftertaste				
Whole	2.4^{cd}(1.2)	1.8^{ab}(1.0)	1.6^{a}(0.8)	2.6^{cd}(1.4)
Dehulled	2.8^{d}(1.2)	2.2^{bc}(1.0)	1.7^{ab}(0.8)	2.2^{bc}(1.2)
Degree of bitter aftertaste				
Whole	1.2^{a}(0.4)	1.5^{bcd}(0.8)	1.8^{d}(1.0)	1.2^{abc}(0.4)
Dehulled	1.1^{a}(0.4)	1.2^{abc}(0.6)	1.6^{cd}(0.9)	1.2^{abc}(0.6)
		Texture attributes		
Degree of firmness				
Whole	3.0^{b}(1.4)	4.2^{c}(1.3)	4.7^{cd}(1.2)	3.1^{b}(1.4)
Dehulled	2.0^{a}(1.2)	2.9^{b}(1.3)	5.2^{d}(1.4)	2.1^{a}(1.0)
Degree of mushiness				
Whole	3.2^{cd}(1.7)	2.6^{cd}(1.7)	1.9^{ab}(1.2)	3.3^{de}(1.8)
Dehulled	4.8^{f}(1.3)	3.6^{de}(1.5)	1.6^{a}(1.1)	4.2^{ef}(1.6)
Chewy/rubbery				
Whole	2.9^{bcd}(0.9)	3.3^{d}(1.4)	3.2^{cd}(1.3)	2.9^{bcd}(1.3)
Dehulled	2.3^{a}(1.3)	2.4^{ab}(1.1)	3.2^{cd}(1.4)	2.6^{bcd}(1.1)

Scale 1-9: 1 not intense; 9 Very intense. Means followed by different superscripts for a specific attribute (whole and dehulled samples) are significantly different at $p<0.05$. Standard Deviations in parenthesis

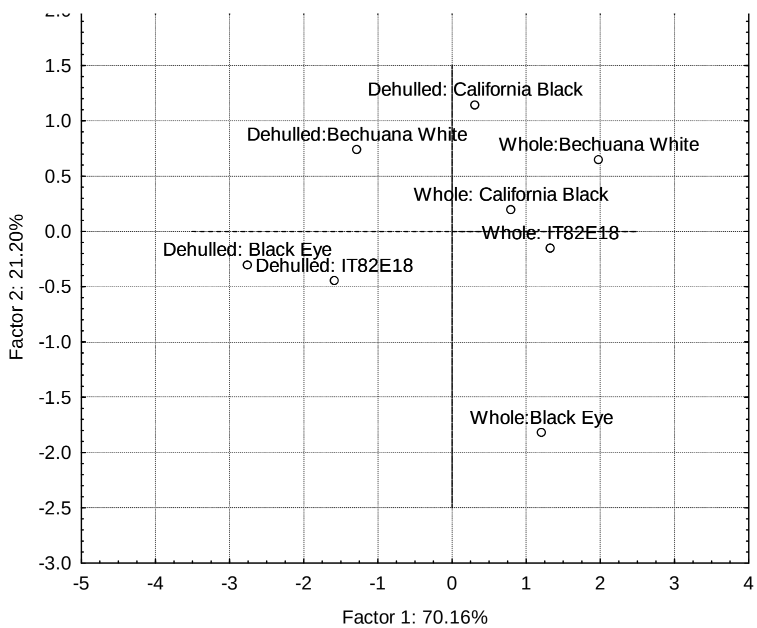
Aroma, flavour, aftertaste and texture characteristics

Figures 3.3.3, 3.3.4 and 3.3.5 show the Principal Component Analysis (PCA) where the data were analysed in three parts: The first part comprised aroma attributes, the second part covered flavour and aftertaste attributes and the third part included texture attributes. Each part is presented by a figure with A showing the projection of the scores of the whole and dehulled cowpea samples and B showing the loading projections of the sensory characteristics.

Figure 3.3.3 shows two principal components of aroma attributes. The first two principal components described 91% of the total variation in whole and dehulled cowpea samples and aroma attributes. The first principal component (PCA 1) explained 70% of the total variation of the data. Whole cowpea samples (right side of plot) were characterised by the attributes cooked cowpea aroma (more intense in Bechuana White) and spicy aroma (more intense in whole Black Eye) whereas dehulled samples (left side of plot) had intense nutty and grassy aromas. The second principal component (PCA 2) explained 21% of the variation and separated the cowpea samples (at top of plot) in terms of cooked cowpea aroma for whole and dehulled samples of Bechuana White and California Black from the other samples below (dehulled samples of Black Eye and IT82E 18, which were characterised by having more intense nutty, grassy aroma and whole Black Eye characterised by having more spicy aroma attributes. The figure illustrated that cooked cowpea aroma was affected by the presence of seed coat as it was mostly perceived in whole cowpeas. Dehulled cowpeas exhibited the nuttiest and grassy aroma attributes, which seemed to be masked by the seed coat in the whole cowpea samples.

In terms of grassy aroma, there was a significant structure (whole or dehulled samples) effect on cooked cowpea samples and 17% of variation in grassy aroma between samples can be explained by difference in structure of the samples (whole/dehulled). The low (17%) variation is because the p value is 0.046 (close to 5%). Overall, removal of seed coats increased the intensity of grassy aroma as shown in Figure 3.3.3. Probably phenolic compounds mostly found in the seed coats (Giami, 2005) may mask the grassy aroma compounds in whole cowpeas. California Black cowpea type did not show similar trend as the grassy aroma intensity was similar on the two samples probably as a consequence of presence of hilum (which is part of the seed coat) on dehulled samples. Hilum in dehulled samples of California Black may have masked some grassy aroma compounds.

A



B

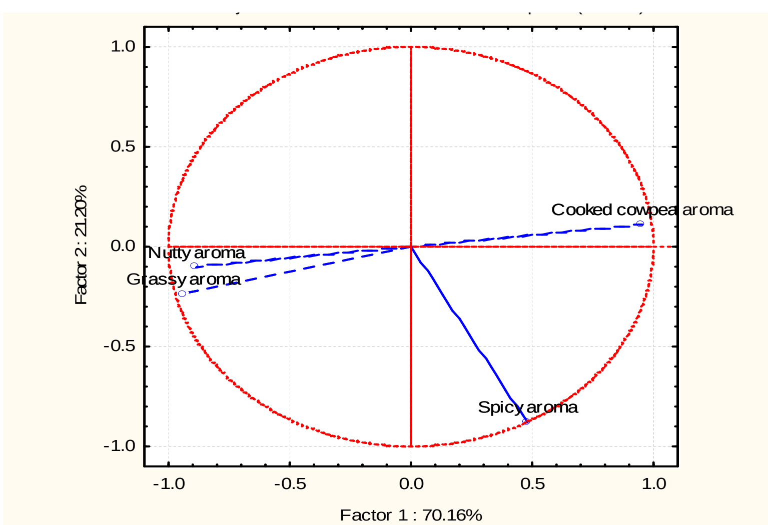
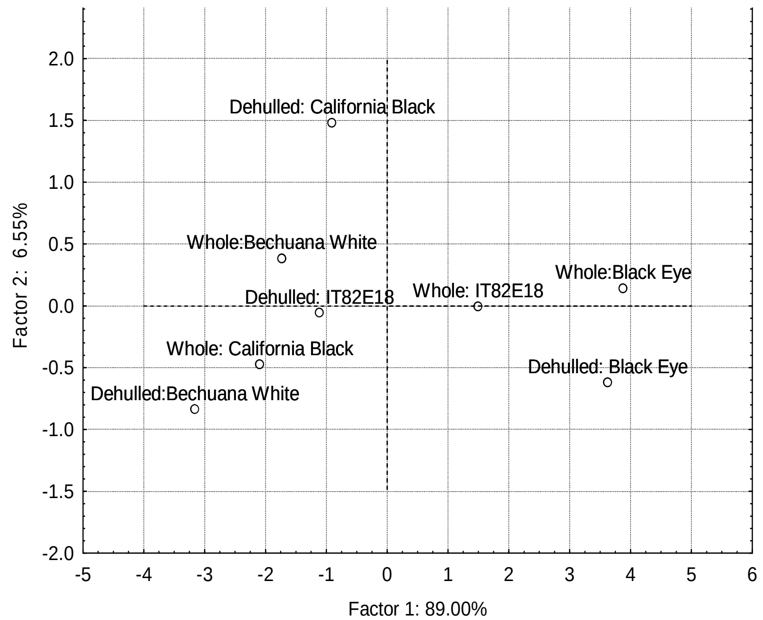


Figure 3.3.3 Principal Component Analysis of eight whole and dehulled cowpea samples, with a) plot of the first two principal components of the cowpea samples and b) Plot of the first two principal components loading projections of aroma attributes

A



B

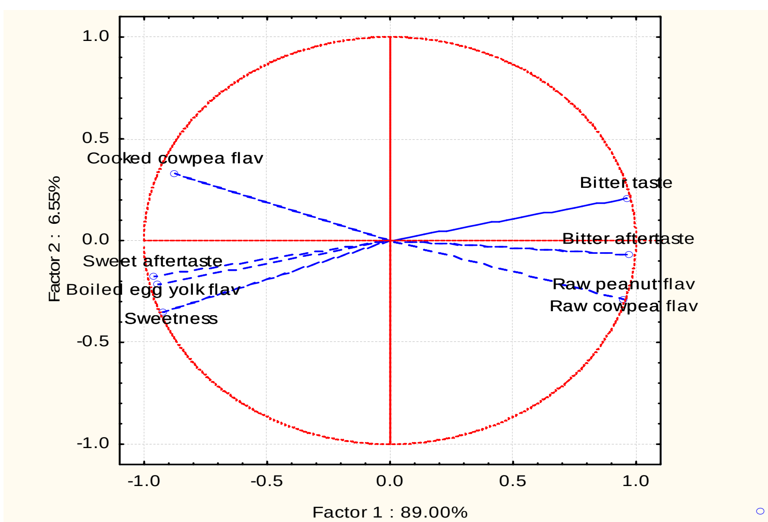
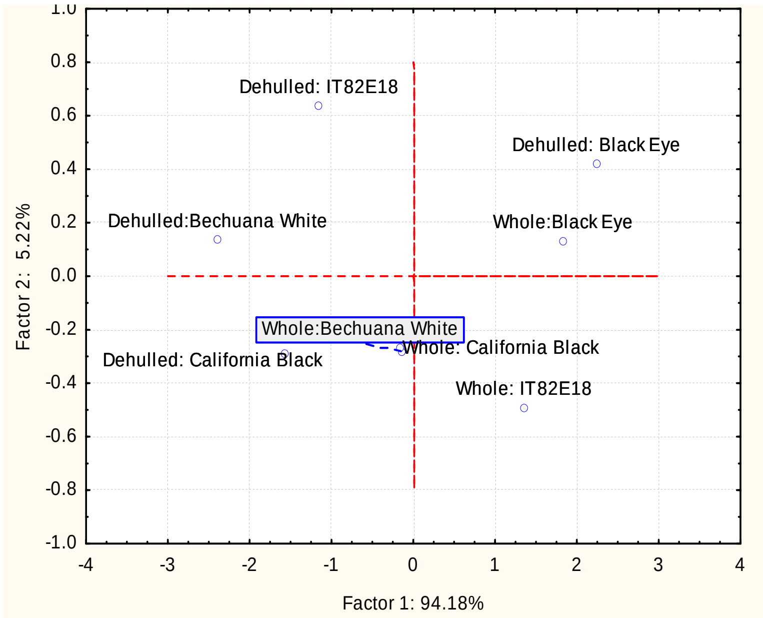


Figure 3.3.4 Principal Component Analysis of eight whole and dehulled cowpea samples, with a) plot of the first two principal components of the cowpea samples and b) Plot of the first two principal components loading projections of the flavour and aftertaste

A



B

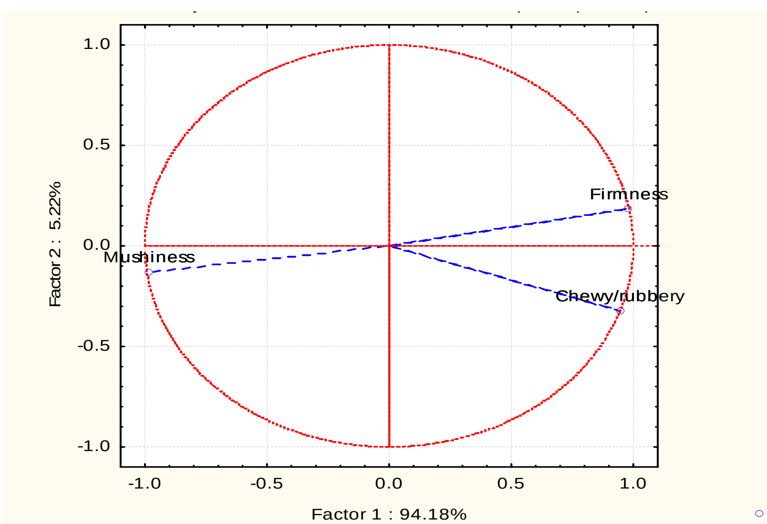


Figure 3.3.5 Principal Component Analysis of eight whole and dehulled cowpea samples, with a) plot of the first two principal components of the cowpea samples and b) Plot of the first two principal components loading projections of the texture attributes

Cooked cowpea aroma was significantly affected by seed structure effect (whole/dehulled samples). Overall, whole cowpea samples showed higher intensities of cooked cowpea aroma than dehulled samples (Figure 3.3.3). 23% of variation in cooked cowpea aroma between samples may be due to presence or absence of seed coats in the samples. The higher cooked cowpea aroma in whole cowpea samples compared to dehulled ones shown in Figure 3.3.3 and Table 3.3.3 may be probably due to higher levels of some chemical compounds such as phenolics in the seed coats than in the cotyledon (Giami, 2005).

Nutty aroma had a significant structure and seed coat x cotyledon interaction effects and the major effect was shown for structure in which 25% of variation in nutty aroma between samples may be explained by structure. In general, dehulled samples had more intense nutty aroma compared to whole samples (Table 3.3.3 and Figure 3.3.3). Presence of seed coats may mask the nutty aroma of cotyledons perhaps because of phenolic compounds located in the seed coat. Dehulling reduced the phenolics in cowpea samples and increased the perception of nutty aroma in dehulled cowpeas samples.

Spicy aroma showed a significant structure as well as significant seed coat x cotyledon interaction effects (Table 3.3.3). The major effect was revealed for structure in which 29% of variation in spicy aroma between samples may be explained by structure. The spicy aroma seemed to be more associated with the presence of seed coat as it was relatively more intense in whole samples (Figure 3.3.3).

Figure 3.3.4, representing the flavour and aftertaste attributes, shows that the two principal components described 96% of the total variance in whole and dehulled samples for flavour and aftertaste attributes of cowpeas. The first principal component (PCA 1) explained 89% of the total variation of the data. Whole and dehulled samples of Black Eye cowpea type in particular, to the right of the plot were differentiated from others by having more intense bitter taste, bitter aftertaste, raw cowpea flavour and raw peanut flavour. Dehulled samples of California Black, IT82E 18 and Bechuana White and whole samples of Bechuana White and California Black, to the left of the plot, had more intense cooked cowpea flavour, sweet aftertaste and higher degree of sweetness.

Overall flavour, texture and aftertaste attributes differed significantly among cowpea types of both whole and dehulled samples except for dry boiled maize flavour attribute (Table 3.3.2 and Table 3.3.4).

Significant seed coat, structure (whole or dehulled samples), cotyledon x structure interaction and seed coat x cotyledon interaction effects on cooked cowpea flavour were observed. The major effect was observed for seed coat x cotyledon interaction effect where 38% of variation in cooked cowpea flavour between samples can be explained by seed coat x cotyledon interaction. Thin seed coat/compact cotyledon (Black Eye) had lower intensity of cooked cowpea flavour in both whole and dehulled samples compared to whole and dehulled samples of Bechuana White, California Black and IT82E 18. The low intensity rating in terms of cowpea flavour for thin seed coat/compact cotyledon cowpea type (Black Eye) as shown in Figure 3.3.4 may be associated with higher intensity of bitter taste, raw cowpea flavour especially in dehulled samples, raw peanut flavour observed in this cowpea type compared to the others. In beans, it was also found that varieties that presented bitter taste had lower intensity ratings for cooked bean flavour (Mkanda, 2007).

There were significant seed coat and seed coat x cotyledon interaction effects between samples in terms of raw cowpea flavour. Seed coat x cotyledon interaction had the major effect and 43% of the variation in raw cowpea flavour between samples can be explained by seed coat x cotyledon interaction. Regardless of thickness of seed coat and compactness of cotyledon, higher raw cowpea flavour intensity was observed in thin seed coat/compact cotyledon (Black Eye) whole and dehulled samples and in thick seed coat/porous cotyledon (IT82E 18) whole samples compared to other samples (PCA in Figure 3.3.4). The higher intensity of raw cowpea flavour in whole samples of IT82E 18 type and in whole and dehulled samples of Black Eye type might be associated with high ratings in bitter taste and bitter aftertaste in these samples (Figure 3.3.4). Bitter taste and bitter aftertaste may have produced a sensation of raw cowpea flavour for whole samples of IT82E 18 and whole and dehulled samples of Black Eye

Seed coat (thickness), seed coat (thickness) x cotyledon (compactness) interaction and seed coat (thickness) x structure (whole/dehulled samples) interaction had significant effects on bitter taste intensity. The major effect was observed in seed coat x cotyledon interaction and 33% of the variation in bitter taste between samples can be explained by seed coat x cotyledon interaction. From Table 3.3.4 it can be seen that a higher intensity in bitterness was observed in whole and dehulled samples of thin seed coat/compact cotyledon (Black Eye) compared to the other samples. Bitterness has been reported to be due to the presence of phenolic compounds in the seed coat and cotyledon, which varies according to cowpea type (Bressani & Elias, 1980).

Figure 3.3.5 shows the principal components of texture attributes. The two principal components described 99% of the total variance in whole and dehulled samples for texture attributes of cowpeas. The first principal component PCA 1) explained 94% of the total variation of the data. Whole and dehulled samples of Black Eye had more intense degree of firmness while to the left of the plot, whole and dehulled samples of Bechuana White and California Black had more intense degree of mushiness of cooked cowpeas. A small variation of 5% was described by Factor 2 of the principal components. At the top of the plot, whole and dehulled samples of Black Eye in particular had more intense degree of firmness compared to the other side where dehulled California Black, whole samples of Bechuana White, California Black had higher degree of mushiness and IT82E 18 had higher degree of chewy/rubbery.

Degree of firmness differed significantly among cowpea samples with statistically significant effects on all variables (Table 3.3.2). The major effect was observed on seed coat x cotyledon interaction and 55% of the variation in degree of firmness between samples can be explained by seed coat x cotyledon interaction. Higher degree of firmness in whole samples was observed in thin seed coat/compact cotyledon (Black Eye) and IT82E 18 compared to the other samples (Table 3.3.4) being much higher in Black Eye (Figure 3.3.5). Statistically, neither seed coat thickness nor cotyledon compactness influenced the degree of firmness of cooked cowpeas. Other factors such as chemical components of cowpeas may have contributed to the degree of firmness of cooked cowpeas. Low total soluble pectin content for example has been reported to play a role on the high degree of firmness of beans (Bernal-Lugo *et al*., 1997). Hemicelluloses were reported to contribute to harder texture of cooked cowpeas (Sefa-Dedeh *et al*., 1978).

Regarding seed structure (whole or dehulled samples), whole cowpeas had significantly higher ratings in degree of firmness compared to dehulled cowpeas. Similar trend was observed when a texture analyser was used to measure the softness of cooked whole and dehulled cowpeas in section 3.2.4.6. Overall, seed coat removal significantly decreased the degree of firmness of cooked cowpeas as cooked dehulled cowpeas were softer than the whole ones. These results suggest that the presence of seed coat plays an important role in maintaining the firmness of cooked cowpeas. Conversely, thin seed coat/compact cotyledon cowpea type (Black Eye) remained hard even after dehulling the seeds. Similar results were also observed when firmness of cooked cowpeas was analysed using texture analyser. Thus, a correlation analysis was done and a significant ($p<0.05$) positive correlation ($r=+0.90$) was found between texture of cooked cowpeas as determined by texture analyser and that determined by descriptive sensory evaluation. Hard texture of cooked cowpeas even after seed coat removal suggest that the presence of seed coat is not the only factor playing a role in the maintenance of seed integrity of cooked cowpeas. Sefa-Dedeh & Stanley (1979b) reported that during cooking there are structural changes in the seed such as starch gelatinisation, breakdown of the middle lamella cementing material found in the cotyledon and as a result of pectin solubilisation the seeds soften. According to these authors, the inherent susceptibility of the starch granules and protein surrounding substances (i.e. pectins, and hemicelluloses) in the cotyledon cells to softening during cooking might play an important role in the degree of softening.

All variables had a significant effect on degree of mushiness of cooked cowpeas (Table 3.3.2). The major effect was the seed coat x cotyledon interaction where 45% of the variation in degree of mushiness between samples can be explained by seed coat x cotyledon interaction. High degree of mushiness was observed in thick seed coat/compact cotyledon (Bechuana White) and thin seed coat/porous cotyledon (California Black) dehulled samples (Table 3.3.4) perhaps owing to softer texture for both cowpea samples. Low degree of mushiness was observed in thin seed coat/compact cotyledon (Black Eye) probably due to harder texture of its cooked cowpeas. Degree of mushiness is related to the degree of splitting as Bechuana White had high percentage of splitting of cooked cowpeas while Black Eye did not split. Regarding the structure (whole/dehulled samples) of the cowpea seeds, overall, removal of seed coat increased the degree of mushiness. This suggests that in whole cowpeas, regardless of its cotyledon compactness, the presence of seed coat played a significant role in maintaining the firmness of cowpeas during cooking**.**

Degree of sweet aftertaste differed significantly between cowpea samples (Table 3.3.5). The major effect was a significant seed coat x cotyledon interaction where 49% of the variation in degree of sweet aftertaste between samples can be explained by seed coat x cotyledon interaction. Thick seed coat/compact cotyledon (Bechuana White) whole and dehulled samples had a higher degree of sweetness while a lower degree was perceived in thin seed coat/compact cotyledon (Black Eye) whole and dehulled samples (Figure 3.3.4). Lower degree of sweet aftertaste may be because cowpea type Black Eye had lower intensity of cooked cowpea flavour, higher intensity of bitter taste and higher degree of bitter aftertaste in both whole and dehulled samples compared to other cowpea types. In terms of influence of seed coat thickness, a general trend showed that thick seed coats masked the sweet aftertaste in whole cowpeas as after dehulling the degree of sweet aftertaste tended to increase.

There were significant seed coat, cotyledon, structure and seed coat x cotyledon interaction effects in terms of bitter aftertaste of cowpea samples Tables 3.3.2 and 3.3.5). The seed coat x cotyledon interaction was the major effect and 38% of the variation in bitter aftertaste between samples can be explained by this interaction. Bitterness may be due to presence of phenolic compounds in both seed coat and cotyledon (Bressani & Elias, 1980). Higher intensity of bitter aftertaste was observed in thin seed coat/compact cotyledon (Black Eye) whole and dehulled samples and It82E 18 whole samples compared to the other samples. This was also illustrated in Figure 3.3.4. These cowpea samples might have higher levels of phenolic compounds and some other chemical components responsible for bitterness.

3.3.4.2 Consumer sensory evaluation

Whole cowpeas

Significant ($p<0.05$) differences in acceptability of the cooked cowpea samples in terms of appearance, flavour, texture (firmness) and overall liking were observed (Table 3.3.5). In terms of appearance, significant differences were observed among cowpea types with thick seed coats. Thick seed coat/porous cotyledon cowpea type (IT82E 18) was more liked than thick seed coat/compact cotyledon (Bechuana White). Although splitting (section 3.2.4.4) was not described by the descriptive panel in this study, it might have influenced the lower liking of the appearance of thick seed coat/compact cotyledon (Bechuana White) compared to thick seed coat/porous cotyledon (IT82E 18) since the former cowpea type showed higher percentage of splitting (>40%) than other cowpeas (<20%) as shown in section 3.2.4.4.

Table 3.3.5 Effect of seed coat thickness and cotyledon compactness of whole cooked cowpeas on consumer preference

	Thick seed coat		**Thin seed coat**	
	Compact cotyledon (Bechuana White)	**Porous cotyledon (IT82E 18)**	**Compact cotyledon (Black Eye)**	**Porous cotyledon (California Black)**
Appearance	4.7^{a} (2.1)	6.1^{b}(2.0)	5.4^{ab}(2.0)	5.2^{ab}(2.0)
Flavour	6.1^{b}(2.0)	5.8^{b}(2.2)	4.7^{a}(2.3)	5.8^{b}(2.0)
Texture	6.3^{b}(1.9)	5.7^{ab}(2.1)	5.1^{a}(2.3)	6.6^{b}(1.6)
Overall liking	5.9^{b}(2.1)	5.7^{b}(2.0)	4.8^{a}(2.3)	6.1^{b}(1.8)

Scale 1-9: 1 dislike extremely; 2 dislike very much; 3 dislike moderately; 4 dislike slightly; 5 neither like nor dislike; 6 like slightly, 7 like moderately; 8 like very much; 9 like extremely. Means followed by different superscripts in a row are significantly different at $p<0.05$. Standard Deviations in parentheses

In terms of flavour, thick seed coat/compact cotyledon (Bechuana White), thin seed coat/porous cotyledon (California Black) and thick seed coat/porous cotyledon (IT82E 18) cowpea types were more preferred compared to thin seed coat/compact cotyledon cowpea type (Black Eye). These most preferred cowpea types, with exception of IT82E 18 were described by the descriptive panel as having higher degree of sweetness and sweet aftertaste. These characteristics might have contributed to its preference by consumers compared to the least preferred Black Eye. In contrast, the harder texture of thin seed coat/compact cotyledon (Black Eye) may partly explain its lower preference. Hard texture of cooked beans was also observed as a reason for low preference of some bean varieties (Mkanda, 2007). Additionally, it can be clearly seen in Figure 3.3.4 that thin seed coat/compact cotyledon cowpea type (Black Eye), the least preferred cowpea type was separated (including IT82E 18) from others by having high intensity of raw cowpea flavour, raw peanut flavour, higher intensity of bitter taste as well as higher intensity in bitter aftertaste.

In terms of texture of cooked cowpeas, there were significant differences between cowpea types. Thin seed coat/porous cotyledon (California Black), thick seed coat/compact cotyledon (Bechuana White), and thick seed coat/porous cotyledon (IT82E 18) cowpea types were more liked than thin seed coat/compact cotyledon cowpea type (Black Eye) in terms of texture of cooked cowpeas. The lower preference for thin seed coat compact cotyledon cowpea type (Black Eye) may be explained by the high degree of firmness as described by descriptive panel. The texture of cooked cowpeas for Black Eye measured using a texture analyser in this study was also higher than the others. These findings are in agreement with Taiwo *et al.* (1998) who reported that texture is an important quality for acceptability of cooked beans and may vary upon varieties. Hard texture of cooked cowpeas has been attributed to the incomplete gelatinisation of starch granules during cooking (Wang, Daun & Malcolmson, 2003) as a result of insufficient cooking time. But, this is not the case in this study because cooking time was determined using a Mattson cooker and Black Eye cowpea type had the longest cooking time. Bernal-Logo *et al*. (1997) reported that hard texture of cooked legumes is related to low total soluble pectin content which causes incomplete cellular separation during cooking.

In terms of overall liking, there were significant differences between cowpea samples. Thin seed coat/compact cotyledon cowpea type (Black Eye) was the least preferred probably due to its lower preference in terms of flavour and texture compared to the other cowpea types. It was found that beans with low acceptability had a harder texture and low cooked bean flavour (Mkanda, 2007). Additionally, this cowpea type had high ratings of raw cowpea flavour, raw peanut flavour, bitter taste and bitter aftertaste during descriptive sensory evaluation (Figure 3.3.4).

Dehulled cowpeas

Table 3.3.4 shows significant ($p<0.05$) differences in consumer preferences of dehulled cowpeas in terms of appearance, flavour, texture and overall liking.

The appearance of cooked dehulled cowpea samples differed significantly between cowpea types. Thin seed coat/compact cotyledon (Black Eye) cowpea type was the most preferred, while thin seed coat/porous cotyledon (California Black) was the least liked. The appearance of Black Eye was more liked perhaps because of the intact seeds that it had. The reason for less liking for California Black probably could be due to the black eye (hilum) that remained attached to the cotyledon after seed coat removal. The hilum attached to the cotyledon on dehulled cowpeas of California Black may have affected the appearance of the samples and consequently give a negative influence on the consumer preferences.

Table 3.3.6 Effect of cotyledon compactness of dehulled cooked cowpeas on consumer preference

	Thick seed coat		**Thin seed coat**	
	Compact cotyledon (Bechuana White)	**Porous cotyledon (IT82E 18)**	**Compact cotyledon (Black Eye)**	**Porous cotyledon (California Black)**
Appearance	4.9^{b}(2.4)	5.8^{bc}(1.7)	5.9^{c}(1.9)	3.6^{a}(2.3)
Flavour	6.5^{b}(2.1)	6.0^{ab}(1.9)	5.4^{a}(2.0)	5.2^{a}(2.2)
Texture	6.9^{c}(1.6)	6.0^{b}(1.7)	5.0^{a}(2.1)	5.9^{b}(2.0)
Overall liking	6.4^{b}(1.9)	6.0^{ab}(1.7)	5.4^{a}(2.1)	5.2^{a}(3.0)

Scale 1-9: 1 dislike extremely; 2 dislike very much; 3 dislike moderately; 4 dislike slightly; 5 neither like nor dislike; 6 like slightly, 7 like moderately; 8 like very much; 9 like extremely. Means followed by different superscripts in a row are significantly different at $p<0.05$. Standard deviations in parentheses

In terms of flavour, thick seed coat/compact cotyledon (Bechuana White) was more liked while thin seed coat/compact cotyledon (Black Eye) and thin seed coat/porous cotyledon (California Black) were less liked. The preference of Bechuana White by consumers may be explained by its higher degree of sweet aftertaste compared to the others as described by the descriptive panel. The presence of hilum on dehulled cowpeas may have influenced the flavour of thin seed coat/porous cotyledon (California Black) adversely and therefore lead to the low consumer preferences.

Thick seed coat/compact cotyledon (Bechuana White) was the most preferred cowpea type in terms of texture after removal of seed coat, while thin seed coat/compact cotyledon (Black Eye) was less preferred cowpea type. The harder texture described by descriptive panel for thin seed coat/compact cotyledon cowpea type Black Eye) for both whole and dehulled samples, explains the reduced preference by consumers. Mkanda (2007) found that texture hardness and bitterness were some of the reasons for disliking of some bean varieties.

In terms of overall liking, the consumers significantly liked the thick seed coat/compact cotyledon (Bechuana White) cowpea type while the types thin seed coat/compact cotyledon (Black Eye) and thin seed coat/porous cotyledon (California Black) were less liked. The most preferred cowpea type was also the best liked in terms of flavour and texture and was indicated to have higher degree of sweet aftertaste by the descriptive panel. These results are in agreement with the findings of Mkanda (2007) who reported that the most preferred bean varieties were described by descriptive sensory evaluation as having cooked bean flavour and soft texture.

3.3.4 Conclusions

Seed coat thickness influences the colour of whole cowpeas. Thick seed coats have higher brown colour intensity compared to cowpeas with thin seed coats. The influence of seed coat thickness and cotyledon compactness on the rest of sensory attributes is not demonstrated. However, a strong interaction effect can be seen between seed coat and cotyledon on sensory characteristics such as cooked cowpea flavour, raw cowpea flavour, degree of bitter taste, degree of sweet aftertaste and bitter aftertaste. These results indicate that both seed coat and cotyledon influence sensory characteristics and consequently consumer preferences.

High cooked cowpea flavour, high degree of sweetness, high degree of sweet aftertaste, and high degree of mushiness positively contributed to consumer preferences of thick seed coat/compact cotyledon (Bechuana White). Conversely, high raw cowpea flavour, high bitter taste, high degree of bitter aftertaste and high degree of firmness negatively contribute to consumers' disliking of the thin seed coat/compact cotyledon (Black Eye) cowpea type.

Whole cowpea samples have more intense cooked cowpea aroma, spicy aroma, high degree of bitter aftertaste, high degree of firmness and high degree of chewiness/rubberiness compared to dehulled samples. Seed coat removal results in high intensity of nutty and grassy aromas, high intensity of raw peanut flavour as well as high degree of mushiness. Seed coats in whole cowpeas may mask nutty and grassy aromas and raw peanut flavour.

Cowpea type (in terms of genotype and some chemical components) has a great influence on degree of firmness and bitter taste, which ultimately influence consumer preferences. However, a research on chemical composition of the studied cowpea types (for whole cowpea seeds, seed coats and cotyledon) would confirm these results as high degree of firmness and high bitter taste of cooked cowpeas appear to be cowpea type dependent in terms of genotype and chemical composition.

The appearance of thick seed coat/compact cotyledon (Bechuana White) cowpea type was less preferred by consumers due to high percentage of splitting. Splitting of cooked cowpeas influences consumer preferences.

4 GENERAL DISCUSSION

4.1 Critical review of the methodologies used

In the first section, 10 cowpea types were characterised in terms of seed coat and cotyledon structure as well as physicochemical characteristics to select four cowpea types representing different seed coat thickness and cotyledon compactness. The cowpea samples were obtained from South Africa and from cowpea consuming countries such as Mozambique and Malawi to obtain a more representative sample.

For characterisation of the cowpea types in terms of seed coat thickness and cotyledon compactness, scanning electron microscopy was used. According to Postek, Howard, Johnson & McMichael (1980), scanning electron microscopy uses a focused beam of high energy electrons that systematically scan across the surface of a solid specimen. The interaction of the beam with the specimen produces a large number of signals at the sample surface, which reveal the information about the sample, for example structure and orientation of the materials making up the sample. Data are generally collected over a selected area of the surface of the sample and a two-dimensional image is generated displaying spatial variations in these properties. Clear images of seed coat (showing epidermal layer with palisade cell layer of thick seed coats and amorphous cell layer of thin seed coats) and cotyledon (compact/porous) like those observed by Sefa-Dedeh & Stanley (1979a, b) were observed.

Selection of the four cowpea types used in the section 3.2 and 3.3 also considered the physicochemical characteristics of the cowpea types and sample availability. Some cowpea types, best represented a particular seed coat and cotyledon structure type but they failed to be selected due to insufficient amount of samples for running the entire experiment and problems. Arrangements were made to obtain more samples from the same branch but some seeds had developed the hard to cook phenomenon (shown by changes in colour of cowpea seeds, which were darker colours compared to fresh seeds) and long cooking time ranging from four to more than five hours). Garcia, Filisetti, Udaeta & Lajolo (1998) reported that hard to cook phenomenon is a complex process that affects different components of the cells, such as cell wall polymers, phenolics, starch and proteins among others. For example Garcia *et al*. (1998) found that the presence of phenolic compounds like ferulic acid bound to soluble pectin rendering it insoluble. This consequently lead to a textural defect by impairing cell separation upon cooking of hard to cook beans. Low textural quality has been reported to be one of the factors reducing consumer acceptability of beans with hard to cook defect (Shiga, Lajolo & Filisetti, 2004). Therefore, cowpea samples with this defect were unsuitable for the present study.

Research section 3.2 and 3.3 included the use of not only whole but also dehulled samples for better observation of the actual influence of cotyledon compactness of cowpeas on cooking and sensory characteristics. Additionally, dehulled samples illustrated what happens to cooking and sensory characteristics when seed coat is absent or removed during processing or sample preparation.

Dehulling of the seed samples was done using a laboratory grain dehuller model tangential abrasive dehulling device (TADD). Before dehulling using TADD mill, samples are usually preconditioned to loosen the seed coats and facilitate its separation from the cotyledons, thus reducing dehulling losses (Opoku, Tabil, Sundaram, Crerar & Park, 2003). In this study preconditioning such as tempering or soaking was not done because of possible changes in the seed coat and cotyledon structure components (Sefa-Dedeh & Stanley, 1979c). Phadi (2004), for example found a change in the shape of starch granules as well as the starch protein matrix upon soaking. Dehulling cowpeas using these preconditioning treatments may influence cooking characteristics of dehulled cowpeas. Dry dehulling (i.e. roasting or non roasting prior to dehuling) methods employed by Amonsou, Houssou, Sakyi-Dawson & Saalia, 2009), for example involved heat that changes the physicochemical characteristics of the seed coats (arrangement of the cells) and chemical components such as protein. Proteins may denature (unfolding of the polypeptide chain) resulting in decreased protein solubility (Klepacka, Porzucek & Kluczynska, 1997). Reduced protein solubility affects water absorption characteristics, cooking time, splitting and texture of cooked cowpeas. These will consequently affect sensory characteristics and consumer preferences.

All the above procedures were thus not suitable for use in this research project. Therefore, dehulling using TADD mill was done without any pre-treatment. Other researchers reported that dehulling was done using traditional methods which consist of soaking the seeds followed by manual removal of the seed coats (Sinha & Kawatra, 2003). These methods were not suitable for this study due to the possible physicochemical changes in the seed coat and cotyledon as explained above. Tempering also reduced the time necessary for maximum water absorption by cowpea seeds during cooking. Hand pounding dry cowpeas using mortar and pestle and separation of seed coats by winnowing (Sefa-Dedeh & Stanley, 1979c) resulted in splits instead of whole cotyledons required for this study.

Seed coat removal using TADD mill was effectively achieved however, elevated dehulling losses and scratching of the cotyledon surfaces during dehulling were observed. Scratching of the cotyledon surfaces could have influenced the rate of water absorption during soaking and cooking, thus influencing the other cooking characteristics as well as sensory results. The hilum of thin seed coat/porous cotyledon cowpea type (California Black) resisted removal. When dehulling time was increased in order to remove the hilum, the seeds started to break. Additionally, dehulling of cowpeas using an abrasive dehuller was time consuming and required a lot of sample quantity. During dehulling, many different fractions were produced which needed to be manually separated from dehulled seeds. These fractions included flour produced during abrasion, breakage and partially dehulled seeds. The partially dehulled seeds needed to be redehulled to obtain dehulled seeds. For research works where seed coats and intact cotyledons are required without changing the initial status of the seed samples, TADD mill seems to be more appropriate compared to other methods. However, improvements on TADD mill are necessary to reduce dehulling losses and scratching of the dehulled seeds. TADD manufacturers need to adjust the horizontal rotating abrasive discs of TADD mill to accommodate relatively bigger grains like cowpeas since TADD was designed for smaller grains such as sorghum and millets.

Water absorption during soaking was determined using a modified method of Agbo *et al*. (1987) used by various researchers (Taiwo *et al*., 1997a; Mwangwela, 2006; Salvador, 2007). It was planned to also measure the amount of water absorbed by seed coats during soaking to determine the amount of water retained by seed coats. However, measurement of water absorbed by seed coats was problematic because the seed coat fractions obtained after seed dehulling were small in size particularly for thin seed coat/porous cotyledon (California Black), as part of it was transformed into powder during the abrasive action. The small fractions of seed coats made the process of blot drying by absorbent paper difficult. Improvement on dehulling may result in bigger seed coat fractions that would make it possible to study water absorption of seed coats per se.

Cooking time is the time needed to attain a cooked soft texture of cowpeas acceptable for consumption. Cooking time has been reported to be one of the constraints acceptability of legumes (Taiwo *et al*., 1998). Cooking time has been determined using the Mattson cooker device (Mattson, 1946) method modified by Jackson & Varriano-Marston (1981). Different results of cooking time have been obtained by different researchers (Akinyele *et al*., 1986; Proctor & Watts, 1987; Demooy & Demooy, 1990; Salvador, 2007) due to the use of different pre-treatments and variation in the weight of the rods. In this study lighter rods of 49.8 g were used as Proctor & Watts (1987) observed that lighter rods best predicted the cooking times of legumes. Thus, all samples were cooked at the cooking times recommended by Mattson Bean Cooker, for cooking characteristics and sensory analyses.

However, the determination of cooking time using the Mattson Bean Cooker was time consuming. The cylindrical holes (perforations where seeds are placed) made for common beans are relatively bigger in size for cowpeas, making the process of placing the rods on the seeds and then positioning the cooker into boiling water difficult especially for cowpeas with thick seed coats because they were characterised by having smooth surfaces making it slippery. Fortunately, different perforated plates with different sizes of holes to accommodate the seeds are now available and can be used to minimise this problem. Although expensive, use of automated models that address the problem of attending to samples throughout the cooking period would be better. The new devices will save time of regular attention of the operator to monitor the penetration time of each rod throughout the cooking period.

Texture analysis was done using a TA-XT® Plus Texture Analyser (Stable Micro System, Godalming, UK) with attachments of the Ottawa Texture Measuring System (OTMS). In early research studies (Mwangwela, 2006; Salvador, 2007) texture was determined using an attachment that measured the force needed to cut a single seed. Results obtained in this matter were not repeatable compared to the results obtained when OTMS was used because the first method results were characterised by having high coefficients of variation. For example, from the results of Mwangwela (2006) the coefficients of variation were calculated and found to be very high (27.4 and 28.1%). In contrast, with the OTMS attachment which determines the force required to compress a layer of about 15 seeds, the results of texture of cooked cowpeas were superior with good repeatability, shown by low coefficients of variation ranging from 3.7 to 4.5% of the means due to good sampling. Nevertheless, the use of OTMS attachment requires careful organisation of seeds in order to face the same side. When seeds face the same side, better compression is obtained.

Consumer studies were done to identify the possible influence of seed coat and cotyledon structure on consumer preferences of the cowpeas. Descriptive sensory evaluation was used to explain consumer preferences. Knowledge of sensory characteristics and consumer preferences may help breeders to release cowpea types that are in accordance with what consumers prefer.

Although the selected panellists for the descriptive sensory panel were familiar with descriptive sensory evaluation as a method, it would have been more ideal if the selection of panellists had included more extensive screening of participants. Screening is necessary to ensure eligibility of panellists in terms of their ability to identify basic tastes (i.e. bitter, sour, salty, sweet and umami); to differentiate between texture of whole and dehulled cowpea samples and to describe different cowpea samples in terms of flavour, texture and appearance. The panel group was trained to familiarise them with cowpeas and to develop descriptive terms for cowpeas. Training was planned for four days but the use of the programme Panel Check showed inconsistencies in terms of judging of some descriptors. One more day was used to ensure reliability of the results. Each replicate of eight samples (four whole and four dehulled samples) randomly mixed was divided in two sub-replicates since Calvo &

Del Rey (1999) recommended use of four samples in each evaluation session to minimise fatigue of panellists.

Consumer sensory evaluation was done in two days, four samples per day to avoid tiring. On the first day consumers evaluated whole cowpea samples and on the second day the same consumers evaluated the dehulled samples. Consumer sensory evaluation could have been done in one day only (with 15 or 30 min interval between the two sessions) to save time for both consumers and the sensory team.

4.2 Critical review of the results

Table 4.1 shows the summary of results regarding possible influence of seed coat and cotyledon structure of cowpeas on physicochemical, cooking and sensory characteristics as well as overall liking of cooked cowpeas.

The influence of the presence of seed coat refers to the influence of the presence of seed coat regardless of its structure (thick/thin). All the studied cooking and sensory characteristics as well as overall liking were influenced by seed coat removal. Dehulled samples had higher rates of water absorption during soaking and cooking, cooked faster and had a softer cooked texture compared to whole cowpeas. This is because seed coats that constitute a barrier to rapid water entry to the cotyledons in whole cowpeas have been removed facilitating water entry to the cotyledons, reducing cooking time and obtaining a soft texture of cooked cowpeas.

Presence of seed coat influenced sensory characteristics as follows. Seed coat removal reduced the intensity of brown colour, increased the intensity of grassy aroma, nutty aroma and the degree of sweetness and decreased the intensity of cooked cowpea aroma, compared to whole samples. The increase of intensity of grassy and nutty aromas in dehulled cowpeas indicates that seed coats mask nutty and grassy aroma of whole cowpeas.

Table 4.1 Summary of results showing the influence of seed coat, seed coat thickness, cotyledon compactness of cowpeas and the influence of other factors on cooking sensory and overall liking of cowpea samples

Characteristics	Influence of the presence of seed coat	Influence of seed coat thickness	Influence of cotyledon compactness	Other factors
Cooking characteristics				
Water absorption during soaking	Yes	Yes	Yes	Seed chemical composition
Water absorption during cooking	Yes	No	No	No
Cooking time	Yes	No	Yes	Seed chemical composition
Percentage of splitting during cooking	Yes	Yes	No	Seed chemical composition [1, 2]
Texture of cooked cowpeas	Yes	No	No	Soluble pectin
Sensory characteristics using sensory panels				
Appearance (colour)	Yes	Yes	No	Phenolic compounds, anthocyanins
Flavour	Yes	No	No	Seed chemical components [3, 4,5]
Texture of cooked cowpeas	Yes	No	No	Soluble pectin
Splitting of cooked cowpeas	Yes	Yes	No	Soluble pectin, calcium content
Overall liking	Yes	No	No	Consumer perception

[1]- Calcium content, [2]- drained weight, [3]- proteins and binding of protein with phenolic compounds or with saponins [4]- Phenolic compounds, 5- lipids)

Phenolic acids have been reported to affect flavour (aroma and taste) of cooked red kidney beans (Van Ruth *et al*., 2004). Masking of grassy and nutty aromas may be due to binding of these aromatic compounds with phenolics which are reported to mostly be located in the seed coats (Giami, 2005). Seed coat removal positively influenced overall liking of the cooked cowpeas. Dehulling of cowpeas prior to cooking improved consumers' liking in terms of texture (softer) and flavour (sweeter). Previous studies reported that consumer preferred cowpeas with short cooking times (Garcia *et al*., 1998) to save time and energy. Shorter cooking times of dehulled cowpeas would therefore be advantageous.

Breeders should work with food scientists in order to integrate agronomic aspects of cowpeas (e.g. early mature varieties, drought and disease tolerant varieties) with consumer preferences (i.e. short cooking time varieties that are sweet tasting with a soft cooked texture) before releasing new cowpea varieties.

Seed coat thickness influenced water absorption during soaking, where cowpea types with thin seed coats had higher rates of water absorption during soaking compared to cowpeas with thick seed coats. This was probably because of the amorphous cells that make thin seed coats more permeable to water compared to well organised palisade cells of thicker seed coats. These results confirm what other researchers have found (Sefa-Dedeh & Stanley, 1979c). However, during cooking the influence of seed coat thickness and cotyledon compactness on water absorption was not evident**.** Differences in varieties in terms of seed coat thickness and cotyledon compactness and chemical components (e.g. proteins, polysaccharides) of cowpeas have been reported to influence water absorption during cooking (Taiwo *et al*., 1998).

The influence of seed coat structure was also observed on the intensity of the brown colour of whole cowpea samples. Cowpeas with thick seed coats were browner compared to cowpeas with thin seed coats probably because thick seed coats have more components such as phenolic compounds including those responsible for colour pigmentation. However, brown colour intensity did not appear to influence the overall liking in terms of appearance of cooked cowpeas.

For appearance, consumers liking of whole cooked cowpeas was adversely affected by splitting of cooked cowpeas since the least preferred cowpea type had high percentage of splitting. Percentage of splitting of cooked cowpeas appeared to be cowpea type dependent. Splitting may be due to differences in cowpea type in terms of physicochemical characteristic of cowpea types (cooking time, starch and proteins). For instance, Akinyele *et al*. (1986) observed a positive correlation between protein content and cooking time as well as amylose content and water absorption during cooking.

Cotyledon compactness influenced water absorption during soaking of dehulled samples where cowpea types with compact cotyledons had higher rates of water absorption than cowpeas with porous cotyledon. Probably other factors such as size of starch granules and their envelopment in protein matrix may have contributed to water absorption during soaking (Agbo *et al*., 1987). Cotyledon compactness also influenced cooking time of whole cowpeas. Cowpea types with compact (few intercellular spaces) cotyledons had longer cooking times than cowpeas with porous (many intercellular spaces) cotyledons**.**

It is clear from the summary of results that seed coat and cotyledon structures directly influenced very few of the cooking and sensory characteristics. Some seed components of cowpeas, for example phenolic compounds probably played a more significant role on cooking and sensory characteristics as well as overall liking of cooked cowpeas. Differences of varieties in terms of chemical composition were found to presumably be responsible for cooking and sensory characteristics. Proteins, the major water absorbing components of cowpeas (due to their hydrophilicity) were reported to positively correlate with cooking time (Akinyele *et al*., 1986). Proteins were also reported to bind with flavour compounds, and may thus influence the taste perception of food (Heng *et al*., 2004). Binding of proteins with flavour compounds such as saponins may result in bitter cooked cowpeas reducing their preference by consumers.

5 CONCLUSIONS AND RECOMMENDATIONS

Seed coat thickness of studied cowpeas influences water absorption during soaking. Due to their more permeable amorphous cell layers, cowpeas with thin seed coats have higher rates of water absorption than cowpeas with thick seed coats characterised by well an organised palisade cell layers less permeable to water.

Cotyledon compactness influences cooking time of whole cowpeas. Cowpeas with porous cotyledons cook faster compared to cowpeas with compact cotyledons because the structural arrangement of porous cotyledon cells have more intercellular spaces for rapid water entry and cell expansion that favour a faster cooking process compared to compact cotyledons.

The percentage of splitting during cooking of cowpeas is influenced by the seed coat thickness, texture of cooked cowpeas and probably by other factors (e.g. calcium content) that may be in limited content favouring splitting of seeds during cooking. Cowpeas with thick seed coats have higher percentage of splitting compared to cowpeas with thin seed coats. High percentage of splitting negatively influenced consumer preferences in terms of appearance of cooked cowpeas.

High intensity of cooked cowpea flavour, degree of sweetness, degree of sweet aftertaste and degree of mushiness positively contribute to consumers' liking of cowpeas. Conversely, high intensity of raw cowpea flavour, bitter taste, degree of bitter aftertaste and degree of firmness negatively contribute to consumers' disliking of cowpeas. Sensory characteristics seem to be most related to other factors such as seed chemical composition (proteins, saponins, phenolic compounds). Further research to confirm the above statement is recommended.

Consumer preferences of the studied cowpeas are not solely influenced by seed coat and cotyledon structure but more likely by chemical components in the seed responsible for sensory characteristics such as appearance (low percentage of splitting), flavour (good aroma and sweet taste) and texture (soft texture). Thus, further study that includes determination of sugar content is recommended to help in explaining consumer preferences of some cowpeas mentioned to have sweet taste.

Bitter taste in cooked cowpeas is an undesirable sensory characteristic. Dehulling of cowpeas seems to reduce bitter taste. Thus, dehulling for consumption of cowpeas with bitter taste is recommended as bitterness seems to be mainly due to phenolic compounds concentrated in the seed coat.

It is recommended that breeders must work together with food scientists in order to release cowpeas types that are preferred by consumers (i.e. cowpeas with good appearance (low percentage of splitting), good flavour and soft texture.

6 REFERENCES

AFOAKWA, E.O., YENYI, S.E & SAKYI-DAWSON, E. 2006. Response surface methodology for optimizing the pre-processing conditions during canning of a newly developed and promising cowpea (*Vigna unguiculata)* variety. *Journal of Food Engineering* 73, 346-357.

AGBO, G.N., HOSFIELD, G.L., UEBERSAX, M.A & KLOMPARENS, K. 1987. Seed Microstructure and its Relationship to Water Uptake in Isogenic Lines and a Cultivar of Dry Beans (*Phaseolus vulgaris* L.). *Food Microstructure* 6, 91-102.

AGUNBIADE, S.O. & LONGE, O.G. 1999. The physico-functional characteristics of starches from cowpea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*) and yam bean (*Sphenostylis stenocarpa*). *Food Chemistry* 65, 469-474.

AKINYELE, I.O., ONIGBINDE, A.O., HUSSAIN, M.A. & OMOLOLU, A. 1986. Physicochemical characteristics of 18 cultivars of Nigerian cowpeas (*V. unguiculata)* and their cooking properties. *Journal of Food Science* 51, 1483-1485.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS (AACC). 1995. in *Approved methods of the American Association of Cereal Chemists.* Anonymous American Association of Cereal Chemists, St. Paul. Minnesota. USA.

AMONSOU, E.O., HOUSSOU, P.A., SAKYI-DAWSON, E. & SAALIA, F.K. 2009. Dehulling characteristics, sensory and functional properties of flours from selected cowpea varieties. *Journal of Science of Food and Agriculture* 89, 1587-1592.

AREMO, C.Y. 1991. Selected physicochemical properties of five varieties of cowpea. *Food Chemistry* 41, 123-128.

ASIEDU, E.M., POWELL, A.A. & STUCHBERY, T. 2000. Cowpea seed chemical analysis in relation to storage seed quality. *African Crop Science Journal* 6, 283-294.

BAKR, A.A. & GOWISH, R.A. 1991. Nutritional evaluation and cooking quality of dry cowpea (*Vigna sinensis* L) grown under various agricultural conditions. I. Effect of soaking and cooking on the chemical composition and nutritional quality of cooked seeds. *Journal of Food Science and Technology* 28, 312-316.

BERNAL-LUGO, I., PARRA, C., PORTILLA, M., PENA-VALDIVIA, C.B. & MORENO, E. 1997. Cotyledon thermal behaviour and pectin solubility as related to cooking quality in common beans. *Plant Food for Human Nutrition* 50, 141-150.

BISHNOI, S. & KHETARPAUL, N. 1993. Variability in physical properties and nutrient composition of different pea cultivars. *Food Chemistry* 47, 371-373.

BLASZCKSAK, W., VALVERDE, S. & FOMAL, J. 2005. Effect of high pressure on the structure of potato starch. *CarbohydratePolymers* 59, 377-383.

BRESSANI, R. & ELIAS, L.G. 1980. The nutritional role of polyphenols in beans (Ed. Hulse J. H). International Development Research Centre, Ottawa, Canada.

BUETNER, A. & SCHIEBERLE, P. 2000. The influence of mastication on the concentrations of aroma volatils- some aspects of flavour release and flavour perception. *Food Chemistry* 73, 347- 354.

BUCKERIDGE, M.S., DOS SANTOS, H.P. & TINE, M.A. 2000. Mobilisation of storage cell wall polysaccharides in seeds. *Plant Physiology and Biochemistry* 38 (1/2), 141-156.

CALVO, M.S., DEL REY, J.A. 1999. Sensory analysis of beans (*Phaseolus vulgaris*). *Biotechno. Agron. Soc. Environ* 3 (4), 201-204.

CENKOWSKI, S. & SOSULSKI, F.W. 1997. Physical and cooking properties of micronized lentils. *Journal of Food Process Engineering* 20, 249-264.

CHAN, C. & PHILLIPS, R.D. 1994. Amino acid composition and subunit constitution of protein fractions from cowpea (*Vigna unguiculata* L. Walp) seeds. *Journal of Agricultural Food Chemistry* 42, 1857-1860.

CAMPECHANO-CORRERA, E., CORONA-CRUZ, A., CHEL-GUERRERO, L. & BETANCUR-ANCONA, D. 2007. Effect of pyridextrinization on available starch content of lima bean (*Phaseolus lunatus*) and cowpea (*Vigna unguiculata*) starches. *Food Hydrocolloids* 21, 472-479.

COULTATE, T.P. 2002. Food. *The Chemistry of its Components*. Cambridge, pp 52-57.

DAMODARAN, S. 1996. Amino acids, peptides, and proteins. In O. Fennema, (Ed), Food Chemistry, 3rd Ed. New York: Marcel Deker Inc, pp 321-430.

DAVIS, D.W., OELKE, E.A., OPLINGER, E.S., DOLL, J.D., HANSON, C.V. & PUTNAM, D.H. 1991. Cowpea. Alternative Field Crops Manual. [Online available]: www.hort.purdue.edu/newcrop/afcm/cowpea.html. [Accessed: 12/07/2006]

DEL VALLE, J.M., STANLEY, D.W. & BOURNE, M.C. 1992. Water absorption and swelling in bean seeds. *Journal of Food Processing and Preservation* 16, 75-98.

DEMOOY, B.E. & DEMOOY, C.J. 1990. Evaluation of cooking time and quality of seven diverse cowpea (*Vigna unguiculata* L. Walp.) varieties. *International Journal of Food Science and Technology* 25, 209-212.

DE SOUSA, F.D. & MARCOS-FILHO, J., 2001. The seed coat as a modulator of seed-environment relationship in Fabaceae. *Revta Brasil.Bot., Sao Paulo* 24, 365-375.

DURANTI, M. 2006. Grain legume proteins and nutraceutical properties. *Fitoterapia* 77 (2), 67-82.

EHLERS, J.D. & HALL, A.E. 1997. Cowpea (*Vigna unguiculata* L. Walp.). *Field Crop Research* 53, 187-204.

EINSTEIN, M.A. 1991. Descriptive techniques and their hybridisation, In *Sensory Science: Theory and Application in Foods*, Ed. by Lawless. & Klein, B.P. Marcel Dekker. Inc, New York, pp. 317-330.

FASINA, O.O., TYLER, R.T., PICKARD, M.D. & ZHENG, J.F. 1999. Infrared heating of hull-less and pearled barley. *Journal of Food Processing and Preservation* 23, 135-151.

FREITAS, R.L., TEIXEIRA, A.R. & FERREIRA, R.B., 2004. Characterization of the proteins from *Vigna unguiculata* seeds. *Journal of Agricultural and Food Chemistry* 52, 1682-1687.

GARCIA, E., FILISETTI, T.M.C.C., UDAETE, J.E.M. & LAJOLO, F.M. 1998. Hard to cook Beans (*Phaseolus vulgaris*): Involvement of phenolic compounds and pectates. *Journalof Agriculture and Food Chemistry* 46, 2110-2116.

GENSTAT® for Windows® (7th Edition) – Introduction (Editor R.W. Payne), Published 2003 by VSN International, ISBN 1-904375-08-1.

GIAMI, S.Y. 2005. Compositional and nutritional properties of selected newly developed lines of cowpea (*Vigna unguiculata* L. Walp). *Journal of Food Composition and Analysis* 18, 665-673.

GIAMI, S.Y. & UKWECHIME, U.I. 1993. Physicochemical properties and cooking quality of four new cultivars of Nigerian cowpea (*Vigna unguiculata* L Walp). *Jornal of Science, Food and Agriculture* 63, 281-286.

GOLONKA, P., DRIZEK, J. & KLUSA, M. 2002. Bean cotyledon microporosity under hydration conditions. *Nukleonika 47 (4), 137-140.*

GUICHARD, E. 2002. Interactions between flavour compounds and food ingredients and their influence on flavour perception. *Food Reviews International* 18, 49-70.

HENG, L., VAN KONINGSVELD, G.A., GRUPPEN, H., VAN BOEKEL, M.A.J.S., VINCKEN, J.P., ROOZEN, J.P. & VORAGEN, A.G.J. 2004. Protein-flavour interactions in relation to development of novel protein foods. *Trends in Food science and Technology* 15, 217-224.

HORAX, R., HETTIARACHCHY, N.S., CHEN, P. & JALALUDDIN, M. 2004. Preparation and characterization of protein isolate from cowpea (*Vigna unguiculata* L. Walp). *Journal of Food Science* 69, 114-118.

HSIEH, H.M., POMERANZ, Y. & SWANSON, B.G. 1992. Composition, cooking time, and maturation of Akuzi (*Vigna angularis*) and common beans (*Phaseolus vulgaris*). *Cereal Chemistry* 69, 244-248.

HUANG, J., SCHOLS H.A., VAN SOEST, J.J.G. JIN, Z., SULMANN, E. & VORAGEN, A.G.J. 2007. Physicochemical properties and amylopectin chain profiles of cowpea, chickpea and yellow pea starches. *Food Chemistry* 101, 1338–1345.

INTERNATIONAL INSTITUTE OF TROPICAL AGRICULTURE (IITA). 2006. Cowpea. *Research to Naurish Africa*. [online available]: www.IITAresearch.org. [Accessed on 11th September 2007].

JACKSON, G.M. & VARRIANO-MARSTON, E. 1981. Hard-to-cook phenomenon in beans: Effects of accelerated storage on water absorption and cooking time. *Journal of Food Science* 46, 799-803.

JACOBS, H. & DELCOUR, J.A. 1998. Hydrothermal modification of granular starch, with retention of the granular structure. A Review. *Journal of Agriculture and Food Chemistry* 46(8), 2896-2905.

KLEPACKA, M., PORZUCEK, H. & KLUCZYNSKA, M. 1997. Effect of heat treatment on chemically modified proteins of legume seeds. *Food Chemistry* 58, 219-222.

LANGYINTUO, A.S., NTOUKAM, G., MURDOCK, L., LOWENBERG-DEBOER, J. & MILLER, D.J. 2004. Consumer preference for cowpea in Cameroon and Ghana. Agricultural Economics 30, 103-213.

LAWLESS, H.T. & LEE, C.B. 1993. Common chemical sense in food flavor. In T.E. Acree and R. Teranishi, (Ed), *Flavor Science,* American Chemical Society, Washington pp. 21-65

LIU, K., PHILLIPS, R.D. & McWATTERS, K.H. 1993. Mechanism of pectin changes during soaking and heating as related to Hard-to-Cook defect in cowpeas. *Journal of Agriculture and Food Chemistry* 41, 1476-1480.

LIU, K., PHILLIPS, R.D., HUNG, Y.C., SHEWFELT, R.L. & McWATTERS, K.H. 1992. Hard-to-cook defect in cowpeas: storage-induced and treatment- induced development. *Journal of Food Science* 57, 1155-1160.

LONGE, O.G. 1980. Carbohydrate composition of different varieties of cowpea (*Vigna unguiculata). Food Chemistry* 6, 153-161.

LU, W., CHANG, K.C., GRAFTON, K.F. & SCHWARZ. 1996. Correlations between physicochemical properties and canning quality of navy bean (*Phaseolus vulgaris* L.). *Cereal Chemistry* 73, 788-790.

LUSH, W.M. & EVANS, L.T. 1980. The seed coats of cowpeas and other grain legumes: structure in relation to function. *Field Crop Research* 3, 267-286.

MA, F., CHOLEWA, E., MOHAMED, T., PETERSON, C.A. & GIJZEN, M. 2004. Cracks in the palisade cuticle of soybean seed coats correlate with their permeability to water. *Annals of Botany,* 1-16 [Online available]: www.aob.oupjournals.org.

MAHALAKSHMI, V., Ng, Q, LAWSON, M & ORTIZ, R. 2007. Cowpea (*Vigna unguiculata* (L) Walp) core collection defined by geographical, agronomical and botanical descriptors. *Plant Genetic Resources* 5, 113-119.

MKANDA, A.V. 2007. Relating consumer preferences to sensory and physicochemical properties of dry beans (*Phaseolus vulgaris* L.). MSc (Agric)(Food Science and Technology) dissertation. University of Pretoria.

MKANDA, A.V. 2007. Relating consumer preferences to sensory and physicochemical properties of dry beans (Phaseolus vulgaris). *Journal of the Science of Food and Agriculture* 87, 2868-2879.

MWANGWELA, A.M. 2006. Physicochemical characteristics of conditioned and micronized cowpeas and functional properties of the resultant flours. PhD Thesis. (Food Science). University of Pretoria.

MOSCOSO, W., BOURNE, M.C. & HOOD, L. F. 1984. Relationship between the hard-to-cook phenomenon in red kidney beans and water absorption, puncture force, pectin, phytic acid, and minerals. *Journal of Food Science* 49, 1577-1583.

MURALIKRISHNA, G. & THARANATHAN, N. 1994. Characterization of pectic polysaccharides from pulse husks. *Food Chemistry* 50, 87-89.

NUGDALLAH, G.A. & EL TINAY, A.H. 1997. Effect of cooking on cowpea protein fractions. *Plant Foods for Human Nutrition* 51, 277–282.

OLAPADE, A., OKAFOR, G.I., OZUMBA, A.U. & OLATUNJI, O. 2002. Characterization of common Nigerian cowpea (*Vigna unguiculata L.* Walp) varieties. *Journal of Food Engineering* 55, 101-105.

OPOKU, A. TABIL, L. SUNDARAM, J. CRERAR, W.J. & PARK, S.J. 2003. Conditioning of pigeon peas and mung beans. *The Canadian Society for Engineering in Agricultural, Food and Biological Systems* 03-347, 1-17.

OTTO, T., BAIK, B. & CZUCHAJOWSKA, Z. 1997. Microstructure of seeds, flours and starches of legumes. *Cereal Chemistry* 74, 445-451.

PATANE, C., IACOPONI, E. & RACCUIA, S.A. 2004. Physicochemical characteristics, water absorption, soaking and cooking properties of some Sicilian populations of chickpea (*Cicer arietinum* L.). *International Journal of Food Science and Nutrition* 55, 547-554.

PHADI, M.M. 2004. Physicochemical effects of micronization on cowpeas (*Vigna unguiculata* L. Walp). MInst Agrar Dissertation, University of Pretoria.

PHILLIPS, R.D. & McWATTERS, K.H. 1991. Contribution of cowpeas to nutrition and health. *Food Technology* 45, 127-130.

PHILLIPS, R.D., McWATERS, K.H., CHINNAN, M.S., HUNG, Y., BEUCHAT, L.R., SEFA –DEDEH, S., SAKYI-DAWSON, E., NGODDY, P., NNANYELUGO. D., ENWERE, J., KOMEY, N.S., LIU, K., MENSA-WILMOT, Y., NNANNA, I.A., OKEKE, C., PRINYAWIWATKUL, W. & SAALIA, F.K. 2003. Utilization of cowpeas for human food. *Field Crop Research* 82, 193-213.

POSTEK, M.T., HOWARD, A.H., JOHNSON, K.L. & McMICHAEL. 1980. Scanning electron microscopy a student hand book. Ed. Michael T. Postek, Jr and Ladd Research Industries, Inc.pp 7-66

PREET, K. & PUNIA, D. 2000. Proximate composition, phytic acid, polyphenols and digestibility (in vitro) of four brown cowpea varieties. *International Journal of Food Science and Nutrition* 51, 189-193.

PRINYAWIWATKUL, W., McWATTERS, K.H., BEUCHAT, L.R. & PHILLIPS, R.D. 1996. Cowpea flour: a potential ingredient in food products. *Critical Review of Science and Nutrition* 36, 413-436.

PROCTOR, J.R. & WATTS, B.M. 1987. Development of a Modified Mattson Bean Cooker Procedure Based on Sensory Panel Cookability Evaluation. Con. Inst. REHINAN, Z., RASHID, M. & SHAH, W.H. 2003. Insoluble dietary fibre components of food legumes as affected by soaking and cooking processes. *Food Sci. Technol. J.* 1, 9-14.

RANGASWAMY, N.S. & NANDAKUMAR, L. 1985. Correlative studies on seed coat structure, chemical composition, and impermeability in the legume Rhinchosia Minima. *Botanical Gazette* 146, 501-509.

REHINAN, Z., RASHID, M. & SHAH, W.H. 2003. Insoluble dietary fibre components of food legumes as affected by soaking and cooking processes. *Food Chemistry* 85 (2), 245-249

SAIO, K. & MONMA, M. 1993. Micro structural approach to legume seeds for food uses. *Food Structure* 12, 333-341.

SAINZ, C.B., BUTLER, M, WEAVER, T. & BENT, J. 2007. Starch gelatinization under microwave irradiation and conduction heat. *Carbohydrate Polymers* 69, 224-232.

SALVADOR, B. das V. 2007. Improvement in the cooking and physicochemical characteristics of hard-to-cook cowpeas by pre-conditioning and micronization. MSc (Agric) Food Science and Technology dissertation (Food Science). University of Pretoria.

SATHE, S.K., DESHPANDE, S.S. & SALUNKHE, D.K. 1984. Dry beans of *Phaseolus.* A Review . Part 2. Chemical Composition: Carbohydrates, Fibre, Minerals, Vitamins, and Lipids. Vol. 21, Issue 1.

SATHE, S.K. 2002. Dry bean protein functionality. *Critical Review in Biotechnology* 22, 175-223.

SEFA-DEDEH, S. & STANLEY. D.W. 1979a. Microstructure of cowpea variety Adua Ayera. *Cereal Chemistry* 56, 367-371.

SEFA-DEDEH, S. & STANLEY. D.W. 1979b. Textural implications of the microstructure of legumes. *Food Technology* 33 (10), 77 - 83.

SEFA-DEDEH, S. & STANLEY. D.W. 1979c. The relationship of microstructure of cowpeas to water absorption and dehulling properties. *The American Association of Cereal Chemists* 56, 379- 386.

SEFA-DEDEH, S., STANLEY. D.W. & VOISEY, P.W. 1978. Effect of soaking time and cooking conditions on texture and microstructure of cowpeas (*Vigna unguiculata* L.). *Journal of Food Science* 43, 1832-1838.

SEFA-DEDEH, S., STANLEY. D.W. & VOISEY, P.W. 1979. Effect of storage time and conditions on the Hard to Cook Defect in cowpeas (*Vigna unguiculata* L.). *Food Science* 44, 790- 796.

SHEWRY, P.R., NAPIER, J.A. & TATHAM, A.S. 1995.Seed storage proteins: structure and biosynthesis. *The Plant Cell* 7, 945-956.

SHIGA, T.M., LAJOLO, F.M. & FILISETTI, T.M.C.C. 2004. Changes in the cell wall polysaccharides during storage and hardening of beans. *Food Chemistry* 84, 53-64.

SHOMER, I., PASTER, N., LINDNER, P. & VASILIVER, R. 1990. The role of cell wall structure in the hard-to-cook phenomenon in beans (*Phaseolus vulgaris* L.). *Food Structure* 9, 139-149.

SINHA, R. & KAWATRA, A. 2003. Effect Of processing on phytic acid and polyphenol contents of cowpeas (*Vigna unguiculata* (L) Walp). *Plant Foods for Human Nutrition* 58, 1-8.

SIKORSKI, Z.E. 1997. Proteins. In Z.E. SIKORSKI, Chemical and functional properties of food components, Lancaster: Technomic Publishing Company, Inc, pp 119-160.

SNEDECOR, G.W & COCHRAN, WG. 1980. Statistical methods (7th Ed.). Ames: Iowa State University Press, pp 507.

SWANSON, B.G., HUGHES, J.S. & RASMUSSEN, H.P. 1985. Seed microstructure: Review of water imbibition in legumes. *Food Microstructure* 4, 115-124.

SZCZESNIAK, A.S. 2002. Texture is a sensory property. *Food Quality and Preference* 13, 215-225.

TAIWO, K.A. 1998. The potential of cowpea as human food in Nigeria. *Technovation* 18 (5/6), 469-481.

TAIWO, K.A., AKANBI, C.T & AJIBOLA, O.O. 1997a. The effects of soaking and cooking time on the cooking properties of two cowpea varieties. *Journal of Food Engineering* 33, 337-346.

TAIWO, K.A., AKANBI, C.T. & AJIBOLA, O.O. 1997b. Establishing processing conditions for canning cowpea seeds in tomato sauce. *International Journal of Food Science and technology* 32, 313-324.

TAIWO, K.A., AKANBI, C.T. & AJIBOLA, O.O. 1998. Regression Relationships for the soaking and Cooking Properties of two Varieties. *Food Engineering* 37, 331- 344.

TESTER, R.F. & KARKALAS, J. 1996. Swelling and gelatinisation of oat starch. *Cereal Chemistry* 73, 271-277.

THARANATHAN, R.N. & MAHADEVAMMA, S. 2003. A Revision: grain legumes a boon to human nutrition. *Trends in Food Science and Technology* 14, 507- 518.

UWAEGBUTE, A.C., IROEGBU, C.U. & EKE, O. 2000. Chemical and sensory evaluation of germinated cowpeas (*Vigna unguiculata*) and their products. *Food Chemistry* 68, 141-146.

UZOGARA, S.H., MORTON, I.D. & DANIEL, J.W. 1990. Influence of various salts in the cooking water on pectin losses and cooked texture of cowpeas (*Vigna unguiculata*). *Journal of Food Biochemistry* 14, 283-291.

VAN RUTH, S.M., DINGS, L., BUHR, K. & POSTHUMUS, M.A. 2004. In vitro and in vivo volatile flavour analysis of red kidney beans by proton transfer reaction-mass spectrometry. *Food Research International* 37, 785-791.

WANG, N., DAUN, J.K. & MALCOLMSON, L.J. 2003. Relationship between physicochemical and cooking properties, and effects of cooking on antinutrients, of yellow field peas (*Pisum sativum*). *Journal of the Science of Food and Agriculture* 83, 1228-1237.

WU, X. 2002. Correlation of Physicochemical Characteristics in the seed coat and Canning Quality in Different Dark Red Kidney Bean (*Phaseolus Vulgaris* L.) Cultivars. A Research paper for Masters degree. Food Science and Technology. University of Wisnconsinstut.

WU, X.J., JAMES, R. & ANDERSON, A. 2005. Mineral Content in Seed Coat and Canning Quality of Selected Cultivars of Dark Red Kidney Beans (*Phaseolus vulgaris* L.). *Journal of Food Processing and Preservation* 29**,** 63-74.