3. GENERAL DISCUSSION

This chapter is in three sections. Firstly, the methodologies applied in this study are critically evaluated. In the second section, the main findings of the investigations of (1) Finger millet grain phenolics and antioxidant activity of different grain types; (2) the Effect of phenolic content and amount of phenolic type on the malt quality of finger millet grain; and (3) the Impact of finger millet grain phenolics on cookie quality, are discussed. Lastly, based on the main research findings, the postulation "finger millet grain is a premium cereal grain for human food" is put forward and critically evaluated.

3.1. Methodologies

This section discusses the strengths and weaknesses of most of the major methods applied in this study. Suggestions of how the methodologies could have been approached differently and/or improved are made.

As stated earlier, the Bleach test was for the first time used to detect the presence of tannins in finger millet grain. The principle of the test, as applied to sorghum grain for which it was first developed, is that sodium hypochlorite solution (Bleach) containing alkali dissolves away the outer pericarp layer of submerged grain, revealing the presence of a black pigmented testa layer in the case of tannin sorghums, or its absence in the case of non-tannin sorghums (Price and Butler 1977, Taylor 2001). The kernels with a pigmented testa stain black in the Bleach reaction. According to the procedure of the Bleach test, when applied to sorghum grain, the reaction should occur in 20 minutes (Waniska et al 1992, Taylor 2001). However, when the Bleach test was applied to finger millet grain, the reaction took a much longer time (incubation had to be left overnight) than in sorghum grain. The reason for this could be that the pericarp of finger millet is thicker than that of sorghum. According to Taylor and Belton (2002), the pericarp of sorghum contains a waxy cuticle layer, a layer of epidermal cells; under these are two or three layers of the hypodermis, beneath which is the mesorcarp. From this review, it seems that the sorghum

pericarp is not made up of many layers. In contrast, microscopic analysis of the outer layers of finger millet grain in this study showed that it was made up of several layers. The observation was similar to that of McDonough et al (1986) who reported that the pericarp of the finger millet grain appeared to be made up of several layers of tissue (subsection 1.2.1.1). The merit of the Bleach test, when applied to sorghum, is that it is simple, rapid and inexpensive (Dykes and Rooney 2006). However, when applied to finger millet, the Bleach test would not be rapid as when applied to sorghum. That would be of disadvantage when used in situations such as in the screening of tannin and non-tannin grains for marketing.

According to Price and Butler (1977), the Bleach test, when applied to sorghum, is subject to error because of interference in some varieties by plant pigments, the colour of which may persist through the test and make identification of the testa ambiguous. Dykes et al (2002) reported that severely weathered, insect damaged or moulded sorghum without a pigmented testa turned dark after Bleaching, which could lead to erroneous, false positive results indicating that a sorghum kernel contained tannins. In the current study, sound finger millet kernels were selected for the Bleach test and sound sorghum standards (tannin and non-tannin sorghum standards) were included. The incidence of false positives caused by the presence of damaged or weathered kernels was therefore unlikely. However, interference by pigments naturally-occurring in the finger millet kernels was possible, but no false positives were found in this study. The Bleach test agreed well with the Vanillin-HCl assay (chapter 2.1, Table 2.1.3). The correlation of the two assays indicates that the Bleach test can be used to test for presence of tannins in finger millet grain.

There may be room for improvement of the Bleach test for use in finger millet grain. Raising the incubation temperature could be one way of reducing the duration of the reaction. The “scratch test” which is an alternative of the Bleach test was deemed inappropriate in finger millet because it would be practically almost impossible to scratch such tiny kernels. The “scratch test” is used to determine the presence of tannins in sorghum grain. In the “scratch test”, the outer pericarp of sorghum grain is scratched away with a sharp knife or scalpel to determine the presence or absence a pigmented testa. The presence of a pigmented testa is a positive result for the presence of tannins in the grain (Waniska et al 1992).

The location of tannins in the finger millet grain was determined by using a combination of methods, *viz*. the Bleach test; the Vanillin-HCl assay and light microscopy (chapter 2.1). The results showed that finger millet grain types that stained black in the Bleach test had condensed tannins, whilst those that did not stain black had no tannins (chapter 2.1, Table 2.1.3). It was thus possible to put the finger millet grain types into two groups, non-tannin types and tannin types, similar to the work of Mason et al (1972) with sorghum. Analysis by light microscopy indicated that the dark colour was concentrated in the testa layer (chapter 2.1, Figure 2.1.1). In contrast, the non-tannin grain types had a light testa layer (Figure 2.1.1.). Because in sorghum, it has been established that tannins are located in a dark testa layer, it could therefore be deduced that in finger millet grain, tannins are located in the testa layer, as in sorghum. Blakely et al (1979) and Moral et al (1981), similarly, used light and electron microscopy to determine the location of tannins in sorghum grain and to analyse the structure of tannin-containing tissues. Blakely et al (1979) observed that the outstanding feature of high tannin sorghums was the presence of a testa, which appeared as a dark strip just external to the aleuronic layer. Their observation is similar to that made in this study (Figure 2.1.1). Because, the methodology used to determine the location of tannins in finger millet grain is similar to the methodologies that have been used to study tannins in sorghum grain, the methodology could have been improved by including non-tannin and high-tannin sorghums as standards.

Acidified methanol was used when extracting for the determination of TP and flavan-4-ols, whilst in the determination of condensed tannins absolute methanol was used. In the determination of anthocyanins, initial extraction was with absolute ethyl acetate and finally with acidified methanol (chapter 2.1). The solubility of phenolic compounds is governed by the polarity of the solvent, degree of polymerisation of the phenolics, as well as interaction of phenolics with other food components and formation of insoluble complexes (Naczk and Shahidi 2004). With regard to the solvents used in this study, methanol and ethyl acetate are polar solvents, and acidified methanol is more polar than absolute methanol and ethyl acetate. Polar solvents are suitable for extracting polar phenolic compounds and non-polar solvents for non-polar phenolic compounds. Therefore, the effectiveness of the solvents used in this study partly depended on the polarity of the phenolic compounds in the samples. While Kaluza et al (1980) found 75% (v/v) aqueous acetone the best solvent for extracting phenolic compounds from

sorghum grain, there are several reports (e.g. Sripriya et al 1996, Dykes et al 2005, Hedge and Chandra 2005, Dlamini et al 2007) in which either absolute or acidified methanol has been used to extract phenolic compounds from sorghum and finger millet. While Waterman and Mole (1994) recommend absolute methanol over acetone and acidified methanol for extracting condensed tannins for the Vanillin-HCl assay, in the Price et al (1978) modification of the Vanillin-HCl method acidified methanol is used to extract the tannins in type II tannin sorghums. It is important to note that in the human being, phenolic compounds are not extracted from food by the solvents used in this study. Instead, the phenolic compounds are extracted into aqueous solutions during mastication and digestion. Therefore, the assayed phenolic levels do not give a direct indication of the phenolic levels that would be extracted in the gut.

Interaction of phenolics, particularly the condensed tannins, with other chemical components of the finger millet grain, and cookie doughs and cookies might have reduced their extractability. The condensed tannins could have interacted with the macromolecular carbohydrates and proteins, and minerals forming insoluble complexes that were not extractable (Porter 1989, Slabbert 1992, Emmambux and Taylor 2003). Phenolic compounds might also have interacted with Maillard reaction products [MRPs] to form insoluble and hence unextractable complexes. The reduction in the levels of assayable total phenolics, condensed tannin content and antioxidant activity during the making of cookies (chapter 2.3, Table 2.3.2) could indeed have been due to a decrease in the extractability of phenolic compounds due to their interaction with other chemical components of the cookie doughs. There is no standard procedure for the extraction of all phenolics or a class of phenolics in plant materials (Naczk and Shahidi 2004). The extraction methodology used in this study could have been improved by employing different extraction procedures in which some of the critical extraction parameters, such as temperature, time and solvent, were varied. The extraction yields could then be compared.

Extraction of cell wall-bound phenolic compounds was not attempted. The extraction of cell wall-bound phenolic compounds involves thie hydrolysis with NaOH (Maillard and Berset 1995). As reviewed earlier, substantial amounts of cell-wall bound phenolic compounds have been reported in finger millet grain (Subba Rao and Muralikrishna 2001, 2002). Therefore, the phenolic contents of the finger millet grain types, and cookie doughs and cookies are actually

assayable phenolic contents. They are highly likely to be an underestimation of the actual phenolic contents of the finger millet grain types, cookie doughs and cookies. It is relevant to note this because in the human being digestion and the action of micro-organisms in the gut may release substantial amounts of cell wall-bound phenolic compounds (Manach et al 2005). Cell-wall bound phenolic compounds have been shown to contribute to the antioxidant properties of finger millet grain (Subba Rao and Muralikrishna 2002).

The Folin Ciocalteu assay was used to estimate the total phenolics (TP) of finger millet grain types, and cookie doughs and cookies chapters 2.1 and 2.3). The Folin Ciocalteu assay is based on the measurement of the reducing power of phenolic hydroxyl groups (Singleton et al 1999). The limitation of the Folin Ciocalteu assay is that it is not specific to a particular class of phenolic compounds (Singleton et al 1999). Interfering compounds, with reducing power, such as unanticipated phenolics or enols (e.g. food additives and microbial metabolites), aromatic amines and aminophenols, purines, tyrosine and tryptophan, proteins, and ascorbic acid can react with the Folin Ciocalteu reagent (Singleton et al 1999). Some of these substances, which may interfere with the Folin Ciocalteu assay, are likely to have been present in the finger millet grain types, and cookie doughs and cookies. These substances would have contributed to TP as measured by the Folin Ciocalteu assay. The shortening (margarine) used in making cookies contained additives, including phenolic antioxidants (shown on the ingredients label of the packaging), which were probably detected by the Folin Ciocalteu assay. In the cookies, Maillard reaction products (MRPs) may have been detected by the Folin Ciocalteu assay, as was reported by Michalska et al (2008) working with bread. Therefore the TP of the finger millet grain types, and cookie doughs and cookies could have been overestimated.

According to Singleton et al (1999), the Folin Ciocalteu assay is usually preferred to other methods in most situations where the objective is to make a direct comparison of the TP of samples that are similar. Other workers, e.g. McDonough et al (1986), Hegde and Chandra (2005), and Chethan and Malleshi (2007) have also used the Folin Ciocalteu assay to measure TP in finger millet grain. In this study, the Folin Ciocalteu assay was similarly deemed appropriate for estimating the relative TP of finger millet grain types, and cookie doughs and cookies, respectively. Inclusion of non-tannin and high tannin and sorghums standards could have

improved the method. Other assays that measure TP, such as the Ferric ammonium citrate assay of the International Organization for Standardization (ISO) (1988) and the Prussian Blue assay (Price and Butler 1977), could also have been employed and the results compared.

The modified Vanillin-HCl assay of Price et al (1978) was used to determine condensed tannins in finger millet grain types, cookie doughs and cookies (chapters 2.1 and 2.3). The Vanillin-HCl assay is based on the reaction of flavanols with the aldehyde vanillin in an acidic medium (Swain and Hills 1959; Porter et al 1986). The Vanillin-HCl assay is not specific for condensed tannins. It detects both polyflavanols (condensed tannins) and flavanol monomers (Scalbert 1992). Thus, the assay can over-estimate condensed tannin content by measuring also the naturally-occurring flavanol monomers. For example, the results of this study indicate the occurrence of flavan-4-ols in the finger millet grain types (chapter 2.1, Table 2.1.2). These compounds could have been detected by the Vanillin-HCl assay. Indeed, the highly significant positive correlation ($r= 0.666$, $p<0.001$) (chapter 2.1, Table 2.1.3) between the flavan-4-ols and condensed tannins suggests that flavan-4-ols contributed to the assayed condensed tannin content of the finger millet grain types.

Sarkar and Howarth (1976) demonstrated that the Vanillin-HCl assay was not specific for flavanols. These authors showed that the requirement for the vanillin reaction is a single bond between C-2 and C-3 of the flavonoid nucleus (chapter 2.1, Figure 1.2.3) and free meta-oriented OH groups on the B ring. Flavonoid compounds such as dihydrochalcones, anthocyanins or anthocyanidins and flavanones may produce a reaction in the Vanillin-HCl assay (Sarkar and Howarth 1976). The flavonoid flavones have been reported in finger millet leaves (section 1.2.4). Flavones have a double bond between C-2 and C-3 (Markham 1989). Thus, they would not be involved in the vanillin reaction, presuming that they were present in the finger millet grain types of this study. However, the results of this study indicate the occurrence of anthocyanins or anthocyanidins (chapter 2.1, Table 2.1.2). These compounds, as already stated, may be involved in the vanillin reaction. Other compounds possessing chemical structures, which are suited to the vanillin reaction, may have been present in the finger millet grain types, and cookie doughs and cookies; and they would have contributed to overestimation of condensed tannins.

In this study, blanks were used in the Vanillin-HCl assay to counteract the possible error due to background colour of other pigments. However, Earp et al (1981) commented that when blanks are subtracted, initial colour is removed, but this still does not eliminate the measurement of non-tannin, vanillin positive compounds. While catechin, a flavanol monomer, was used as a standard in the Vanillin-HCl assay in this study, it has been shown that condensed tannins are less reactive than catechin (Goldstein and Swain 1963, Sun et al 1998). These findings suggest that only some of the internal flavanol units of condensed tannins react with vanillin. Thus, structural variations in the condensed tannins will affect the colour yield with vanillin (reviewed by Schofield et al 2001). Unfortunately, because of the complexity and variability of the condensed tannin structures, it is difficult to obtain an appropriate standard for condensed tannins (Schofield et al 2001).

However, the Vanillin-HCl assay is widely used for quantification of condensed tannins in plant materials, and particularly in grains (Naczk and Shahidi 2004). Other workers (McDonough et al 1986, Sripriya 1996, Hegde and Chandra 2005) have also used the Vanillin-HCl assay to measure tannins in finger millet grain. Earp et al (1981) evaluated seven methods for determining tannins in sorghum, and concluded that, for most of the analytical purposes and food applications, the modified Vanillin-HCl assay of Price et al (1978) when used in combination with either the scratch or Bleach test for determining the presence of a pigmented testa, was the most recommended. These authors commented that determination of absolute values of condensed tannins by the methods they evaluated was not possible; rather, each of those assays was a relative measure of the tannins in sorghum.

As with the measurement of total phenolics, the results of the Vanillin-HCl assay in this study could have been improved by including non-tannin and high tannin sorghums as standards. Other methods for measuring condensed tannins, which, because of their specificity for condensed tannins, could have given better results than the Vanillin-HCl assay, include the optimised Proanthocyanidin (Butanol-HCl) assay (Porter et al 1986), and HPLC techniques (reviewed by Schofield et al 2001, Dykes and Rooney 2006). These methods, however, are not as simple as the Vanillin-HCl assay, and as with the Vanillin-HCl assay, it is difficult to obtain an appropriate standard for condensed tannins (Dykes and Rooney 2006).

The anthocyanin content of the finger millet grain types was determined using a method based on the characteristic behaviour of anthocyanins under acidic conditions (Fuleki and Francis 1968). Under acidic conditions, anthocyanins possess a flavylium ion nucleus, which is responsible for their characteristic red colour. They absorb in the UV-visible light region (Escribano-Bailón et al 2004). In this study, absorbance was measured in the visible region (475 nm and 495 nm [chapter 2.1), which should have been superior to the UV region because interference by UV-absorbing substances such as protein, nucleic acids and amino acids should have been minimal (Naczk and Shahidi 2006). However, other coloured compounds like carotenoids, if they were present in the samples, would have interfered with the determination of anthocyanins.

The spectral properties (including absorbance maxima) of anthocyanins vary according to their chemical nature, such as type of functional groups on the B ring, glycosylation and presence of acyl groups (Escribano-Bailón et al 2004). Although apigeninidin and luteolinidin have been found to absorb maximally at 475 nm and 495 nm, respectively (Menkir et al 1996), other anthocyanins and anthocyanin-related compounds may absorb significantly at these wavelengths. Therefore, if the finger millet grain types of this study contained several molecular types of anthocyanins and other anthocyanin-related compounds, measurement of anthocyanins as 3-deoxyanthocyanins, apigeninidin and luteolinidin, could have resulted in a significant error. The method could have been improved by applying diagnostic techniques, e.g. use of HPLC equipped with a diode array detector and scanning spectrophotometry, to test for the presence of anthocyanin species and their absorption maxima. The data could have been then reported as crude 3-deoxyanthocyanin or anthocyanin content.

The principle of the assay used to measure flavan-4-ols is that, when left to stand at room temperature for about 1 h in acidified alcohol (butanol-HCl), flavan-4-ols convert to pink anthocyanidin pigments, which absorb strongly at 550 nm (Watterson and Butler 1983). Condensed tannins also undergo the same reaction in butanol-HCl, but only after boiling the reaction mixture (Butler 1982). Monomeric flavan-3-ols do not convert to anthocyanidins under these reaction conditions (Butler 1982). The possible drawback of the assay used to measure flavan-4-ols is that naturally-occurring anthocyanidin pigments may also be detected. Hence, the flavan-4-ols contents of the finger millet grain types might have been over-estimated. The

significant and positive correlation (r= 0.513, $p<0.05$) (chapter 2.1, Table 2.1.3) between apigeninidin content and flavan-4-ols content of finger millet grain supports the suggestion that naturally-occurring anthocyanidins could have contributed to the assayed flavan-4-ols contents of the finger millet grain types.

Colorimetric methods could only estimate total phenolics and contents of classes of phenolic compounds in finger millet grain types, cookie doughs and cookies. Molecular types were not identified. Methods such HPLC and NMR techniques could have identified molecular types of the phenolic compounds. HPLC analysis was tried, but unsuccessfully. The HPLC system developed a high pressure when analysis of phenolic acids and flavonoids was attempted in the reverse phase. The peaks were poorly resolved. It was thought that large molecules such as sugars and tannins in the extracts were blocking the column. An attempt was therefore made to purify the samples by separating out the high molecular weight substances through solid phase extraction. Several attempts were made to analyse the purified samples, using new columns and purging the column at intervals. There was no significant improvement in the analysis and the work was abandoned. The HPLC analysis may be successful if sample preparation and analysis procedures are further improved. However, estimation of phenolic contents using colorimetric methods was adequate for determining the relative levels of phenolic compounds in the samples.

The Trolox assay measures the relative ability of an antioxidant to scavenge the free radical chromogen 2,2´-azinobis (3-ethyl-benzothiazolline-6-sulphonic acid) ($ABTS^{\cdot+}$) generated in the aqueous phase, as compared with trolox (Miller and Rice-Evans 1997). Loss of the blue-green $ABTS^{\cdot+}$, due to antioxidant activity, is measured by observing a decrease in absorbance at a specific wavelength. In this study, $ABTS^{\cdot+}$ was generated by reacting an ABTS salt with potassium persulphate and absorbance was measured at 734 nm (Chapter 2.1).

The Trolox assay and the DPPH assay are the most widely used assays that are based on the free radical-scavenging activity of radical chromogens (Arnao 2000). When the Trolox assay was applied in this study, it was found to be rapid (save that $ABTS^{\cdot+}$ generation was overnight), easy to perform and had good repeatability (chapter 2.1, Table 2.1.2 and chapter 2.3, Table 2.3.6). These advantages of the Trolox assay have also been reported by Miller and Rice-Evans (1997)

and Awika et al (2003b). Another advantage of using the Trolox assay in this study was that interferences by coloured compounds, such as anthocyanins and carotenoids (Arnao 2000) and probably also the MRPs of the cookies, would have been minimal as absorbance was measured far away from 415-515 nm range, where significant interferences have been observed (Arnao 2000). Furthermore, because $ABTS^{\cdot+}$ is soluble in both aqueous and organic solvents (Arnao 2000), the antioxidant activity of hydrophilic and lipophilic compounds in extracts from the finger millet grain types, and cookie dough and cookies should have been detected. The two advantages of the Trolox assay, which have been just stated, make it superior to the DPPH assay (Arnao 2000). The Trolox assay was performed in buffered media at pH 7.4, which is relevant as it is the approximate human physiological pH. However, the antioxidant activity of the samples could have been under-estimated due to under-extraction of antioxidant compounds, as discussed earlier.

One of the weaknesses of the Trolox assay is that it is not fully standardized and hence comparison of results across laboratories is problematic (Awika et al 2003b). Another weakness of the assay is the use of the $ABTS^{\cdot+}$, which is foreign to biological systems. Hence, the antioxidant activities of finger millet grain and cookies reported in this study may not be a good indicator of their antioxidant activities *in vivo*. With respect to this, the oxygen radical capacity (ORAC) assay, which measures the ability of antioxidants to protect protein from damage by typical biological systems radicals, $ROO^{\cdot}$, $OH^{\cdot}$ and Cu^{2+} (Cao et al 1993), would have been more appropriate than the Trolox assay. However, the ORAC assay suffers the drawback of using expensive equipment and that data variability can be large across equipment (Awika et al 2003b). On the other hand, Awika et al (2003b) working with sorghum and sorghum products found a very high correlation (r^2= 0.99) between the Trolox assay and the ORAC assay, which indicates that Trolox assay results show antioxidant activity trends that are similar to those of the ORAC assay.

The moulds that infected the unmalted finger millet grain types and their malts were analysed by the direct plating method, while enumeration of all the fungi, i.e. yeasts and moulds (total fungal count [TFC]) that contaminated the surface of the unmalted finger millet grain types and their malts was performed by the standard plate count method (chapter 2.2). In the direct plating

method, the unmalted and malted finger millet kernels were surface sterilized with 76% (v/v) ethanol, and thus the moulds growing on the media after incubation were presumed to be those, which had infected the kernels. Selective media were used to reduce competition amongst the moulds and to supply nutrients to different mould types according to, as far as possible, their requirements. Thus, applying the findings of Rabie et al (1997) working with barley and according to the protocol used by the Centre for Applied Mycological Studies (CAMS) of the University of Pretoria/CSIR, Potato Dextrose Agar (PDA) was used as a non-selective medium; Malt Salt Agar (MSA) for the selective growth of *Aspergillus*, *Eurotium* and *Penicillium* spp.; and Pentachlorobenzene Agar (PCNB) for the selective growth of *Fusarium* spp.

Moulds grow by means of hyphae, which tend to spread rapidly resulting in overgrowth, as opposed to growth by division of individual distinct cells in bacteria (Harrigan 1998). Thus, enumerating moulds by the standard plate count method may be difficult. In this study, counting was done only in plates in which, due to dilution, there were distinct individual mould propagules.

When used in this study, the direct plating method was easy to follow. The mould propagules growing on the plates were distinct, which made their enumeration, purification and subsequent identification possible. Results of the direct plating method (chapter 2.2, Tables 2.2.1 and 2.2.3) showed that finger millet malt grain was infected by more species of moulds than the unmalted grain. These trends seem, as discussed previously, logical as it is expected that changes during malting such as increase in moisture content of the grain would make it more susceptible to fungal infection. Thus, the direct plating method, as used in this study, seems to have been effective at detecting fungal infection levels.

Rabie et al (1997) compared the effectiveness of dilution plating and direct plating methods to enumerate moulds that grew on barley. These authors found that the direct plating method detected a greater diversity of mould species than the dilution plating method. A much larger variety of species of both field and storage fungi were enumerated in the direct plating method. These authors thus recommended the direct plating method over the dilution method. Many workers, e.g. Petters et al (1988), Ackermann (1998), and Lefyedi et al (2005) have used the

direct plating method on the basis that it is one of the best methods for assessing growth of fungi in cereal grains. One drawback of the direct plating method is that, unlike the colony count methods (Harrigan 1998), it does not determine the quantity, as for example cfu/g, of the fungi infecting the kernels. The method only detects the proportion of infected grain in a sample, but the severity (quantity of fungi) of infection is not detected. Another disadvantage of the direct plating method is that it consumes a lot of time, media and plates. Other methods such as microscopic counts, flow cytometry and ATP determination by bioluminescence (Harrigan 1998) could have been tried, but as explained the direct plating method was deemed the most appropriate.

The 9-point hedonic rating test was used, as it is the appropriate method for determining the overall acceptability of a product by consumers (Lawless and Heymann 1998). Although the design of the sensory test followed the principles of randomisation to minimize error, significant "psychological errors" are likely to have occurred. Psychological errors have to do with the peculiarities of human judgment (Stone and Sidel 2004). For instance, psychological errors classified as "contrast and convergence errors" could have occurred. For example, the panellists might have given the light cookies made with cake flour or partially substituted with the non-tannin finger millet an exaggerated high appearance acceptability score because of the contrast in colour between them and the brown cookies containing high levels of the high-tannin finger millet. Whilst the light lightness (Hunter L values) of wheat cake flour cookies was significantly higher than that of composite cookies (chapter 2.3, Table 2.3.2), the appearance acceptability of the cake flour cookies was the same as that of cookies containing 15% non-tannin finger millet (Table 2.3.7). That was probably because the small but significant colour differences between the two types of cookies was, in terms of appearance acceptability, masked or overshadowed (convergence error [Stone and Sidel 2004]) by the large difference between the much lighter cake flour cookies and the much darker cookies containing high levels of the high-tannin finger millet.

The consumer panel comprised university students of different races, gender and ages who were regular consumers of sugar snap cookies. The consumer panel was thought to be appropriate for the test as it represented a wide spectrum of consumers of sugar snap cookies. The drawback in the use of the described panel was that they were not consumers of finger millet. Consumers of

finger millet might have liked the cookies substituted with finger millet more than the panel used in this study. On the other hand, the panel used in this study would be appropriate if the cookies were being targeted at health-conscious, modern urban-based consumers. A second panel of regular consumers of finger millet could have been used to evaluate the market potential of the cookies in a community of regular consumers of finger millet.

Analysis of the acceptability of selected attributes of the cookies gave an indication of their contribution to the overall acceptability of the cookies, but the data did not describe the sensory characteristics of the cookies. The sensory evaluation questionnaire could be improved by including questions eliciting for data on the sensory characteristics of the cookies, and questions eliciting for comments about the cookies could be included. Alternatively, the sensory analysis could be expanded to include analytical tests, e.g. descriptive tests (Lawless and Heymann 1998), to obtain information on the sensory characteristics of the cookies.

3.2. Research findings

This section discusses the main findings of this study, which show that finger millet contains various phenolic compounds that contribute to the antioxidant properties of the grain and its food products, and that the phenolics seem to have a positive influence on finger millet malt quality, but contribute to some of the poor quality attributes of composite wheat-finger millet cookies.

As described earlier (chapter 2.1, Tables 2.1.1 and 2.1.2), this study shows that finger millet grain types produced by tan and purple plant types contain various phenolic compounds, including condensed tannins, flavan-4-ols and anthocyanins. Total phenolics, condensed tannins, flavan-4-ols and anthocyanins vary across grain types. These findings indicate that pigmented grain types contain higher amounts of phenolic compounds than light types. Grain types with a pigmented testa, which are produced by purple plant types, contain condensed tannins, as in sorghum (Dykes et al 2005). These findings clearly indicate that genetic factors (variety) strongly affect the phenolic content and composition of finger millet grain. However, unlike in sorghum (Dykes and Rooney 2006), the actual genotypes that control grain colour, presence of a pigmented testa and tannin content are not known. Although confirmatory analyses are required, this study seems

to be first to report on the presence of the flavonoid monomers anthocyanins (i.e. the 3-deoxyanthocyanidins apigeninidin and luteolinidin) and flavan-4-ols in finger millet grain. Occurrence of these flavonoids in finger millet grain should be significant as they may, together with other phenolic compounds, impact on food quality and safety, as will be discussed further.

Due to its much smaller kernel size, finger millet should have a larger surface area to volume ratio than sorghum. The testa layer of the finger millet grain should therefore have a larger surface area relative to that of the sorghum grain. Since in both sorghum and finger millet tannins are located in the testa layer, it would therefore be expected that the finger millet grain have relatively higher tannin content than sorghum grain. However, the tannin contents (not detected to 2.1 mg of catechin equivalents/100 mg) (chapter 2.1, Table 2.1.2) of the finger millet grain types of this study were generally lower than those often reported for sorghum grain (e.g. 0.0 to 5.5 mg catechin equivalents/100 mg [Beta et al 1999]). The unexpected findings could be due to possible underestimation of tannins in the finger millet as has already been suggested or the difference was due to genetic factors.

Genetic factors seem to strongly affect the phenolic content and composition of finger millet grain. The relationships established in this study between phenotypic attribute (plant type, grain colour and presence of a pigmented testa) and grain phenolic content and composition in finger millet should be significant as they could be used in screening for grain types with the desired phenolic contents and phenolic types in plant breeding, grain marketing and other practical purposes. For example, grain pigmentation may be used as a selection criterion for grain types with high phenolic content as suggested by the significant and positive correlation ($r = 0.567$, $p<0.01$) (Table 2.1.3) between the Hunter a values and TP. The Bleach test may be used to detect tannin finger millet types as discussed earlier.

The findings of this study show that phenolic compounds make a large contribution to the antioxidant properties of finger millet grain (chapter 2.1, Tables 2.1.1 and 2.1.2). Tannin finger millet grain types exhibit much higher antioxidant activity than non-tannin types, which is in agreement with the hypothesis stated in section 1.3. The results indicate that condensed tannins contribute largely to antioxidant activity of finger millet grain. This may be attributed to the

chemistry of condensed tannins. Condensed tannins contain numerous hydroxyl groups (chapter 1, Figure 1.2.4), which can be involved in antioxidant activity reactions by donating hydrogen or electrons and thereby scavenge free radicals and quench reactive oxygen species (Rice-Evans et al 1997, section 1.2.3). An increase in the number of hydroxyl groups in a phenolic compound has been found to correspond with an increase in antioxidant activity (reviewed in section 1.2.3). The findings of this study thus suggest that tannin finger millet grain types/varieties are good sources of phenolic antioxidants, which may have health-promoting effects. These findings are useful as they may be used for the selective breeding of tannin finger millet grain types/varieties, which could be processed into antioxidant-rich ("health") foods as will be discussed further.

The findings of this study indicate that unmalted and malted pigmented finger millet grain types, which had higher contents of phenolic compounds, had lower fungal loads than the light coloured grain types (chapter 2.2, Tables 2.2.1 and 2.2.3). In fact, the fungal loads of unmalted and malted finger millet grain were significantly negatively correlated with phenolic content and type (condensed tannins, anthocyanins or flavan-4-ols) (chapter 2.2, Tables 2.2.2 and 2.2.4). These findings indicate that finger millet grain phenolics contribute to resistance of the grain to fungal invasion. Finger millet grain phenolics thus seem to exhibit antimicrobial activity. These findings are similar to those reported by few (Seetharam and Ravikumar 1994, Viswanath et al 2008) and several authors (reviewed in chapter 1, subsection 1.2.6.4) working with finger millet grain and sorghum grain, respectively.

The positive correlation between finger millet germinative energy and malt quality (enzymic activity) and phenolic content and amount of phenolic type (Table 2.2.6) suggests that phenolics in finger millet grain promote its germination as indicated by high enzymic activity of the malt. The phenolic compounds could have promoted germination by inhibiting fungi. The mechanisms of antimicrobial activity of the phenolic compounds could be the same as those that have been proposed (reviewed in chapter 1, subsection 1.2.6.5). The finger millet tannins might have attenuated invasion of the grain by fungi by forming a physical barrier in the testa, as suggested by McGrath et al (1982) when working with sorghum. The finger millet grain phenolics might have been toxic to the fungi by reacting with their cell walls and membranes and cell

components, such as physiological and structural proteins and carbohydrates, as suggested in the literature (Butler et al 1984, Scalbert 1991, Cowan 1999). Several reaction mechanisms, including hydrogen bonding, oxidation and complexation might have been involved. The integrity and functionality of the fungal cell walls and membranes and cell components would have been affected negatively. For example, the functionality of cell membrane-bound enzymes and protein factors presumably mediating host (grain) penetration by the fungi might have been affected negatively by the finger millet phenolics. The finger millet phenolics could have been toxic to fungi through reacting with their enzymes and thereby inhibiting them from mediating vital metabolic reactions, including those involved in the germination of spores (reviewed by Harborne 1994b). Simple phenols and phenolic acids present in the finger millet grain could have reacted with fungal enzymes through, e.g. oxidation reactions such as the oxidative formation of disulphide bonds or through non-specific interactions (reviewed by Cowan 1999). The finger millet tannins might have complexed with fungal enzymes through hydrogen bonding and hydrophobic interactions (Butler et al 1984, Scalbert 1991). The finger millet grain tannins might have also complexed with metal ions in the grain rendering them unavailable to the fungi, as suggested in the literature (Butler et al 1984, Scalbert 1991). It is noted that whilst this study showed a highly significant positive correlation between finger millet malt quality and total phenolics and amount of phenolic type, the cause and effect hypothesis that phenolics in finger millet grain play a positive role in its malt quality was not tested.

The contribution of finger millet grain phenolics to its antimicrobial activity, as indicated by the findings of this study, should be significant in food quality and safety. Pigmented finger millet grain types with higher contents of phenolic compounds relative to the light grain types could be deliberately selected for, as they would have good storage, malt quality due to the antifungal activity of their phenolics. There would be a low risk that these grain types would be contaminated with mycotoxins. The high-phenol finger millet grain types and their malts would preserve their quality during storage and marketing. The grains of high-phenol finger millet types would be highly suitable for storage as seed. As stated earlier, the prevailing humid and hot conditions in the tropical regions, including much of sub-Saharan Africa, are favourable for the proliferation of micro-organisms, including fungi, which cause grain deterioration and produce mycotoxins. In addition, as stated previously, the communities of these regions are

predominantly poor and thus can not afford modern and effective technologies for storing and processing food. The contribution of finger millet grain phenolics to its resistance to fungi should be, therefore, significant in food security and food safety for these communities.

It is particularly significant to note that the β-amylase activities of the high-phenol finger millet grain types were much higher than those of sorghum malts, although these β-amylase activities were much less than that of barley (chapter 2.2, Table 2.2.5). In order to save foreign exchange, some countries in Africa (e.g. Nigeria, Kenya and Zimbabwe) are now using sorghum to produce lager beers. Sorghum, unfortunately, generally has low levels of β-amylase (Taylor et al 2006). Because finger millet malt has a relatively higher β-amylase activity than that of sorghum malt, it could be a better substitute for barley malt in the brewing of lager beers. However, the economics of replacing barley with finger millet would have to be considered as will be discussed. Furthermore, finger millet has been found to be of superior quality for producing malt-based weaning foods compared to other cereals (pearl, foxtail, proso and barnyard millet, wheat, triticale, maize, rice and sorghum) (Malleshi and Desikachar 1986b). Finger millet was found easy to malt, the malt had high α-amylase activity that contributed to low viscosity, and the malt had desirable flavour and taste. Weaning foods produced from malts of the high-phenol finger millet grain types of this study would also have low viscosities as the malts had high α-amylase activity

The findings of this study suggest that phenolics in finger millet grain, particularly the tannins, impact negatively on the quality of composite wheat-finger millet cookies, with respect to cookie spread, texture and integrity (chapter 2.3). The finger millet phenolics also contribute to an objectionable dark colour in the cookies, especially in cookies substituted with a brown high-tannin finger millet, which appeared to reduce product. However, the finger millet phenolics, particularly the tannins, impact positively on the health-promoting potential of the composite cookies as they make a large contribution to their antioxidant activity. Thus, with respect to health-promoting potential, high-tannin finger millet grain types would be more suitable for making composite wheat-finger millet cookies than non-tannin types. It is noted that, as with the hypothesized positive role played by phenolics in finger millet grain in its malt quality, it was not proven that the presence of finger millet grain phenolics really promoted good health.

The quality of the cookies containing high-tannin finger millet grain could be improved. To improve the appearance acceptability of the dark composite cookies, they could be made in the form of "ginger nut type" cookies. Ginger type cookies are characteristically brown and are acceptable to consumers. The low spread factor of the composite cookies was thought to have been partly due to low levels of plant oils essential for cookie spread (chapter 2.3). Addition of vegetable plant oils could therefore increase cookie spread, as was found by Badi and Rooney (1976) working with sorghum and pearl millet. It was suggested (chapter 2.3) that fibre and large endosperm particles of the whole meal finger millet flour contributed to the grittiness of the composite cookies. The grittiness could be reduced by using refined finger millet flour, i.e. the fibre content and the particle size of the finger millet flour could be reduced by, for example, sieving. The problem with doing this is that the antioxidant activity would be reduced since, as stated earlier, finger millet phenolics are concentrated in the outer layers of the grain. Gums and thickeners, such as locust bean gum and guar gum, and special starches, such as rice, maize and potato starch and modified starches, and vegetable and dairy fat could be added to reduce the crumbliness and brittleness of the composite cookies and improve their surface texture (Badi and Rooney 1976, Schober et al 2003, Gallagher et al 2004). These materials could improve the quality of the cookies through various mechanisms including stabilising the dough and binding the dough components together similar to the action of gluten (Gallagher et al 2004).

Although composite wheat-finger millet cookies would be a suitable carrier of the finger millet grain phenolic antioxidants due to their shelf-stability and high nutrient density, other "health" products could also be made from high-tannin finger millet grain. The other products could include baked goods such as "health" high-tannin finger millet muffins and bread. The pigmented high-tannin finger millet grain would impart a brown colour to the products as with cookies, but similar to what was suggested for "ginger nut type" finger millet cookies above, some consumers might associate the brown products with health (Taylor et al 2006). In addition, as with "ginger nut type" cookies, consumers are familiar with brown muffins and brown bread. Brannan et al (2001) found brown muffins containing brown sorghum hybrids acceptable to a test panel. A large part of Sub-Saharan Africa is plagued by hunger and HIV/AIDS. Phenolic compounds have been reported to exhibit anti-HIV activity (Chen et al 1992, Chang et al 1994). The antioxidant-rich ("health") composite wheat-finger millet cookies of this study and other

"health" high-tannin finger millet products, some of which are suggested above, could be used to feed malnourished and HIV/AIDS-affected children in school feeding programmes. The "health" products could also be consumed by elderly people, as they are susceptible to degenerative diseases, which, as reviewed earlier (Halliwel et al 1995), are largely caused by free radical reactions.

3.3. Finger millet is a premium cereal grain for human food?

This section discusses, based mainly on the findings of this study, the merits and demerits of finger millet grain as a source of human food. The postulation "finger millet is a premium cereal grain for human food" is thus evaluated.

Finger millet grain has a lower fat content (chapters 2.2 and 2.3, Tables 2.2.7 and 2.3.2) relative to that of other cereals, e.g. wheat, barley, sorghum and pearl (Klopfenstein 2000, McDonough et al 2000). As discussed earlier, the low fat content of finger millet grain may be of advantage as its products would be relatively less susceptible to rancidity than products of a high-fat grain such as maize. This is particularly important for the storage quality of its food products because finger millet is generally processed into whole grain or whole grain meal products (US National Research Council 1996).

The findings (chapter 2.2) of this study indicate that finger millet grain phenolics exhibit antifungal activity. Thus, finger millet phenolics should contribute to reduction of grain quantity and quality loss during storage and to the safety of finger millet food products, as discussed earlier (chapter 2.2 and section 3.2).

Although research information could not be found, the literature (US National Research Council 1996, Malleshi 2004) suggests that finger millet grain is resistant to insect attack. The suggested resistance to insect attack may be partly attributed to the tiny size of the finger millet grain. An insect may not be able to complete its life cycle in the tiny grain, and/or tiny grains can pack tightly during storage leaving no spaces for insects (Malleshi 2004). It is also a possibility that phenolic compounds, particularly condensed tannins, contribute to the resistance of finger millet

grain to insect attack, as was found in groundnuts (Grayer et al 1992). The prevailing humid and hot conditions in the tropical regions, including much of sub-Saharan Africa, are also favourable for the proliferation of insects. Resistance to insect attack would, therefore, also contribute significantly to reduction of grain losses and enable storage of grain as seed and ultimately contribute to food security in sub-Saharan Africa.

The findings of this study indicate that finger millet grain is nutritionally superior to other cereal grains, e.g. wheat, rice, maize, barley and sorghum (Klopfenstein 2000), with respect to fibre (Tables 2.2.7 and 2.3.2) and mineral (Tables 2.2.7 and 2.3.2) contents. It was stated earlier that finger millet is generally consumed in the form of whole grain or whole meal products. The minerals and fibre that are concentrated in the outer layers (McDonough et al 2000) are therefore maximally taken in on consumption of finger millet products. The high fibre content of finger millet grain is thought to contribute to the slow digestibility of finger millet foods, which keeps the consumer full for a long period and may contribute to the lowering of glycaemic index (Malleshi 2004). Because cereal grain phenolics are largely associated with the grain fibre, it is currently thought that the fibre plays a significant role in delivering the potentially health-promoting phenolic compounds into the gut (Vitaglione et al 2008). However, it may be a disadvantage that finger millet grain is rich in both dietary fibre and minerals as the fibre may interfere with the absorption of minerals.

However, the findings of this study (chapters 2.2 and 2.3, Tables 2.2.8 and 2.3.3a) indicate that the quality of finger millet protein is poor, in terms of amino acid composition. Similarly, the protein quality, with respect to amino acid composition, of finger millet malts and composite wheat-finger millet cookies of this study was poor (chapters 2.2 and 2.3, Tables 2.2.8 and 2.3.3a). As already stated, lysine is particularly limiting in finger millet, as in other cereal grains. Nonetheless, the protein quality of finger millet grain is still considered better than that of most other cereal grains (subsection 1.2.1.2). However, as discussed earlier, finger millet should not be used as the only source of protein in infant and child foods. Finger millet should be combined with other food materials that have quality protein, such as legumes and dairy products.

The antioxidant activities (38.4-195.4 mM trolox equivalents/kg) (chapter 2.1, Table 2.1.2) of the finger millet grain types of this study are similar to those often reported for sorghums of varied genotype, for example 10.0-175.5 mM trolox equivalents/kg (Dykes et al 2005). Sripriya et al (1996) found the free radical activity of methanolic extracts from brown finger millet higher than methanolic extracts from rice, wheat and other millets (pearl and foxtail millet). The antioxidant property of cookies containing high-tannin finger millet was much superior to that of cake flour cookies and cookies containing a non-tannin finger millet and a variety of plant foods on the market (chapter 2.3). Finger millet grain has been shown, using model animals, to potentially attenuate degenerative diseases, which is thought to be largely due to the phenolic antioxidants (reviewed in section 1.2.5). Therefore, finger millet grain, particularly the high-tannin types, could be a highly suitable material for the production of "health" foods, as discussed previously.

The tiny size of the finger millet grain may be disadvantageous. The appearance of tiny grains may be unacceptable to consumers who are used to larger cereal grains like maize. Handling of the tiny finger millet kernels during quality control and food processing may be difficult. In this study, it was difficult to clean the finger millet grain, as it tended to block the sieve holes. A kernel counter used for counting sorghum kernels could not be used for counting finger millet kernels as more than one kernel passed through the orifice. As stated earlier, the "scratch test" may not be used to detect tannin finger millet types due to the tiny size of the grain. .The tiny size of finger millet grain makes its milling difficult (subsection 1.2.1.2). In industrial floor malting, finger millet and pearl millet are mixed with sorghum and malted together because if the tiny millet grains were malted alone they would pass or block the slotted malting floor (reviewed in subsection 1.2.6.2).

Although the findings of this study indicate that, due to their antifungal and antioxidant activity, finger millet phenolics impact positively on its malt quality and on its health-promoting potential, they may impact negatively on some of the food quality properties of the grain. The phenolics may impart unusual and hence unacceptable colours to some food products, as was the case with the composite wheat-finger millet cookies of this study. Phenolic compounds may impact negatively on the flavour of food. Although it was not the case with the composite wheat-finger millet cookies of this study, the finger millet tannins, in particular, may contribute to bitterness

and astringency. Phenolic compounds are known to inhibit the activity of enzymes by reacting with them and may thus exhibit antinutritional activity. Tannins may interfere with the utilisation of metal ions and proteins and polysaccharides by reacting with them (reviewed in section 1.2.2; Lule and Xia 2005). Finger millet tannins have been shown to reduce the *in vitro* protein digestibility (Ramachandra et al 1977), and crude phenolic extracts and individual phenolic compounds from finger millet have been shown to inhibit finger millet malt amylases (Chethan et al 2008). The results of this study showed a significant difference between the peptone and water extract DP in high-tannin finger millet grain types (chapter 2.2, Table 2.2.5), indicating that the tannins inhibited malt enzymes. This enzymic inhibition effect may be particularly significant if high-tannin finger millet types are malted traditionally at home without treatment with formaldehyde as is done during the industrial malting of sorghum (Daiber and Taylor 1995).

While finger millet can, by virtue of its being adapted to the harsh agro-climatic environments prevalent in sub-Saharan Africa, ensure food security and save foreign exchange, its economic value may be reduced by its low yield and by that, its production is laborious (Obilana and Manyasa 2002). The yield of finger millet, 0.8 mt/ha in 1989 (Obilana and Manyasa 2002) is much lower than that of maize, 1.3 mt/ha (Rohrbach 2003). High-yielding finger millet varieties should be developed. The market price of finger millet is generally higher than that of other cereals, e.g. wheat, maize and sorghum. For example, in Nakuru province, Kenya, the market prices of 1 kg of finger millet, wheat, maize and sorghum, respectively, were 50.00, 31.11, 23.33 and 38.89 Kenyan shillings (Kenya Ministry of Agriculture 2008: http://www.kilimo.go.ke). Thus, commercial products of finger millet may be less profitable than products of other cereals.

As summarised in Table 3.1, finger millet grain has several merits as a human food. The foregoing discussion and Table 3.1 indicate that the merits of finger millet grain outweigh its demerits and thus it is convincing that “finger millet is a premium cereal grain for human food”.

Table 3.1. Merits and demerits of finger millet grain as a human food

Aspect	Merit	Demerit
Grain size	The tiny size of the finger millet grain seems to contribute to its resistance to insect attack.	The appearance of tiny grains may be unacceptable. Tiny grains are hard to handle and process.
Grain colour	Finger millet grain colour, largely due to phenolics, varies from white to dark brown, and hence products of varied colour can be made from finger millet, as preferred by different consumers.	High-phenol, pigmented finger millet grain types may impart unacceptable colour in some foods, e.g. in some normally-light coloured baked goods.
Storage quality and safety	The lower fat content of finger millet grain relative to that of most other cereal grains makes it less susceptible to rancidity. Finger millet phenolics contribute to its antioxidant and antimicrobial properties, which impact positively on storage quality and safety.	Antioxidant and antimicrobial properties are significantly a property of the high-phenol grain types. Low-phenol, light coloured grain types may have lower storage quality and safety.
Health	Finger millet phenolics contribute to its antioxidant activity, which is potentially health-promoting.	Low-phenol, light coloured finger millet types exhibit low antioxidant activity, and hence have low health-promoting potential.
Impact on other functional properties	The high fibre content of finger millet grain may give “body” to its beverage products. Phenolics may contribute to flavour, e.g. bitterness and astringency, which may be traditionally acceptable to some consumers.	Finger millet does not contain gluten, which is required for quality baked goods. The high levels of fibre and phenolics, particularly tannins, may affect the quality negatively, e.g. texture, of finger millet products. Finger millet phenolics may impart objectionable flavour, e.g. bitterness and astringency, to food.
Nutritional quality	Finger millet is nutritionally superior when compared with most other cereal grains. It particularly has relatively higher dietary fibre and mineral contents than most other cereals.	The grain phenolics, particularly the tannins, may exhibit antinutrional activity and thereby reduce the nutritional value of finger millet.

4. CONCLUSIONS AND RECOMMENDATIONS

This study indicates that occurrence of tannins in finger millet grain is a varietal property, as in sorghum. Pigmented grain types have higher levels of phenolics than the light types, and types with a pigmented testa contain condensed tannins, which are located in the testa layer as in sorghum. This study seems to be the first to indicate the occurrence of anthocyanins and flavan-4-ols in finger millet grain. Phenolics in finger millet grain make a large contribution to its antioxidant activity and tannins are predominantly responsible for the antioxidant activity, as in sorghum. Therefore, high-tannin finger millet types have a high health-promoting potential as they exhibit high antioxidant activity.

Phenolics in finger millet grain seem to contribute significantly to its antifungal properties, which should be of importance in grain storage quality and safety. Finger millet types containing high levels of phenolics have considerably superior malt quality to finger millet types with low levels of phenolics, which is seemingly partly due to the antifungal activity of the phenolics.

Phenolics in finger millet grain, particularly the tannins, seem to have a negative effect on the spread, texture and integrity of composite wheat-finger millet cookies, probably by interacting with the wheat gluten proteins and thereby interfering with their functionality. Phenolics in finger millet grain impart a dark colour to the composite cookies, which decreases their acceptance by consumers. Cookies containing a high-tannin finger millet exhibit an appreciable antioxidant activity and therefore could be health-promoting.

The study indicates that finger millet is a valuable food crop. Finger millet is nutritionally superior to most other cereals, although its protein quality is, as that of other cereals, poor. Finger millet grain has a high health-promoting and good storage quality and safety potential. In addition, it is a good malting grain. However, apart from nutritional quality, the good food properties of finger millet grain identified in this study are largely due to its phenolics. Therefore, only the high-phenol grain types would be valuable with respect to these properties.

Further studies should be conducted to confirm the occurrence of 3-deoxyanthocyanin, apigeninidin and luteolinidin, and flavan-4-ols in finger millet grain. The phenolics in finger millet grain should be characterised in order to relate phenolic structure with antioxidant activity. Further work should be done to improve the quality of the composite wheat-finger millet cookies. A wide range of foods containing high-tannin finger millet grain types, particularly those that are normally dark coloured, such as brown bread and muffins (their appearance would be not or less affected by the colour of finger millet phenolics), should be developed to promote the consumption of these grain types, which have a high health-promoting potential. Studies should be done, in a cause effect way, to test the hypothesis that phenolics in finger millet grain play a positive role in finger millet malt quality and in human health.