



University of Venda

**Physical, functional and nutritional properties of flours from finger millet  
(*Eleusine coracana*) varieties fortified with vitamin B<sub>2</sub> and zinc oxide**

By

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## Abstract

Finger millet (FM) (*Eleusine coracana*) grains are the staple food in Africa and India for communities with low socio-economic growth. The grains have high content of calcium, dietary fibre, carbohydrates that are rich in protein, fat, iron, phosphorus, vitamin and essential amino acids. Flours from milky cream (MC), brown and black varieties of FM were fortified with vitamin (vit) B<sub>2</sub> and zinc oxide (ZnO) in order to restore the nutrients that were lost during milling and sieving processes. The main aim of the study was to analyse the physical, nutritional composition and functional properties of flours from three (3) FM varieties fortified with vit B<sub>2</sub> and ZnO. Pearl millet was used for comparison with the results obtained from this study. MC, brown and black varieties of FM flour treatments were arranged as a completely randomized design (CRD) in three (3) replicates. Physical properties: dimensional properties, colour attributes, kernel weight, bulk density (BD), true density, porosity, surface area, kernel volume, aspect ratio, sphericity and moisture content of the FM grains were analysed. Vitamins and minerals were also analysed. Functional properties: colour attributes, bulk density (BD), water absorption capacity (WAC), oil absorption capacity (OAC), swelling capacity (SC), swelling index (SI), foaming capacity (FC), foaming solubility (FS), dispersibility (Dis), viscosity (cool & hot paste), pasting properties, thermal properties and microscopic structure of FM flours were determined. Data generated were analysed using SPSS version 23.0. Moisture content of MC FM grain and flour was significantly higher ( $p < 0.05$ ) than brown and black varieties but was within the specified range of <12%. This indicated the long storage shelf-life of the grains and flours. Length of brown FM grains was significantly higher ( $p < 0.05$ ) when compared to MC and black varieties. MC variety was significantly higher than other varieties in width, kernel weight, bulk density, true density, aspect ratio and sphericity. The information obtained from this study will help in designing suitable equipment for planting, harvesting, storage, processing and packaging of grains. Pearl millet grain was significantly higher than FM flours in all physical properties. MC FM was significantly higher

in  $L^*$  (whiteness/ brightness),  $b^*$  (yellowness/ blueness),  $C^*$  (chroma),  $H^0$  (hue angle) and ZnO values compared to brown and black flours. MC raw fortified finger millet (RFFM) and instant fortified finger millet (IFFM) flours were significantly higher in vitamin B<sub>2</sub>. People prefer fortified MC flour because most of people living in South Africa use white maize as their staple food and it is similar to MC. Colour is the most important quality parameter in food processing industries and it is also attracts the consumer's choice and preference. The vitamins and minerals that were lost during sieving, drying and milling were replaced by the two (2) fortificants added which may help to reduce the micronutrient deficiencies. Milky cream FM flours showed significantly high ( $p < 0.05$ ) values in BD, WAC, OAC, SI, FC and dis. These are the fundamental physico-chemical properties that reflect the interaction between the composition and molecular structure. Length of brown FM grains was significantly higher ( $p < 0.05$ ) when compared to MC and black variety. The MC variety was significantly higher than other varieties in width, kernel weight, bulk density, true density, aspect ratio and sphericity. Pearl millet was significantly higher than FM flours in all physical properties. MCFM variety was significantly higher in  $L^*$  (whiteness/ brightness),  $b^*$  (yellowness/ blueness),  $C^*$  (chroma), and  $H^0$  (hue angle) values as compared to other FM varieties. Moisture content of MC flour was significantly higher as compared to brown and black FM flours. Pasting properties of MC raw finger millet (RFM) and RFFM flours showed significantly higher in peak viscosity (PV) (3518 cP), final viscosity (FV) (6554 cP), breakdown viscosity (BDV) (703 cP) and setback viscosity (SV) (3868 cP) as compared to other RFM and RFFM flours. Brown instant finger millet (IFM) and IFFM flours had significantly higher of PV (723 cP), trough viscosity (TV) (655 cP) and FV (983 cP). IFFM flours had significantly higher values of PV (712 cP), TV (614 cP) and FV (970 cP), respectively. The instant pearl millet (IPM) and instant fortified pearl millet (IFPM) showed significantly higher value in BDV (330 cP and 131 cP) and SV (362 cP and 346 cP), respectively. Thermal properties of black RFM was significantly higher in onset temperature ( $T_o$ ) (74.31), peak temperature ( $T_P$ ) (81.94°C) and conclusion temperature ( $T_c$ ) (89.64) and RFFM starches were significantly high in  $T_o$  (81.80°C),  $T_P$  (84.22°C) and  $T_C$  (92.81°C), respectively. Milky

cream IFM starch showed significantly higher values in  $T_o$  (84.57°C),  $T_p$  (87.27°C),  $T_c$  (92.81°C) and  $\Delta H$  (7.63°C) compared to other starches. Brown IFFM flour was significantly higher value in  $T_o$  (85.88°C) and  $T_p$  (87.14°C). The starch of IFPM was significantly higher in enthalpy of gelatinisation (6.91°C) and PHI (2.94°C) as compared to other FM starches. Brown IFM flour showed significantly higher value in gelatinisation temperature range (13.50°C). The microscopic structure revealed that RFM and RFFM flours had oval and smooth surfaces. RFM and RFFM flours showed positive effect after fortificants were added because the starch granules, protein bodies and protein matrix were visible and formed crystal. IFM and IFFM flours had some holes, dents and rough surfaces. Instant fortified flours showed negative effect after fortificants were added due to technological processes such as re-cooking and remilling of flours. Different variations observed on physical, nutritional and functional properties after adding the fortificants may affect the physical, chemical and organoleptic properties of food produced from fortified flour. There is need to fortify FM flours with ZnO which may help to replace the value lost during milling and sieving operations. It is possible that the availability of ZnO could reduce the incidence of some non-communicable diseases.

**Keywords:** Finger millet, fortification, physical properties, micronutrient deficiency, nutritional composition, functional properties.

## Declaration

“I, **Shonisani** Eugenia Ramashia, hereby declare that the thesis for the PhD in Agriculture (Food Science and Technology) submitted by me to the Department of Food Science and Technology at the University of Venda has not previously been submitted for a degree at this or other university and that it is my own in design, execution and that all reference material contained therein has been acknowledged.”

Signature.....

date.....

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## LIST OF ACCRONYMS

a*	Redness/greenness
ANOVA	Analysis of Variance
BD	Bulk density
BDV	Breakdown viscosity
BLFM	Black finger millet
BRFM	Brown finger millet
C*	Chroma
Ca	Calcium
cP	Centipoise
Cu	Copper
d.w.	Dry weight
Da	Arithmetic mean diameter, mm
Dg	Geometric mean diameter, mm
DSC	Differential Scanning Calorimeter
FC	Foaming capacity
Fe	Iron
FM	Finger millet
FMGV	Finger millet grain varieties
FS	Foaming solubility
FV	Final viscosity

GRAS	Generally regarded as safe
GTR	Gelatinisation temperature range
HCL	Hydrochloric acid
HNO <sub>3</sub>	Nitric acid
H <sub>2</sub> O <sub>2</sub>	Hydrogen peroxide
H°	Hue angle
ICP-AEC	Inductively coupled argon plasma atomic emission
IFFM	Instant fortified finger millet
IFM	Instant finger millet
IFPM	Instant fortified pearl millet
IPM	Instant pearl millet
J/g	Joule per gram
K	Potassium
L	kernel length, mm
M	Mass, g
M <sub>1 000</sub>	1 000 Kernel weight. wt. g
MC	Milky cream
MCFM	Milky cream finger millet
Mg	Magnesium
Min	Minutes
Mn	Manganese
Na	Sodium

OAC	Oil absorption capacity
P	Phosphorus
P <sub>b</sub>	Bulk density, kg/ m <sup>3</sup>
PDA	Photo Diode Array
PHI	Peak height index
PM	Pearl millet
P <sub>T</sub>	True density, kg/ m <sup>3</sup>
PT	Peak time
PV	Peak viscosity
Ra	Aspect ratio,%
RFFM	Raw fortified finger millet
RFM	Raw finger millet
RFPM	Raw fortified pearl millet
RPM	Raw pearl millet
RTE	Ready-to-eat
RVA	Rapid- Visco-Analyser
Sa	Surface area, mm <sup>2</sup>
SA	South Africa
SC	Swelling capacity
SEM	Scanning Electron Microscopic
SI	Swelling index
SPSS	Statistical Package for Social Sciences

SV	Setback viscosity
T	kernel thickness, mm
T <sub>c</sub>	Conclusion temperature
T <sub>o</sub>	Onset temperature
T <sub>p</sub>	Peak Temperature
TV	Trough viscosity
UPLC	Ultra-Performance Liquid Chromatography
UWW	Unfortified whole wheat
V	Volume, mm <sup>3</sup>
Vit B <sub>1</sub>	Vitamin B <sub>1</sub>
Vit B <sub>2</sub>	Vitamin B <sub>2</sub>
Vit B <sub>3</sub>	Vitamin B <sub>3</sub>
Vit B <sub>6</sub>	Vitamin B <sub>6</sub>
W	kernel width, mm
WAC	Water absorption capacity
WI	Whiteness index
WSV	Water soluble vitamin
WWFF	Whole wheat fortified flour
YI	Yellowness index
Zn	Zinc
ZnO	Zinc oxide
ΔE	Total colour different

$\Delta H$ (gel)	Enthalpy of gelatinisation
$\varepsilon$	Porosity, %
$\Phi$	Sphericity, %

## CHAPTER 1 INTRODUCTION

### 1.1. Background to the study

Millets are a group of small-seeded species of cereal crops or grains belonging to the family *Gramineae* (Amadou *et al.*, 2013 and Gupta *et al.*, 2017) and widely grown around the world for food and fodder (Baryeh, 2002). They are staple food in the West, East, Central and Great Lakes region of Africa as well as in Asia and India (Palanisamy *et al.*, 2012). Millets are major food sources for millions of poor people, especially those who live in the hot and dry areas of the world (Kasaoka *et al.*, 2009; Amadou *et al.*, 2013 and Talukder & Sharma, 2015).

Major types of cultivated millet varieties are finger millet (FM) (*Eleusine coracana*), pearl millet (PM) (*Pennisetum glaucum*), Japanese banyard millet (*Ecchinoschloa frumentacea*); foxtail millet (*Setaria italica*); kodo millet (*Paspalum scrobiculatum*) and proso or white millet (*Panicum miliaceum*) (Appendix 1) (Mbithi-Mwikya *et al.*, 2000; Khulbe *et al.*, 2014 and Gupta *et al.*, 2017). Millets have great economic and health importance and are believed to be gluten-free and have low glycemic index (Taylor *et al.*, 2006; Apoorva *et al.*, 2013 and Verma & Patel, 2013).

Millets are healthy food choice for people with celiac disease, the most common disease caused by cereal protein ingestion (Jideani & Jideani, 2011; Amadou *et al.*, 2014 and Talukder & Sharma, 2015). They are a good source of magnesium (Mg) which has been shown to reduce the severity of asthma, reduce frequency of migraines, lower high blood pressure and reduce the risk of heart attacks. Other benefits of millet are the development and repair of body tissue, the prevention of gallstones, protection against breast cancer and protection against postmenopausal complications and the reduction of chances of childhood cancer (Verma & Patel, 2013; Amadou *et al.*, 2013 and Emmanuel *et al.*, 2013).

Millets contain 65 to 75% of complex carbohydrates, 5.6 to 8% protein, 15 to 20% crude fibre and 2.5 to 3.5% minerals (Krishnappa *et al.*, 2009; Saleh *et al.*, 2013 and Shobana *et al.*, 2013). Finger millet also known as *ragi*, has contains low glycemic index and is a gluten–

free cereal grain (Apoorva *et al.*, 2011 and Khulbe *et al.*, 2014). FM grains add substantial value to the diet in terms of protein (Kasaoka *et al.*, 2009 and Hashemi & Erim, 2016) and carbohydrates compared to other cereals (Bachar *et al.*, 2013). Millet is also a good source of vitamins (Verma & Patel, 2013). These nutrients play important roles in human nutrition (Barbeau & Hilu, 1993).

The grains are also a good source of diet for growing children and expectant mothers (Desai *et al.*, 2010). FM ranks fourth in terms of production in semi-arid regions after sorghum, PM and foxtail millet (Upadhyaya *et al.*, 2011 and Shiihii *et al.*, 2011). FM is widely grown around the world for food and fodder (Mannuramathy & Yenagi, 2015 and Gupta *et al.*, 2017) and FM straw can be utilised to feed animals (Sood *et al.*, 2016). Cereal grains are fortified with minerals and vitamins after processing in order to replace nutrients that are often lost during sieving (Saleh *et al.*, 2013).

Major B-group vit that are normally used for fortification are vit B<sub>1</sub> (thiamine), B<sub>2</sub> (riboflavin), B<sub>3</sub> (niacin or niacinamide), B<sub>6</sub> (pyridoxine or pyridoxamine) and B<sub>9</sub> (folic acid or folates) as well as vit A, D and C (Ottawa, 2008). The mineral elements that are used for fortification include calcium (Ca), Fe, iodine, selenium and Zinc (Zn).

Physical properties of grains were conducted in major cereal grains such as, wheat, rough rice and maize (Al-Mahasneh & Rababah, 2007 and Sangamithra *et al.*, 2016; Vanrnamkhasti *et al.*, 2016) and these were compared to FM (Ushakumani, 2009 and Balasubramanian & Viswanathan, 2010).

Functional properties of cereal grains are the fundamental physico-chemical properties that reflect the complex interaction between the structure, molecular components, and composition and physico-chemical properties of food components (Chandra & Samsher (2013). Functional property of food is defined as physical, chemical and/or organoleptic properties of food (Ubwa *et al.*, 2012 and Kumari & Raghuvanshi, 2015). This study sought to fortify FM flour with vit B<sub>2</sub> and ZnO, which reduce the micronutrient deficiencies, a major public health problem in human populations (Wesley & Ranum, 2004 and Akhtar *et al.*, 2011).

## 1.2. Problem statement

Although finger millet grains are gluten-free and have a lot of nutritional advantages, they are a neglected and underutilized crop. A substantial number of people are allergic to gluten (Talukder & Sharma, 2015 and Gupta *et al.*, 2017) hence there is an increasing demand for gluten-free diet products by consumers. Moreover, the grains serve as a staple food in many developing countries, especially for people with low income and who reside in remote rural areas.

However, little information on fortified FM flour is available in terms of research and innovation in comparison to the economic development of major cereals such as maize, wheat and rice. Unfortified FM flours results in various minerals and vitamins related deficiencies such as sore throat, pneumonia and diarrhoea.

## 1.3. Hypotheses

1. Determination of some physical properties may lead high quality of FM grains.
2. Fortified FM flours may have a positive effect on vitamins and minerals.
3. The addition of vit B<sub>2</sub> and ZnO to FM flours may have a positive effects on functional properties.

## 1.4. Rationale and justification of the study

Fortification of FM flours with vit B<sub>2</sub> and ZnO helps to overcome the problem of malnutrition and micronutrient deficiencies such as sore throat, pneumonia and diarrhea in developing countries (Akhtar *et al.*, 2011 and Gupta *et al.*, 2015). Consumption of fortified FM food products have potential health benefits particularly in leprosy, liver disease, measles,

pleurisy and as well as in the control of blood glucose levels in diabetic patients (Bachar *et al.*, 2013).

Therefore, this study sought to determine the physical, functional properties and nutritional composition of FM flours fortified with vit B<sub>2</sub> and ZnO. The information derived from the evaluation of fortified FM flours could be useful in promoting the commercial production of FM flour. In addition, the information may benefit the end users by consuming the fortified FM products.

### **1.5. Aim and objectives**

The general aim of the research was to determine the physical properties of grains of finger millet varieties, nutritional and functional properties of flours fortified with vit B<sub>2</sub> and ZnO. The study intends to promote and the consumption of fortified finger millet food products in urban areas.

The specific objectives of this study are:

1. To determine the physical properties such as dimensional properties (geometric and arithmetic mean diameters), 1 000 kernel weight, BD, true density, porosity, sphericity, aspect ratio, kernel volume, kernel surface area and colour attributes of FM grains.
2. To determine the nutritional composition (moisture, ash, protein, crude fibre, vitamins and minerals) of fortified FM flours.
3. To determine the functional properties of fortified FM flours (pasting properties, thermal properties and microscopic structure).

### **1.6. Thesis outline**

This study consist of six (6) chapters where each of the three (3) chapters has been arranged to address a specific objective of the thesis. Chapter One (1) gives an overall

introduction. Chapter Two (2) provides an overview of literature review of finger millet (FM), origin of FM, vernacular or common names of FMs that are cultivated around the world, structure and morphology, nutrient composition of grains, physical and functional properties together with the global uses and application of FM grains/flour. The chapter also discuss the traditional processing techniques of FM grain/flour and their food products. Cereal grains are important food vehicles for fortification and biofortification. Identified research gaps about FM grains/flours include (i) functional and physical properties of fortified flours with vit B<sub>2</sub> and ZnO and (ii) technological solutions for gluten-free challenges.

Chapter Three (3) discusses the physical properties of FM grains obtained from sub-Saharan Africa which include moisture content, 1 000 kernel weight, BD, true density, porosity, aspect ratio, kernel volume, kernel surface area and dimensional properties (length, width and thickness). Chapter Four (4) discusses the effect on nutritional composition of fortified FM flours with vit B<sub>2</sub> and ZnO. Proximate composition, pH, minerals and vitamins B complex were conducted. This chapter highlights some potential health benefits that are derived after adding the fortificants.

Chapter Five (5) provides the influence of vit B<sub>2</sub> and ZnO fortification on functional properties of FM flour which include colour attributes, viscosity, foaming, water absorption capacity (WAC), oil absorption capacity (OAC), swelling capacity (SC), pasting properties, thermal properties and microscopic structure. Chapter Six (6) gives the final conclusion and recommendations of the research outcome for each specific objective studied and also summerises the research findings.

## CHAPTER 2 LITERATURE REVIEW

### 2.1. Origin of finger millet

Finger millet (FM) (*Eleusine coracana*) is an annual plant (Shiihii *et al.*, 2011) belonging to the family *Poaceae* and originated in Ethiopia (Shiihii *et al.*, 2011; Wolie & Belete, 2013 and Kumar *et al.*, 2016) before reaching India (Siwela *et al.*, 2010; Blench, 2012 and Swami *et al.*, 2013). The crop is cultivated in Nepal (Apoorva *et al.*, 2011; Adhikari, 2012 and Jideani, 2012), Sri Lanka, Bhutan and the Himalayan region and in China, Japan to a limited extent (Mathur, 2012), as well as in Sumatra, Java, South Carolina in the United States and Taiwan (Blench, 2012).

Finger millet (55-60%) is cultivated in the Eastern, Central and Southern Africa (Siwela, 2009; Shimelis *et al.*, 2009; Apoorva *et al.*, 2011 and Blench, 2012) in countries such as Kenya, Nigeria, Malawi, Tanzania, Uganda, Zambia and Zimbabwe (Mathur, 2012; Gull *et al.*, 2016). FM is adapted to various agro-climatic conditions even though it prefers fertile, well-drained sandy to sandy loamy soils and the annual rainfall should ranged between 500 and 1 000 mm and matures within the period of 100 -130 days (David *et al.*, 2014 and Gull *et al.*, 2014).

The annual total production of FM grain worldwide is approximately 5 million tons with India alone producing about 2.2 million tons and Africa about 2 million tons (Mathur, 2012). India is the largest producer (Wankhede *et al.*, 1979 and Pandhre *et al.*, 2011) contributing 60% of the global production (Shukla & Srivastava, 2014). It is the oldest cereal crop in India and is referred to as “*nrttakondaka*” and also called as “*rajika*” or “*markataka*” which means dancing grain (Shobana *et al.*, 2013). Table 1 shows other vernacular or common names of FM that are cultivated around the world.

**Table 1.** Common names of finger millet in different countries of the world.

Country	Common names	References
Afrikaans/ Dutch	<i>Vogel gierst</i>	Mathur, 2012
Arabic	<i>Tailabon</i>	Chethan, 2008
Boutu	<i>Bale</i>	Mathur, 2012
Chad	<i>Sarga</i>	Blench, 2012
China	<i>Cānzi</i>	Blench, 2012
England	<i>African millet, finger millet and koracana</i>	Singh & Raghuvashi, 2012
Ethiopia	<i>Takuso, gadussa, dzoko and barankiya</i>	Blench, 2012; Singh & Raghuvashi, 2012 and Onyango, 2016
France/	<i>Coraca, petit mil, eleusine cultivee and koracana</i>	Singh & Raghuvashi, 2012 and Mathur, 2012
Taiwan	<i>Kamuku, kamui, saalal, takalaia and chayana</i>	Blench, 2012
Germany	<i>Fingerhirse</i>	Chethan, 2008 and Singh & Raghuvashi, 2012
India	<i>Ragi, mandua, koracana, African millet, bird's foot millet, nachani, nagli and bajari</i>	Pandhre <i>et al.</i> , 2011; Gupta <i>et al.</i> , 2015 and Ramashia <i>et al.</i> , 2018.
Japan	<i>Shikokubie</i>	Blench, 2012
Kenya	<i>Wimbi and mugimbi</i>	Mathur, 2012; Singh & Raghuvashi, 2012 and Onyango, 2016
Korea	<i>Susu</i>	Blench, 2012
Malawi	<i>Poko, hawere, lipoke, usanje, khawke, malesi, mulirubi, lupodo, mawe and dègi</i>	Blench, 2012; Mathur, 2012 and Shobana <i>et al.</i> , 2013
Nigeria	<i>Tamba, pwana and sarga</i>	Jideani <i>et al.</i> , 1996; Fernandez <i>et al.</i> , 2003; Shiihii <i>et al.</i> , 2011 and Blench, 2012
Nepal	<i>Kaddo, kodo</i>	Karki & Kharel, 2012 and Singh & Raghuvashi, 2012
Sri Lanka	<i>Ravi, ravana and oshada</i>	Kumari <i>et al.</i> , 2017
South Africa	<i>Mufhoho (venda)</i>	Blench, 2012
Sudan	<i>Telebun, akima, bek, mataighio and kal</i>	Shimelis <i>et al.</i> , 2009 and Blench, 2012
Swahili	<i>Wimbi and ulezi</i>	Chethan, 2008 and Shimelis <i>et al.</i> , 2009
Tanzania	<i>Mwirubi, mbege and dègi</i>	Chethan, 2008; Mathur, 2012 and Shobana <i>et al.</i> , 2013
Uganda	<i>Bulo</i>	Shimelis <i>et al.</i> , 2009 and Blench, 2012
Zambia	<i>Lupoko, mawe, amale, bule, kambale, majolothi and bulo</i>	Chethan, 2008; Singh & Raghuvashi, 2012 and Blench, 2012
Zimbabwe	<i>Poko, rapoho, zviyo, njera, uphoko, ruweza and mazhovole</i>	Chethan, 2008; Singh & Raghuvashi, 2012 and Onyango, 2016.

## 2.2. Structure and morphology of finger millet

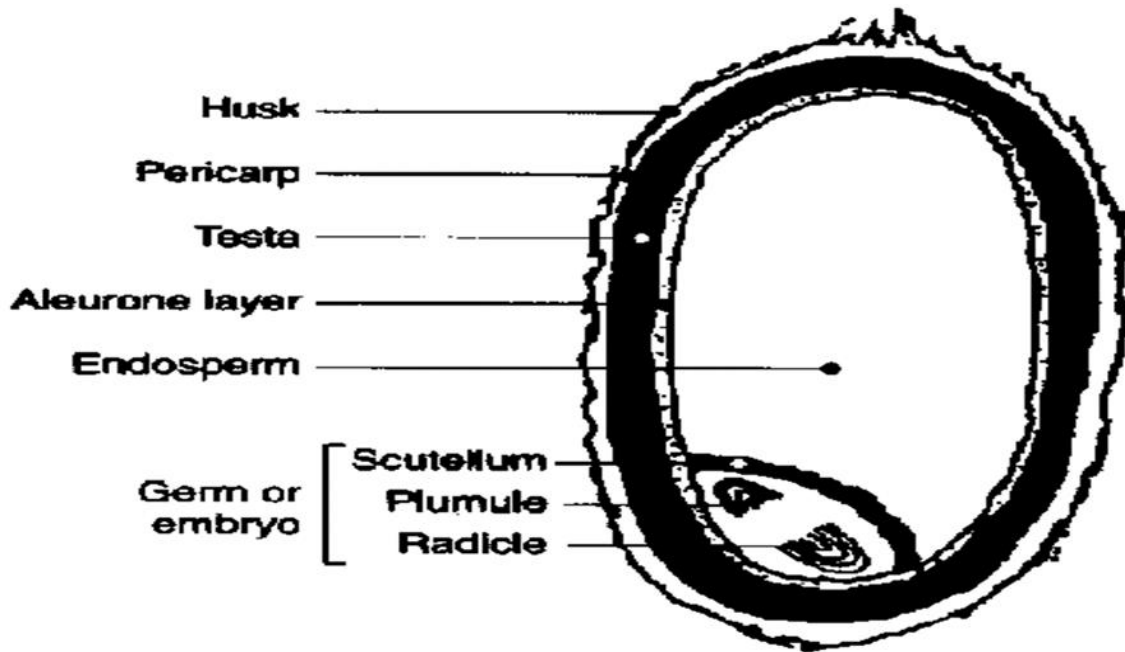
The structure of finger millet (FM) has not been studied compared to those of conventional cereal grains such as wheat. Figure 1 shows FM grains.



**Figure 1.** Finger millet seeds (<http://portals.wi.wur.nl/foodnut/images/p255.gif>, Accessed on 21 July 2014).

The structure of the FM and proso millet are regarded as utricles since the pericarp is loosely attached to the sample and not completely fused to the grain coat or testa. The structure of other millets such as pearl millet, foxtail millet, fonio millet and teff millet are regarded as a caryopses. Caryopses is a single-seeded fruit in which the fruit coat or pericarp surrounds the grains and adheres tightly to the grain coat (Wrigley & Batey, 2010).

The principal anatomical parts of the millets are pericarp, germ and the endosperm. The endosperm forms the largest anatomical component of the sample. The pericarp consists of three (3) layers with varying thickness such as the epicarp (outermost layer), mesocarp and the inner layer (Siwela, 2009 and Wrigley & Batey, 2010). The grain coat of millet is an edible component of the sample and is rich in polyphenol and crude fibre which helps to prevent constipation, diabetes, intestinal cancer and high cholesterol formation (Gupta *et al.*, 2017) (Figure 2). The FM is globular in shape and diameter varies between 1.0 to 1.8 mm (Siwela, 2009, Gull *et al.*, 2015 and Gull *et al.*, 2016). The predominant colour of FM is Indian brown (*purna*) seed coat and few varieties have Indian white (*hamsa*) seed coat (Wankhede *et al.*, 1979; Vadivoo *et al.*, 1998; Shobana *et al.*, 2013).



**Figure 2.** Structure of finger millet grain.  
(<http://portals.wi.wur.nl/foodnut/images/p255.gif>, Accessed on 24 July 2014).

### 2.3. Nutrient composition of finger millet grains

Finger millet grains are more nutritious (Upadhyaya *et al.*, 2011; Devi *et al.*, 2011 and Tadele *et al.*, 2016) than most cereal grains (Adhikari, 2012) with respect to proximate composition and mineral content but are less utilized worldwide (Roopa & Premavalli, 2008 and Swami *et al.*, 2013). The grains are also consumed as whole grain have good taste and are easy digested (Salasya *et al.*, 2008; Tenywa *et al.*, 1999 and Thapliyal & Singh, 2015). Table 2 shows the nutritional composition of FM. The grains contain high value of Ca 162 to 358.0 mg/100 g (Chethan & Malleshi, 2007 and Roopa & Premavalli, 2008) and P 130 to 250.0 mg /100 g (Shobana *et al.*, 2013).

Ca is also a good source of diet for growing children, pregnant women and elderly people (Jideani, 2012 and Chappalwar *et al.*, 2013) because it is important for normal growth of body tissue such as strengthening bone and teeth (Subastri *et al.*, 2015). Thapliyal & Singh (2015) reported that a deficiency of Ca may lead to bone and teeth disorder and this can be addressed by consuming FM foods in consumer's daily diet.

**Table 2.** Chemical composition of finger millet grain.

<b>Nutrients</b>	<b>g/100 g</b>	<b>References</b>
Moisture	7.15 - 13.1	Siwela, 2009; Pandhre <i>et al.</i> , 2011; Mathanghi & Sudha, 2012 and Shobana <i>et al.</i> , 2014
Carbohydrates	59.4 – 85	Abulude <i>et al.</i> , 2005; Krishnappa <i>et al.</i> , 2009; Saleh <i>et al.</i> , 2013; Verna & Patel, 2013 and Tadele <i>et al.</i> , 2018
Protein	5.6 - 12.7	Krishnappa <i>et al.</i> , 2009 ;Shihii <i>et al.</i> , 2011; Amadou <i>et al.</i> , 2013; Verna & Patel, 2013 and Tadele <i>et al.</i> , 2018
Fat/ Lipids	1.0 - 1.8	Singh & Raghuvanshi, 2012; Saleh <i>et al.</i> , 2013 and Verna & Patel, 2013
Total dietary fibre	15 – 22	Subba Rao, 2004; Krishnappa <i>et al.</i> , 2009; Upadhyaya <i>et al.</i> , 2011 and Patel <i>et al.</i> , 2015
Ash	1.7 - 4.3	Singh & Raghuvanshi, 2012; Saleh <i>et al.</i> , 2013; Amadou <i>et al.</i> , 2013 and Verna & Patel, 2013
<b>Minerals</b>	<b>mg/100 g</b>	<b>References</b>
Calcium	162 - 358.0	Dharmaraj & Malleshi, 2011; Upadhyaya <i>et al.</i> , 2011; Saleh <i>et al.</i> , 2013 and Wafula <i>et al.</i> , 2018
Chlorine	84.0	Siwela, 2009
Copper	0.18 - 0.79	Siwela, 2009; Shimelis <i>et al.</i> , 2009 and Chandra <i>et al.</i> , 2016
Iodine ( $\mu\text{g}$ )	10.0	Siwela, 2009 and Shimelis <i>et al.</i> , 2009
Iron	3.3 - 14.89	Saleh <i>et al.</i> , 2013 and Shobana <i>et al.</i> , 2014
Magnesium	78 - 201.0	Shimelis <i>et al.</i> , 2009 and Chandra <i>et al.</i> , 2016
Manganese	17.61 - 48.43	Siwela, 2009 and Shimelis <i>et al.</i> , 2009
Phosphorus	130 – 408	Singh & Raghuvanshi, 2012 and Chandra <i>et al.</i> , 2016
Potassium	0.43 - 0.49	Shobana <i>et al.</i> , 2014 and Chandra <i>et al.</i> , 2016
Sodium	49.0	Siwela, 2009
Zinc	0.97 - 2.56	Dharmaraj & Malleshi, 2011; Singh & Raghuvanshi, 2012 and Shobana <i>et al.</i> , 2013

Finger millet is an most important cereal grains as it serve as a good source of vitamins and fatty acid to poor people, especially those living in Africa and some parts of Asia (Shimelis *et al.*, 2009 and Verma & Patel, 2013). Table 3 shows the vitamins and fatty acid content of FM. The grains have been reported to have both water soluble and liposoluble vitamins, and are rich in vit A and thiamine (Upadhyaya *et al.*, 2011; Chappalwar *et al.*, 2013 and Devi *et al.*, 2011) but vit C is absent in the dried grain (Siwela, 2009). Finger millet is also rich source of vitamins B complex such as B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, B<sub>6</sub> and B<sub>9</sub> even though the available literature review in this regard is scarce. The grains are very poor source of  $\beta$ -carotene which ranges between (0 - 1  $\mu\text{g}/100\text{ g}$  (Thapliyal & Singh, 2015).

**Table 3.** Major vitamin content and fatty acids of finger millet.

Nutrients	mg/100 g	References
<b>Vitamins</b>		
Vit A (Retinol)	6.0	Siwela, 2009
Vit B <sub>1</sub> (Thiamine)	0.2 - 0.48	Saleh <i>et al.</i> , 2013
Vit B <sub>2</sub> (Riboflavin)	0.12	Devi <i>et al.</i> , 2011
Niacin	1.0 - 1.30	Saleh <i>et al.</i> , 2013
Vit C (Ascorbic acid)	0.0 - 1.0	Siwela, 2009 and Shobana <i>et al.</i> , 2014
<b>Fatty acids</b>		
	<b>g/100 g of total lipids</b>	
Palmitic	21.1 - 24.7	Fernandez <i>et al.</i> , 2003
Oleic acid	49.8	Serna-Saldivar, 2010
Linoleic acid	24.2	Serna-Saldivar, 2010
Linolenic acid	1.3 - 4.40	Fernandez <i>et al.</i> , 2003 and Serna - Saldivar, 2010

The grains are a good source of essential amino acids (Table 4) such as methionine, cysteine (Jideani, 2012 and Shabairo *et al.*, 2014), lysine (Swami *et al.*, 2013) and isoleucine, leucine and phenylalanine (Sood *et al.*, 2017). The grains have dark brown seed coat rich in polyphenols such as tryptin inhibitors, phytates, phenols and tannins (Palanisamy *et al.*, 2012) as compared to other cereals such as rice, maize, barley and wheat (Thapliyal & Singh, 2015). However, the dark brown seed has higher polyphenols levels of 1.2- 2.3% than white varieties which have 0.3 - 0.5% (Thapliyal & Singh, 2015).

**Table 4.** List of essential and non-essential amino acids of finger millet.

Amino acids	g/100 g protein	References
<b>Essential</b>		
Phenylalanine	4.1 - 5.2	Siwela, 2009; Serna-Saldivar, 2010 and Amadou <i>et al.</i> , 2013
Histidine	2.2	Stabursvik & Heide, 1974 and Serna-Saldivar, 2010
Isoleucine	4.3	Thapliyal & Singh, 2015
Leucine	6.6 - 9.5	Serna-Saldivar, 2010 and Palanisamy <i>et al.</i> , 2012
Lysine	2.2	Thapliyal & Singh, 2015
Methionine	2.5 - 3.1	Serna-Saldivar, 2010 and Palanisamy <i>et al.</i> , 2012
Threonine	3.4 - 4.2	Serna-Saldivar, 2010 and Palanisamy <i>et al.</i> , 2012
Tryptophan	1.1 - 1.5	Serna-Saldivar, 2010 and Palanisamy <i>et al.</i> , 2012
Valine	4.9 - 6.6	Fernandez <i>et al.</i> , 2003 and Serna-Saldivar, 2010
<b>Non-essential</b>		
Aspartic acid	6.5 - 7.9	Fernandez <i>et al.</i> , 2003 and Serna-Saldivar, 2010
Glutamic acid	20.3 - 27.1	Fernandez <i>et al.</i> , 2003 and Serna-Saldivar, 2010
Alanine	6.1 - 6.2	Serna-Saldivar, 2010 and Amadou <i>et al.</i> , 2013
Arginine	2.77 - 4.5	Fernandez <i>et al.</i> , 2003 and Serna-Saldivar, 2010
Cystine	1.7 - 2.6	Siwela, 2009 and Serna-Saldivar, 2010
Glycine	2.14 - 4.0	Fernandez <i>et al.</i> , 2003 and Serna-Saldivar, 2010
Proline	7.0 - 9.9	Stabursvik & Heide, 1974; Serna-Saldivar, 2010 and Amadou <i>et al.</i> , 2013
Serine	3.6 - 5.1	Fernandez <i>et al.</i> , 2003 and Serna-Saldivar, 2010
Tyrosine	2.79 - 3.6	Fernandez <i>et al.</i> , 2003 and Serna-Saldivar, 2010

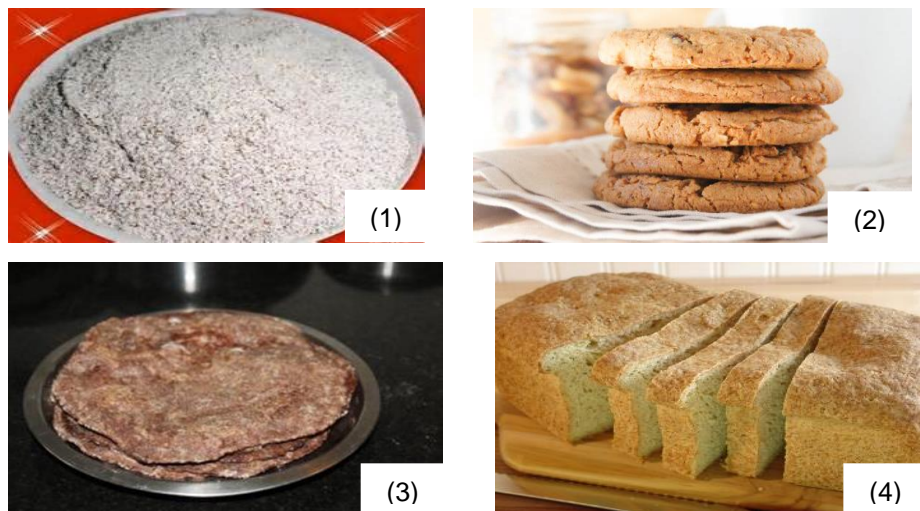
#### 2.4. Physical and functional properties of finger millet grains

Physical properties of grains have previously been studied on some different cereal grains namely, sorghum and rice (Vengaiah *et al.*, 2015) and legumes such as cowpea seeds, soy bean and Bambara groundnuts (Bhattacharya & Malleshi, 2012 and Jideani *et al.*, 1996). The following properties have been compiled to include 1 000 kernel weight, BD, true density, porosity, aspect ratio, kernel volume, kernel surface area and dimension properties (geometric and arithmetic mean diameters) (Zareiforoush *et al.*, 2011; Wasala *et al.*, 2012 and Sobukola *et al.*, 2013).

Functional properties of cereal grains are the fundamental physico-chemical properties that reflect the complex interaction between the structure, molecular components and physico-chemical properties of food components (Chandra & Samsher, 2013). A functional property of food is determined by physical, chemical and/or organoleptic properties of food. Examples of functional properties of food include viscosity, foaming, gelatinisation temperature, emulsification, water absorption capacity, oil absorption capacity and swelling capacity. Ubwa *et al.* (2012) reported that FM gelatinisation temperature ranged between 74.0 and 87.1°C.

## 2.5. Importance of finger millet

Finger millet grains are used primarily for the production of traditional foods such as alcoholic and non-alcoholic beverages. Different types of FM value-added food products made from FM flours are shown in Figure 3.



**Figure 3.** Finger millet value-added products: (1) = finger millet flour; (2) = *Ragi* cookies, (3) = Finger millet *roti* and (4) = *Ragi puttlu* (<http://portals.wi.wur.nl/foodnut/images/p255.gif>, Accessed on 27 September 2016).

Table 5 shows common uses of FM grain/flour. Most food products that are produced from FM grain/flour are not commercialized but food products from sorghum and wheat are commercialized and are available in supermarkets or retail shops (Adebowale *et al.*, 2005; Roopa & Premavalli, 2008 and Siwela, 2009) around the world. Foods prepared from



grain/flour of FM differ from country to country and occasionally from region to region. Abulude *et al.* (2005) reported that FM grains are not toxic to health at any stage of consumption.

**Table 5.** Global uses and application of finger millet grain /flour.

Uses	Country	References
Traditional opaque beer (Kaffir beer)	South Africa	Nout & Davies, 1982
Bread, porridge, soup, cake, beer and distilled liquors	USA	Barbeau & Hilu, 1993 and Jideani, 2012
Beverages, healthy foods such as infant foods, enteral food formulations, weaning foods, pancake, bakery products, puffing or popping, puffed finger millet mix, weaning food, roti, mudde, ambali, dumpling, noodles, opaque beer, composite flour and extruded products	India	Mangala <i>et al.</i> , 1999; Mbithi-Mwikya <i>et al.</i> , 2000; Subba Rao <i>et al.</i> , 2004; Shobana & Malleshi, 2007; Chethan, 2008; Palanisamy <i>et al.</i> , 2012; Verna & Patel, 2013 and Swami <i>et al.</i> , 2013
Noodles, vermicelli, pasta, Indian sweet ( <i>halwa</i> ) mixes, <i>papads</i> , <i>paddu</i> , <i>chakkalil murukku</i> (snack deep fried in oil), <i>museli</i> and finger millet balls	India	Jenagi <i>et al.</i> , 2010; Dharmajar <i>et al.</i> , 2012 and Shobana <i>et al.</i> , 2014
Light and thick porridge; beer called <i>pito</i>	Ghana	Baryeh, 2002
Unleavened flatbread <i>roti</i> , <i>masvusvu</i> a sweet beverage alcohol	China	Amadou <i>et al.</i> , 2013
Production of alcoholic and non-alcoholic drinks, <i>otika</i> , poultry and animal feeding and eaten as cooked food	Nigeria	Nout & Davies, 1982 and Abulude <i>et al.</i> , 2005
<i>Ajon</i> (African brew)	Africa	Blandino <i>et al.</i> , 2003
<i>Amgba</i>	Cameroon	Nout & Davies, 1982
Primary use of finger millet as a malting or brewing grain	South African Development Community	Siwela, 2010
Dumpling, porridge and roti	Kenya	Karki & Kharel, 2012
Weaning and instant food		
Food products: <i>mathri</i> , <i>sevain</i> , <i>kachauri</i> , <i>laddu</i> , <i>cheela</i> , biscuits and <i>halwa</i>	Uttarakhand (India)	Singh & Raghuvanshi, 2012
Traditional ethnic dishes during special occasions and rituals	Karnataka (India)	Yenagi <i>et al.</i> , 2010
<i>Jand</i> (traditional alcoholic fermented undistilled alcoholic beverage), <i>rakshi</i> (distilled alcoholic drink), <i>roti</i> , weaning, instant food, <i>dhindo</i> (puddings) and <i>khole</i> (thin porridge)	Nepal	Karki & Kharel, 2013 and Adhikari, 2012
Polenta, couscous, medicinal herb, folk remedy for leprosy, liver diseases, measles. pneumonia and small pox	Tunisia	Bachar <i>et al.</i> , 2013
Fermented beverage	Tamil	Ilango & Antony, 2014

## 2.6. Traditional processing techniques of finger millet grain/ flour

Finger millet (FM) grains are processed traditionally by soaking, roasting, cooking, germination or malting, fermentation and popping or puffing and these processes are used in order to improve their edible, nutritional and sensory properties (Khamgaonkar *et al.*, 2013; Rasane *et al.*, 2015 and Sarita & Singh, 2016). Fermentation and germination processes have been widely used in the rural households for food security compared to other processes. Commercialization of traditional processed foods has received poor scientific consideration and their products are rare in urban populations (Subastri *et al.*, 2015).

**Soaking** – FM grains are soaked in water, salt solution and/or sodium bicarbonate solution. The process is also used to reduce the antinutritional compounds such as phytic acid which increases the bioavailability of minerals like Zn (Saleh *et al.*, 2013 and Sarita & Singh, 2016).

**Roasting** – this is a process which improves the FM grains to be digestible without the loss of nutritious components. The traditional process method is simpler and commonly used in the rural areas. It removes the antinutritional effects such as trypsin inhibitor, hemagglutinin, gioterogenic agents, cyanogenic glycosides, alkaloids and sapiens and also increase the storage shelf-life. The bioavailability of weaning foods prepared by FM grains has been increase (Singh & Raghuvanshi, 2012).

**Cooking** – this is a process in which FM grains are boiled with water until the grain becomes soft. It helps to reduce the microbial load, improve the desirable sensory quality of the cooked grains (Khamgaonkar *et al.*, 2013).

**Germination** – the whole unhusked grains are soaked for 2 - 24 h, and then spread on a damp cloth for up to 24 - 48 h (Khamgaonkar *et al.*, 2013). It has been used for centuries to soften the kernel structure, improve its nutritional value, reduce antinutritional components, and also improve flavour and taste of foods (Rasane *et al.*, 2015 and Subastri *et al.*, 2015).

**Malting** – this is a combined process of steeping, germination, drying, toasting, grinding and sieving in order to achieve better digestibility of starch (Khamgaonkar *et al.*,

2013). Brown finger millet grains have been reported to decrease the tannin content by 54% during malting (Thapliyal & Singh, 2015).

**Fermentation** – this is the process whereby the raw material becomes the medium for growth of microorganisms. The growing microorganisms then produce their own by-products such as acids or antibiotic by breaking down starches. This process inhibits spoilage and pathogenic microorganisms and improve sensory quality and nutritional value (Khamgaonkar *et al.*, 2013). Fermentation provides health benefits by reducing the antinutritional compounds such as phytates in cereal grains and it is also used as a preservative method in food products (Rasane *et al.*, 2015). Traditional fermented FM foods are thick porridge (*mudde* or dumpling), thin porridge (*ambali*), fried and baked pancake (*roti, dosa*) and beverages (*chang/ jnard*).

**Puffing or popping** – this is a process in which a whole unhusked cereal grains are soaked in water and mixed with sand. It improves the quality of grains by inactivating destructive bacteria (Khamgaonkar *et al.*, 2013). This process is used to prepare the ready to eat products which are crunchy, porous and precooked product. Popped grains have slightly higher fibre content, pleasant aroma and acceptable taste (Singh & Raghuvanshi, 2012 and Sarita & Singh, 2016).

## 2.7. Potential health benefits of finger millet

The finger millet plant is used as a folk medicine for leprosy, liver disease, measles, pleurisy, pneumonia and small pox (Bachar *et al.*, 2013 and Gupta *et al.*, 2017). Starch obtained from FM is used in the pharmaceutical industries as a binder for the preparation of granules for tablets and capsule dosage forms (Shiihii *et al.*, 2011). It is also used to control blood glucose levels in diabetic patients (Chappalwar *et al.*, 2013).

Consumption of FM is known to reduce the risk of diabetes mellitus and gastrointestinal tract disorder (Chethan & Mellish, 2007 and Lansakara *et al.*, 2016). Other potential health benefits are wound healing properties (Mathanghi & Sudha, 2012 and Shobana *et al.*,

2013), reduction in tumor incidence (Emmanuel *et al.*, 2013 and Saleh *et al.*, 2013) and reduced risk of heart attack (Verna & Patel, 2013).

## 2.8. Fortification and biofortification

### 2.8.1. Fortification – Food product enrichment

Cereal grains are important food vehicles for fortification (Wesley & Ranum, 2004 and Tripathi *et al.*, 2010) in developing countries such as in Africa where 95% of populations consume cereals as dietary staple foods (Akhtar *et al.*, 2011). The South African government launched a national food fortification programme in 2003. Thus, fortification of FM flour draws attention to the public health strategy which is used in combating vit B<sub>2</sub> and Zn deficiencies (Tripathi & Platel, 2011).

Food fortification is an effective measure of increasing the intake of minerals and vitamins that are lost during sieving of cereals (Saleh *et al.*, 2013). Wheat flour, maize flour and rice are the main cereal grains that are fortified with vit B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, Fe and Zn in order to prevent anaemia, beriberi and pellagra, especially among low socioeconomic groups (Allen *et al.*, 2006; Serna-Saldivar, 2010 and Kumari *et al.*, 2017) in African countries such as South Africa, Nigeria, Kenya, Tanzania and Ghana. The daily recommended vit B<sub>2</sub> intake is shown in Table 6.

**Table 6.** Estimated daily recommended of vitamin B<sub>2</sub> mg/day

Age/ sex	Mg/day
Infants	0.4 – 0.5
Children	0.8 – 1.2
Males	1.5 – 1.7
Females	1.3
People over 50 years	1.2 and 1.2
Pregnancy	1.6
Lactation	1.8

Zieliński *et al.*, (2005). Note: M = male and F = female

The deficiency of vit B<sub>2</sub> results in sore throat and cracks in the lips (Allen *et al.*, 2006 and Prom-u-thai *et al.*, 2010). The value of 2 - 4 ppm/100 g vit B<sub>2</sub> has been added to wheat flour during fortification. Almost 60 - 80% of vit B<sub>2</sub> is removed during cereal grain milling (Tripathi & Platel, 2010). The deficiency of Zn is recognized as a global health problem particularly in developing countries. The fortification of foods with Zn help to increase Zn absorption in foods by consumers (Shrimpton *et al.*, 2005). According to Tripathi & Platel (2010), approximately 100 million Chinese and 95.4% of the South Asian population are suffering from Zn deficiency. The deficiencies can lead to cognitive function impairment, linear growth impairment, behavioural problems, mood changes, memory impairment problems with spatial learning and neuronal trophy (Tripathi *et al.*, 2012 and Gupta *et al.*, 2015).

Zn deficiency also causes diarrhea, pneumonia and it leads to infant mortality in pregnant women (Brown *et al.*, 2008 and Upadhyaya *et al.*, 2011). The main issue of Zn deficiency is unlimited consumption of animal foods or fats in the developing countries (Tripathi & Platel, 2010; Akhtar *et al.*, 2011 and Kunyanga *et al.*, 2013). The ZnO is the most important Zn used for fortification of cereal based foods due to its chemical stability and low cost (Allen *et al.*, 2006; Prom-u-thai *et al.*, 2010 and Akhtar *et al.*, 2011). Zinc sulfate and zinc gluconate are also used to fortify cereal flour (Akhtar *et al.*, 2011).

Organoleptic problems related to Zn fortification of food have not been reported causing any major problem in food products (Akhtar *et al.*, 2011 and Saleh *et al.*, 2013). The daily recommendation of ZnO intake is shown in Table 7. The fortification of staple foods has been an effective strategy that could be used to overcome the micronutrient deficiencies (Akhtar *et al.*, 2011 and Tripathi *et al.*, 2012). The main advantage of adding fortificants to flour is to meet the nutritional requirements which improve health, productivity and well-being of humans (Serra-Majem *et al.*, 2002). Information regarding the fortification of FM flour with minerals and vitamin in the developed is scarce (Tripathi & Platel, 2010).

**Table 7.** Estimated daily recommended of zinc oxide mg/day

<b>Age/ sex</b>	<b>Mg/day</b>
0 – 6 months	2
7 – 12 months	3.0
1 – 3 years	3.0
4 – 8 years	5.0
9 – 13 years	8
14 -18 years (M/F)	11/9
<b>Pregnancy</b>	
14 -18 years	13
>19 years	11
<b>Lactation</b>	
14 -18 years	14
>19 years	12

Gibson *et al.*, (2016). Note: M = male and F = female

Most of the gluten-free products such as cereal grains do not contain adequate micronutrients that are needed for human health and recommended for daily intake. Allen *et al.* (2006); Tripathi & Platel (2010) and Akhtar *et al.* (2011) reported that there is little information or experience in developing countries about cereal grains flour fortified with vit B<sub>2</sub> and Zn fortificants. Therefore, there is a need to fortify gluten-free products such as FM flour with vit B<sub>2</sub> and Zn in order to meet the requirements of the daily intake (Gebremariam *et al.*, 2014). Fortificants are also added to cereal grains flour to prevent micronutrient deficiencies (Allen *et al.*, 2006).

### 2.8.2. Biofortification of plant foods

Biofortification is the development of micronutrient-dense staple crops using the best traditional breeding practices and biotechnology to improve the nutritional value of foods that are consumed daily like cereals and legumes for poor people living in a rural areas (Allen *et al.*, 2006 and Cakmak, 2008). Biofortification makes plant foods more nutritious by increasing the level of micro-nutrients and minerals within the seeds or grains (Velu *et al.*, 2014). Plant

breeding technology is the most powerful agricultural approach that may help to solve the problem of malnutrition in the developing countries worldwide especially for pregnant women and children below the age of five (5) (Velu *et al.*, 2014).

However, the technology is not effective if the soil types have low micronutrients which is often due to physical (soil moisture and organic matters) and chemical conditions such as soil pH (Mao *et al.*, 2014). Plant breeding is a long-term process which requires a variety of breeding activities, resources such as technology, equipment and trials even though seeds or grains can be available for many years and is cost-effective. Fortification is a method of adding nutrients during processing while biofortification is the process of using plant breeding or genetic engineering in crop production (Table 8). Cakmak (2008) states that it is not clear whether the biofortification strategy will work after long term efforts. Fortification is the best process method that was used in this study because it is easy to implement. Biofortification needs lot of resources and time for conducting trials before starting the original work and it can take up to five (5) years depending on the availability of micronutrients in the soil to conduct a research.

### 2.8.3 Similarities between fortification and biofortification processes

Fortification and biofortification eliminate the micronutrient deficiencies on the staple foods and they are cost effective (Prom-u-thai *et al.*, 2010; Tripathi *et al.*, 2010 and Mao *et al.*, 2014).

**Table 8.** Differences between fortification and biofortification.

Processes	Explanation	References
Fortification	<p>Addition of essential micronutrients such as vitamins and minerals during food processing.</p> <p>Simplest and most practical methods.</p> <p>No research needed, adding of nutrients using a specified value of vitamin and minerals.</p> <p>Not easy to reach the poorest people who are living in a remote geographic areas.</p> <p>It requires a suitable food vehicles example cereal grains.</p>	<p>European Union Comments, 2013 and Bröring &amp; Vintulkina, 2014</p> <p>Ritu &amp; Gupta, 2014</p> <p>Brown <i>et al.</i>, 2008; Prom-u-thai <i>et al.</i>, 2010; Tripathi &amp; Platel, 2010.</p> <p>Horton, 2006</p> <p>Wesley &amp; Ranum, 2004 and Horton, 2006</p>
Biofortification	<p>Process which increase the micronutrients by plant breeding or genetic modification into staple foods.</p> <p>Long-term process which requires substantial effort and resources.</p> <p>Research and extensive trials needed to be conducted.</p> <p>Biofortified seeds can reach the rural areas and available for many more years.</p> <p>Not effective to work if the soil type has low micronutrients available on soil due to physical and chemical conditions.</p>	<p>Cakmak, 2008 and Bröring &amp; Vintulkina, 2014</p> <p>Cakmak, 2008; Velu <i>et al</i>, 2014</p> <p>Nestel <i>et al.</i>, 2006 and Velu <i>et al</i>, 2014.</p> <p>Cakmak, 2008</p> <p>Mao <i>et al.</i>, 2014</p>

## 2.9. Identified research gaps

Recent studies on FM grain/flour included the determination of the effect of soaking, malting, fermentation, sprouting, biofortification and fortification on nutritional, physico-chemical and antioxidant of FM grain/flour (Shiihii *et al.*, 2011; Tripathi *et al.*, 2012; Saleh *et al.*, 2013). The fortification of FM flour with Fe, Zn and folic acid (Tripathi *et al.*, 2010; Tripathi & Platel, 2011) and sensory characteristics of FM food products have also been evaluated (Palanisamy *et al.*, 2012).

However, a lot still remain to be done on (i) functional and physical properties of fortified FM flour with vit B<sub>2</sub> and ZnO, (ii) antioxidant activities, (iii) phenolic compounds (iv) amino acids, (v) enzymes colloidal approaches in gluten-free baking and (vi) technological solutions for gluten-free challenges in meeting consumer expectations on gluten-free products. Traditional processing of FM flour and their food products have been practiced in developed countries (Khamngoarkar *et al.*, 2013). It is envisaged that this study would promote and increase the consumption of FM in urban areas through increased product awareness.

## CHAPTER 3 SOME PHYSICAL PROPERTIES OF FINGER MILLET GRAIN VARIETIES GROWN IN SUB-SAHARAN AFRICA

### Abstract

The study determined the physical properties of finger millet (FM) grain varieties. Physical properties such as colour attributes, sample weight, bulk density (BD), true density, porosity, surface area, sample volume, aspect ratio, sphericity, dimensional properties and moisture content of grain varieties were determined. Length values were significantly higher ( $p < 0.05$ ) in the brown variety than MC and black grain varieties. In width values, the MC was significantly higher while the brown and black varieties were not significantly different. Thickness values for brown variety were significantly higher than milky and black FM grain varieties. Results showed that the MC variety was significantly higher ( $p < 0.05$ ) than other grain varieties in sample weight, BD, true density, aspect ratio and sphericity. However, pearl millet (PM) was used as a comparison and was significantly higher from FM grains on all dimensional properties. Moisture content of the MC showed higher significant differences for both grains as compared to brown and black grain. MC grain variety showed a significant higher on  $L^*$ ,  $b^*$ ,  $C^*$  and  $H^*$  values for FM grains. The study is important for agricultural and food engineers, designers, scientists and processors in the design of equipment for FM grain processing. The results are also likely to be useful in assessing the quality of grains used to fortify FM flour.

**Keywords:** Finger millet, moisture content, dimensional properties, colour attributes.

### 3.1. Introduction

Finger millet (FM) also known as *ragi* (Takhellambam *et al.*, 2016) or *tamba* (Jideani *et al.*, 1996), is consumed without dehulling (Gull *et al.*, 2015). It is named FM because of its growth form of panicles which takes the form of several fingers (Sood *et al.*, 2017). The grains are staple cereal food in some parts of Africa and India (Siwela *et al.*, 2013). Although a gluten-free grain with low-glycemic index with nutritional and nutraceutical advantages, the FM is neglected and underutilized (Jideani & Jideani, 2011 and Amadou *et al.*, 2013). FM belongs to the family *Poaceae* (Sood *et al.*, 2016) and originated in Ethiopia (Shiihii *et al.*, 2011) before reaching India (Siwela *et al.*, 2010). In terms of production in semi-arid regions, FM ranks fourth after sorghum, pearl millet and foxtail millet (Upadhyaya *et al.*, 2011; Shiihii *et al.*, 2011 and Ramashia *et al.*, 2018).

The grains contain a high value of Ca which is an essential macro-nutrients necessary for growing children, pregnant women and the elderly. This is due to Ca's importance for normal growth of body tissue such as strengthening bone and teeth (Jideani, 2012) and for preventing osteoporosis (Kumar *et al.*, 2016). The FM has also been reported to be rich in essential amino acids, such as methionine, tryptophan and lysine (Jideani, 2012). FM contains low fat content of 1.0 - 1.8% (Singh & Raghuvanshi, 2012; Saleh *et al.*, 2013 and Verna & Patel, 2013) which contributes to reducing risks of diabetes mellitus and gastrointestinal tract disorders (Muthamilarasan *et al.*, 2016). According to Roopa & Premavalli (2008) and Jideani (2012), FM grains are also a good source of carbohydrates, phosphorus, magnesium and iron.

The grains are also rich in vitamins B complex such as thiamine, riboflavin, folic acid and niacin (Saleh *et al.*, 2013 and Gull *et al.*, 2015). The plant is used as a folk medicine for treatment of liver disease, measles, pleurisy, pneumonia and small pox (Bachar *et al.*, 2013 and Ramashia *et al.*, 2018). Starch extracted from FM grains are used in the pharmaceutical industries in the preparation of granules for tablets and capsule dosages (Shiihii *et al.*, 2011). Application of grains also involves its use in the preparation of baked products, composite

flour, weaning foods, beverage and non-beverage products (Poutanen, 2012 and Verma & Patel, 2013). The grains are found in different shapes, sizes and colours with the predominant colour being brown (Vadivoo *et al.*, 1998). The physical properties of cereal grains include moisture content, 1 000 kernel weight, BD, true density, porosity, aspect ratio, kernel volume, kernel surface area and perpendicular dimensions (length, width and thickness) (Vanrnamkhasti *et al.*, 2008).

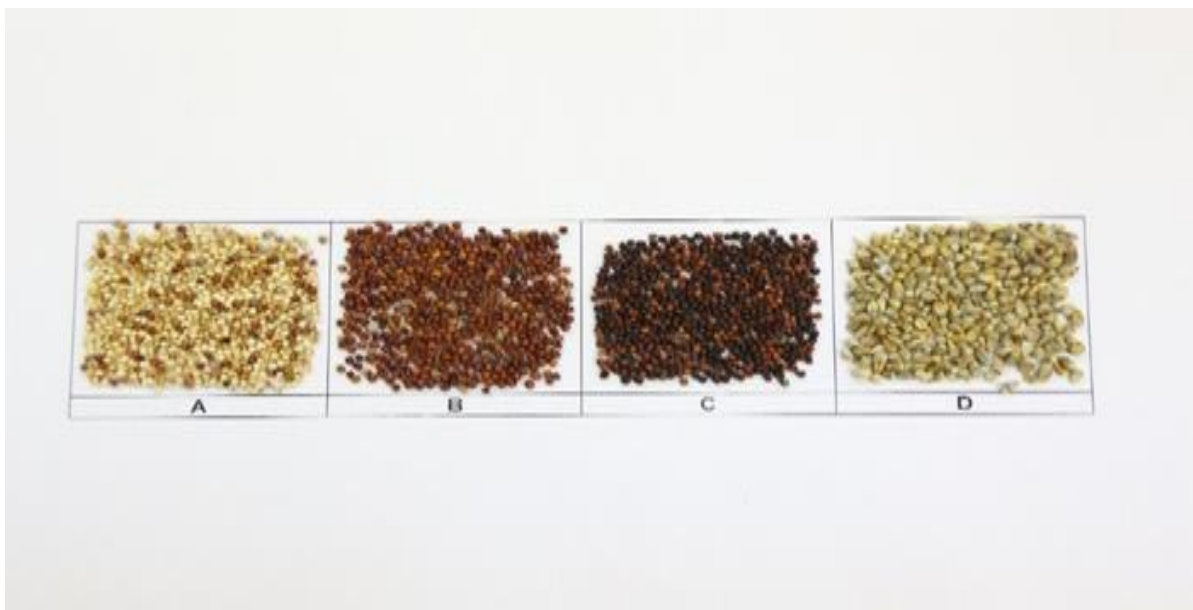
Current review of literature shows that the physical properties of grains have been conducted on major cereal grains such as, wheat, rough rice and maize (Vanrnamkhasti *et al.*, 2008 and Sangamithra *et al.*, 2016) when compared to millets, such as FM, foxtail millet, little millet, kodo millet, common millet and banyard millet (Balasubramanian, & Viswanathan, 2010 and Ramashia *et al.*, 2018). Studies have also been conducted on legumes such as cowpea seeds, soy bean and bambara groundnuts (Bhattacharya & Malleshi, 2012 and Jideani *et al.*, 1996). However, data on physical properties of FM grain varieties is still insufficient, especially in sub-Saharan Africa with few studies reported in Asian countries such as India. The knowledge of the physical properties will be useful in new product development (Faleye *et al.*, 2013) and the design of handling equipment. The objective of this study was to sort mixed FM grains into various varieties and to determine the physical properties of the varieties.

### **3.2. Materials and methods**

#### **3.2.1. Sorting of finger millet grain varieties**

Grains of finger millet (FM) were purchased from the Thohoyandou market, Limpopo province, SA. Foreign materials were removed from the grains by immersion in clean water. After drying and sorting a spatula full of finger millet grains was used and the grains were counted in order to get the accurate percentage of each FM variety, 80% - milky cream, 97%

- brown and 85% - black millet grains based on kernel colour (Figure 4) were obtained. PM (*Pennisetum glaucum*) was used as a comparison as most of the research were conducted. The grain kernels were randomly selected and 20 replicates were performed for dimensional properties (length, width and thickness). The determination of other physical properties such as moisture content, 1 000 kernel weight, bulk density (BD), true density, porosity, aspect ratio, kernel volume and kernel surface area were performed in five (5) replicates for each grain variety. Colour attributes were performed in three (3) replicates.



**Figure 4.** Finger millet grains (A = 80% milky cream, B = 85% black, C = 97% brown) and pear millet (D).

### 3.2.2. Moisture content of finger millet grain varieties

Moisture content was determined with hot air oven drier (Module 278, Labotech Eco therm, South Africa) using the AACC (2000) method 44-15.02 involving equation 1. A dry coded, clean crucible was placed in the oven for about 30 min, cooled and weighed. Four (4) grams of FM grain were weighed into the crucible, and recorded. The grains were dried at 101 to 105°C for 24 h, removed and cooled until a constant weight was obtained. The results of moisture content (%) was calculated using equation 1.

$$\% \text{ moisture} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (1)$$

Where:  $W_1$  = weight of empty crucible

$W_2$  = weight of crucible + flour before drying

$W_3$  = weight of crucible + flour after drying

### 3.2.3. Dimensional properties of finger millet grain varieties

A total of twenty (20) seeds were randomly selected from each variety MC, brown, black, and pearl millet. Three (3) different dimensional properties (mm) were determined by measuring the length (L), width (W) and thickness (T) of the grains using a vernier digital caliper at an accuracy of 0.01 mm (Mpotokwane *et al.*, 2008 and Ramashia *et al.*, 2018).

#### 3.2.3.1. Geometric mean diameter of finger millet varieties

The geometric mean diameter (mm) was determined based on the measured dimensions of FM varieties using equation 2 used by Mpotokwane *et al.* (2008) for bambara groundnut.

$$\text{Geometric mean diameter (Dg) is equivalent to } (L \times W \times T)^{1/3} \quad (2)$$

Where: L = length

W = width

T = thickness

#### 3.2.3.2. Arithmetic mean diameter finger millet grain varieties

The arithmetic mean diameter (mm) of the kernel was obtained using the methods of Mpotokwane *et al.* (2008). Arithmetic mean diameter was calculated from the dimensional values using the following equation 3:

$$\text{Arithmetic mean diameter (Da)} = \frac{L+W+T}{3} \quad (3)$$

Where: L = length

W = width

T = thickness

#### 3.2.4. One thousand (1 000) kernel weight of finger millet grain varieties

The thousand (1 000) kernel weight was determined by weighing, recording the weight and counting manually the number of the FM grains. The varieties were weighed using digital electronic balance (Adam CPW plus-150p, USA) with 0.01 g accuracy (Sangamithra *et al.*, 2016).

#### 3.2.5. Bulk density of finger millet grain varieties

Bulk density ( $\text{kg/ m}^3$ ) is described as the ratio of the mass of the sample to its total volume (Vanramkhasi *et al.*, 2008). It was determined by filling a 500 mL cylinder with grains using method of Mariotti *et al.* (2006). Bulk density ( $\text{kg/ m}^3$ ) was calculated as a ratio between the kernel weight and the volume of the cylinder using the equation 4:

$$\text{Bulk density} = \frac{\text{Sample weight}}{\text{volume}} \quad (4)$$

#### 3.2.6. True density of finger millet grain varieties

The true density ( $\text{kg/ m}^3$ ) was determined by the liquid displacement method using a top loading balance. A total of 100 g of grains were immersed in graduated beaker containing distilled water. The value of water displacement was recorded using equation 5 (Karababa & Coşkune, 2013).

$$P_t = \frac{30 g}{V_2 - V_1} \quad (5)$$

Where:  $P_t$  = true density,  $V_1$  = initial volume and  $V_2$  = final volume

### 3.2.7. Porosity of finger millet grain varieties

Porosity (%) is defined as the fraction of the space in bulk grain that is not occupied by the grain (Sangamithra *et al.*, 2016). It was calculated using equation 6 from the true density and BD using the method of Vanramkhandi *et al.* (2008).

$$\epsilon = \frac{P_t - P_b}{P_t} \times 100 \quad (6)$$

Where:  $\epsilon$  = porosity,  $p_t$  = true density and  $p_b$  = bulk density

### 3.2.8. Sphericity of finger millet grain varieties

Sphericity (%) is explained as the ratio of the surface area of a sphere having the same volume as the grain to the surface area of the grain and was calculated using the method of Hamdani *et al.* (2014) equation 7.

$$\Phi = \frac{(LWT)^{1/3}}{L} \times 100 \quad (7)$$

Where:  $\Phi$  = Sphericity

### 3.2.9. Aspect ratio of finger millet grain varieties

The aspect ratio (%) was calculated using equation 8 according to method of Vanramkhandi *et al.* (2008) as follows:

$$\text{Aspect ratio} = \frac{\text{Width}}{\text{Length}} \times 100 \quad (8)$$

### 3.2.10. Surface area of finger millet grain varieties

The surface area, mm<sup>2</sup> of three (3) FM varieties and PM were calculated using equation 9 according to the method of Karababa & Coşkune (2013):

$$\text{Surface area} = \frac{\pi BL^2}{(2L-B)} \quad (9)$$

Where:  $B = (WT)^{1/2}$

W = width, L = length, T = Thickness

### 3.2.11. Kernel volume of finger millet grain varieties

The volume (mm<sup>3</sup>) of the grains was calculated using equation 10 according to the methods of Karababa & Coşkune (2013).

$$\text{Surface volume} = \frac{\pi B^2 L^2}{6(2L-B)} \quad (10)$$

Where:  $B = (WT)^{1/2}$

W = width, L = length, T = Thickness

### 3.2.12. Colour attributes of finger millet grain varieties

The colour attributes ( $L^*$ ,  $a^*$ ,  $b^*$ , chroma ( $C^*$ ) and hue ( $H^\circ$ ) of the grain and flour were determined using Lovibond LC 100 spectrophotometer and SV 100 test kit (Thilagavathi *et al.*, 2015). The colour attributes were measured and expressed as positive and negative colour space values using  $L^*$  (whiteness/ brightness),  $a^*$  (redness/ greenness) and  $b^*$  (yellowness/ blueness). The  $C^*$  was expressed as either grey or the pure hue with  $H^\circ$  were recorded using different colours such as yellow, green and blue values.

### 3.2.13. Experimental design and data analysis

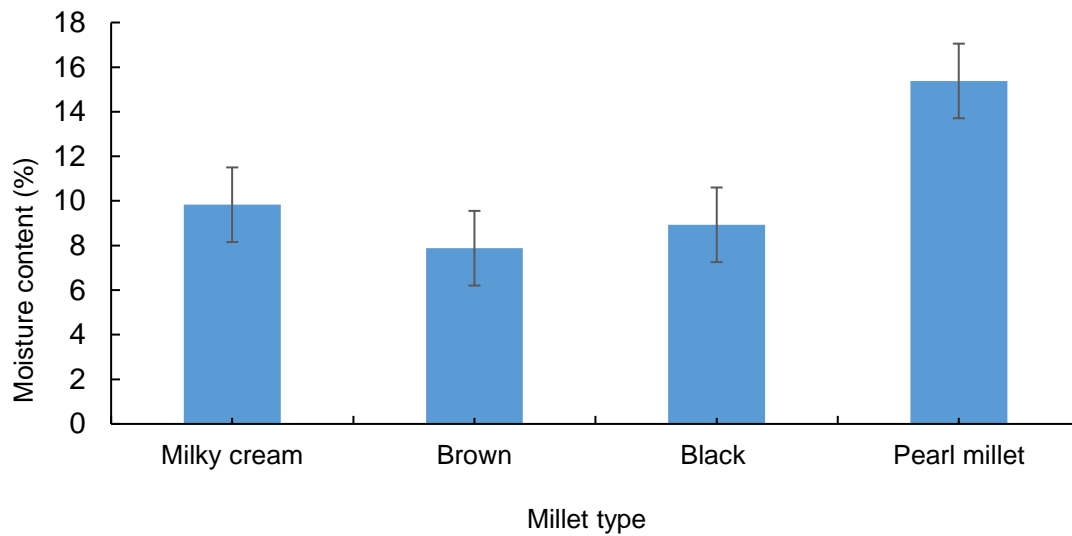
The generated data were subjected to analysis of variance using SPSS version 23 (SPSS, IBM, Chicago USA) and means were separated using the Duncan multiple range test (Kibar & Kibar, 2017). Significance was accepted at 95% confidence interval ( $p < 0.05$ )

## 3.3. Results and discussion

### 3.3.1. Moisture content of finger millet grain varieties

Figure 5 shows the results of the mean moisture content of the varieties of FM grain which ranged from  $7.88 \pm 1.92$  to  $9.38 \pm 3.08\%$ . The highest percentage was recorded for MC and the lowest percentage for the brown variety. Therefore, MC showed significantly higher ( $p < 0.05$ ) moisture content for FM grains. These results compared with the PM which showed significantly higher moisture content than finger millet grain varieties (FMGV) at the highest value of 15.38%. Siroha *et al.* (2016) reported that the moisture content of five (5) pearl millet varieties, ranged from 6.5 to 7.7%.

The results showed that the moisture content was within the specified percentage of  $<12\%$  as shown in the work of Saleh *et al.* (2013). Moisture content is one of the important factors that govern the physical properties of grain (Goswami *et al.*, 2015), Bashar *et al.* (2014) reported that the physical properties of grains are dependent on the moisture content of the grains. It is also a good indicator as to whether the grains can be stored for a long or short period. The higher the moisture content, the shorter the storage life of the grain as high moisture content could cause a rapid growth of mould on grains (Abdullah *et al.*, 2012)



**Figure 5.** Moisture content (%) of finger millet flours. Error bars indicate the standard.

### 3.3.2. Dimensional properties of finger millet grain varieties

The mean results of the length, width and thickness of the three (3) varieties were measured using vernier digital caliper and ranged between  $1.67 \pm 0.01$  to  $1.41 \pm 0.00$  mm for length;  $1.47 \pm 0.01$  to  $1.28 \pm 0.01$  mm for width and  $1.35 \pm 0.06$  mm to  $1.22 \pm 0.01$  mm for thickness (Table 9). Similar results were obtained by Hamdani et al. (2014) for length, width and thickness which ranged from  $8.57 \pm 1.20$  to  $11.31 \pm 1.10$  mm;  $2.70 \pm 0.24$  to  $3.70 \pm 0.18$  mm and  $2.24 \pm 0.09$  to  $2.85 \pm 0.16$  mm for hulled barley and SKO-20 oats at the moisture content of 8.0%.

Similar results were obtained for PM varieties (*babapuri*, *bajra*, & GHB 30) with length, width and thickness ranging from 2.98 mm to 3.12 mm, 1.86 mm to 2.24 mm and 1.70 to 2.01 mm (Jain & Bal, 1997). Length values were significantly higher ( $p < 0.05$ ) for brown variety as compared to MC and black varieties. The width of MC variety was significantly lower ( $p < 0.05$ ) while brown and black were not significantly higher. Thickness values for brown were significantly higher when compared with other varieties.

**Table 9.** Dimensional properties of finger millet grain varieties using vernier digital caliper.

Dimensions (mm)	Finger millet grain varieties			
	Milky cream	Brown	Black	Pearl millet
Length	1.63 <sup>b</sup> ± 0.01	1.67 <sup>b</sup> ± 0.01	1.41 <sup>c</sup> ± 0.00	3.85 <sup>a</sup> ± 0.01
Width	1.28 <sup>c</sup> ± 0.01	1.47 <sup>b</sup> ± 0.01	1.38 <sup>b</sup> ± 0.01	2.40 <sup>a</sup> ± 0.01
Thickness	1.22 <sup>d</sup> ± 0.01	1.35 <sup>b</sup> ± 0.01	1.27 <sup>b</sup> ± 0.01	2.31 <sup>a</sup> ± 0.00
Geometric mean diameter	1.36 <sup>c</sup> ± 0.18	1.49 <sup>b</sup> ± 0.13	1.35 <sup>c</sup> ± 0.06	2.81 <sup>a</sup> ± 0.70
Arithmetic mean diameter	1.38 <sup>c</sup> ± 0.22	1.50 <sup>b</sup> ± 0.06	1.35 <sup>c</sup> ± 0.07	2.85 <sup>a</sup> ± 0.86

Values are mean ± standard deviation, n = 20. Values followed by the same letter in the same row are not significantly different ( $p < 0.05$ ). FM = finger millet.

The geometric mean diameter ranged from  $2.81 \pm 0.71$  mm to  $1.35 \pm 0.06$  mm and arithmetic mean diameter from  $2.85 \pm 0.86$  mm to  $1.35 \pm 0.07$  mm. The results for geometric and arithmetic mean diameters were similar to the results obtained on millet grains by Adebowale *et al.* (2012b), where the average length, width and thickness were 3.85 mm, 2.06 mm and 2.05 mm, respectively. Similar, results were also obtained for geometric and arithmetic mean diameters, 2.44 mm and 4.94 mm at a moisture content of 10%. Jain & Bal (1997) who studied the geometric and arithmetic mean diameters of PM varieties, reported the following results: 1.82 to 2.12 mm and 1.72 to 2.08 mm at the moisture content of 7.4%. Other similar arithmetic mean diameter results from hulled and hullless barley were  $4.96 \pm 0.50$  and  $5.34 \pm 0.31$  mm and for sabzaar oats and SKO-20 oats were  $6.00 \pm 0.26$  and  $5.41 \pm 0.44$  mm, respectively.

Similar results for geometric mean diameter were also found as  $4.33 \pm 0.27$ ;  $4.53 \pm 0.24$  mm;  $4.22 \pm 0.21$  mm and  $4.01 \pm 0.20$  mm for hulled barley, hullless barley, sabzaar oats and SKO-20, respectively at the moisture content of 8.0% (Hamdani *et al.*, 2014). The geometric and arithmetic mean diameters were significantly higher in brown variety and also showed a significantly higher values on MC and black varieties (Table 9). Therefore, PM grain showed a significantly higher values in all dimensions studied when compared to FMGV.

### 3.3.3. Physical properties of finger millet grain varieties

The highest mean result for 1 000 kernel weight was obtained from MC variety,  $775 \pm 5.27$  g and the lowest mean result for 1 000 kernel weight was  $496.8 \pm 5.00$  g from the brown variety. MC was significantly higher ( $p < 0.05$ ) in 1 000 kernel weight when compared to other varieties (Table 10). The results agree with the findings of Balasubramanian & Viswanathan (2010) which were 185.8 kg at the moisture 11.1 to 25%. In the work of Siwela *et al.* (2007) similar mean result of  $2.86 \pm 0.11$  g was reported. Results of analysis also showed that BD ranged from  $993.6 \pm 11.44$  to  $1158 \pm 16.51$  kg/m<sup>3</sup>, respectively with MC showing the highest BD and the brown variety showing the lowest BD (Table 10).

These results were in line with those by Zewdu & Solomon (2007) who reported 696 to 840 kg/m<sup>3</sup> for teff millet at a moisture content ranging from 5.6 to 29.60%. The results for BD of grain variety were similar to those reported by Jain & Bal (1997) who studied three (3) PM varieties ranging from 830.0 to 866.1 kg/m<sup>3</sup>. Goswami *et al.* (2015) also reported a BD ranging from 684.99 to 777.50 kg/m<sup>3</sup> on FM grains. Balasubramanian & Viswanathan (2010) obtained the similar results which ranged from 477.1 to 868.1 kg/m<sup>3</sup> at a moisture content ranging from 11.1 to 25%. MC had significant higher ( $p < 0.05$ ) values as compared to other varieties (Table 10).

BD is an essential factor that determines the grade and test weight of the grains during drying, storage and processing (Adebowale *et al.*, 2012a). The BD results may help in storage and processing because the size and shape of the grains were similar indicating high quality and better production of grains into flours. Table 10 shows that the milky cream finger millet (MCFM) variety had the highest true density of  $1613.4 \pm 48.02$  kg/m<sup>3</sup> and was significantly higher ( $p < 0.05$ ) than the black ( $1515.8 \pm 35.33$  kg/m<sup>3</sup>) and brown variety ( $1515.6 \pm 34.88$  kg/m<sup>3</sup>). These results were in line with the findings by Vanrnankhasti *et al.* (2008) for rough rice, where the mean true density ranged from 1193.38 to 1269.10 kg/m<sup>3</sup>, respectively.

**Table 10.** Some physical properties of finger millet grain varieties.

Physical properties	Finger millet grain varieties			
	Milky cream	Brown	Black	Pearl millet
1 000 kernel weight (wt.g)	775.8 <sup>a</sup> ± 5.27	496.8 <sup>c</sup> ± 5.00	573.4 <sup>b</sup> ± 7.17	176.8 <sup>d</sup> ± 1.94
Bulk density (kg/m <sup>3</sup> )	1158 <sup>a</sup> ± 16.51	993.6 <sup>c</sup> ± 11.44	1146.80 <sup>b</sup> ± 16.04	354.6d ± 3.85
True density (kg/m <sup>3</sup> )	1613.4 <sup>a</sup> ± 48.02	1515.6 <sup>c</sup> ± 34.88	1515.8 <sup>c</sup> ± 35.33	1531.2 <sup>b</sup> ± 42.72
Porosity (%)	28.25 <sup>c</sup> ± 2.47	32.41 <sup>b</sup> ± 5.40	24.31 <sup>d</sup> ± 2.10	76.83 <sup>a</sup> ± 0.47
Aspect ratio (%)	92.21 <sup>a</sup> ± 0.83	88.3 <sup>b</sup> ± 0.55	73.55 <sup>c</sup> ± 0.23	87.81 <sup>b</sup> ± 0.92
Sphericity (%)	92.43 <sup>a</sup> ± 0.15	83.21 <sup>b</sup> ± 0.08	73.75 <sup>c</sup> ± 0.10	64.17 <sup>d</sup> ± 0.16
Surface area (mm <sup>2</sup> )	5.81 <sup>a</sup> ± 0.82	6.97 <sup>b</sup> ± 0.94	5.73 <sup>c</sup> ± 0.90	24.81 <sup>a</sup> ± 1.41
Kernel volume (mm <sup>3</sup> )	0.86 <sup>a</sup> ± 0.02	1.07 <sup>b</sup> ± 0.06	0.82 <sup>d</sup> ± 0.16	3.59 <sup>a</sup> ± 1.12

Values are mean ± standard deviation, n = 5. Values followed by the same letters in the same row are not significantly different ( $p < 0.05$ ). FM = finger millet

Similar results for true density, 884.4 to 1988.7 kg/m<sup>3</sup> were obtained by Balasubramanian & Viswanathan (2010) at a moisture content of 11.1 to 25%. Jain & Bal (1997) obtained similar results on the true density of three (3) PM studied which ranged from 1578 to 1623 kg/m<sup>3</sup>. Zewdu & Solomon (2007) also reported similar results of 1207 to 1361 kg/m<sup>3</sup> for teff millet grain at a moisture content of 5.6 to 29.6%. The mean porosity varied from 24.31 ± 2.10 to 32.41 ± 5.40%. The highest percentage was found in the brown variety with the lowest on black FM variety (Table 10). These results were similar to those obtained by Sangamithra *et al.* (2016) where porosity ranged from 51.30 to 55.83% at a moisture content of 8.7 to 21.7% for maize.

A similar observation was reported by Al-Mahasneh & Rababah (2007), which showed values ranging from 45.61 to 46.66% for green wheat. A study by Zewdu & Solomon (1997) reported porosity values which ranged from 38.31 to 42.32% for teff millet at a moisture content of 5.6 to 29.0%. In a study by Jain & Bal (1997), porosity ranged from 45.1 to 48.8% for PM varieties (babapuri, bajra and GHB 30) at a moisture content of 7.4%. Balasubramanian & Viswanathan (2010) obtained similar results of 32.5 to 63.7% at a moisture content of 11.1 to 25% for minor millets in which FM grain was part of the study. The mean aspect ratio mean ranged from 73.55 ± 0.23 to 92.21 ± 0.83%, where MC was found to have a highest percentage and lowest percentage on black variety (Table 10). Adebowale *et al.* (2012b) revealed that millet grains were found to have 59.62% aspect ratio at a moisture content of 10%, and Markowski *et al.* (2013) also reported the same results of 47.4% at a moisture content of 9.95%. The mean results of sphericity ranged from 73.75 ± 0.10 to 92.43 ± 0.15%. The highest sphericity value was obtained on the MC variety and the lowest result on the black variety (Table 10). The results are in line with the findings of Baryeh (2002) of 78.30 to 80.30% at a moisture content of 5.00 - 22.5%. Similarly, the works of Jain & Bal (1997) showed that sphericity ranged from 93.74 to 94.25% for the PM varieties (*babapuri*, *bajra* and GHB 30).

Table 10 shows that the surface area mean results of this study varied from 5.73 ± 0.90 to 6.97 ± 0.94 mm<sup>2</sup> in which the highest result was obtained from the brown variety and the lowest

result from the black variety. Similar results were obtained by Jain & Bal (1997) who reported 12.27 to 16.38 mm<sup>2</sup> for PM varieties at moisture content of 7.4% while Adebowale *et al.* (2012b) showed that the surface area of millet grain was 18.8 mm<sup>2</sup> at a moisture content of 10%. The mean kernel volume of the varieties studied varied from 1.07 ± 0.06 to 0.82 ± 1.12 mm<sup>3</sup>. The highest result was obtained from brown variety and lowest results from the black variety. Jain & Bal (1997) had similar results which ranged from 3.79 to 5.79 mm<sup>3</sup> at a moisture content of 7.4%. Adebowale *et al.* (2012b) found the volume of 5.56 mm<sup>3</sup> for millet grains at a moisture content of 10%. The MC variety was significantly higher ( $p < 0.05$ ) than other varieties for 1 000 kernel weight, BD, true density, aspect ratio and sphericity (Table 10).

#### 3.3.4. Colour attributes of finger millet grain varieties

Table 11 shows the results of the colour attributes of variety as recorded in terms of the values L\*, a\*, b\*, C\* and H° values. The L\* values ranged from 18.26 ± 1.43 for the black varieties to 51.18 ± 2.78 for the MC grain variety. These result are similar to those by Siwela *et al.* (2007) which ranged from 45.9 ± 0.9 to 68.4 ± 0.6 for FM grain type. Positive values obtained for coordinates a\* and b\* were significantly higher ( $p < 0.05$ ), where a\* values were 18.28 ± 0.81 for brown grain variety. The mean b\* values were 25.38 ± 2.03 for the MC grain variety. The positive values for a\* and b\* coordinates indicated that all varieties had varying concentration of red and yellow pigmentation in their grains. Therefore, MC showed significant higher c\* with the highest value of 29.10 ± 2.03. The H° values ranged from 37.36° ± 2.37 to 68.86° ± 0.42 where the highest H° was obtained from MC variety and the lowest H° from the black variety.

**Table 11.** Colour attributes of finger millet grain varieties

Colour attributes	Finger millet grain varieties			
	Milky cream	Brown	Black	Pearl millet
L*	51.18 <sup>a</sup> ± 2.78	27.42 <sup>c</sup> ± 1.10	18.26 <sup>d</sup> ± 1.43	43.08 <sup>b</sup> ± 1.00
a*	9.66 <sup>b</sup> ± 0.64	18.28 <sup>a</sup> ± 0.81	7.98 <sup>b</sup> ± 0.64	4.12 <sup>c</sup> ± 0.43
b*	25.38 <sup>a</sup> ± 2.03	18.82 <sup>b</sup> ± 0.25	6.04 <sup>c</sup> ± 0.30	19.38 <sup>b</sup> ± 0.15
C*	29.1 <sup>a</sup> ± 2.03	22.10 <sup>b</sup> ± 1.90	10.1 <sup>d</sup> ± 3.99	19.60 <sup>c</sup> ± 0.19
H* (°)	68.86 <sup>a</sup> ± 0.42	45.12 <sup>c</sup> ± 0.95	37.36 <sup>d</sup> ± 2.37	77.58 <sup>b</sup> ± 1.19

Values are mean ± standard deviation, n = 3. Values followed by the same letters in the same row are not significantly different ( $p < 0.05$ ). FM = finger millet.

The H° values are measured as an angle of 0° - 360° with 0° representing red, 90° for yellow, 180° for green and 270° for blue. Hue angle is considered the qualitative attribute of colour and is based on colours which have been traditionally defined as reddish, greenish and others. The H° is most critical to humans with normal colour vision for perception and acceptability. Therefore, the PM showed significant higher H° on both grain and flour with the highest value of 76.87 and 81.13, respectively. The C\* values for grain varieties ranged from 10.1 ± 3.99 to 29.1 ± 2.03 while for FM flours varied from 13.4 ± 0.20 to 7.977.97 ± 0.23.

Chroma increased with increasing pigment concentration and decreased as the sample became darker. Food samples can have similar H° and C\*, but will only be distinguished using their L\* values (Wrolstad & Smith, 2010). The higher the C\* values, the higher the colour intensity of the varieties perceived by humans. Colour is thus an essential quality parameter in the food processing industries and it attracts the consumer's choice and preferences (Ramashia *et al.*, 2018). The MC variety showed a significance difference of ( $p < 0.05$ ) on L\*, b\*, C\* and H° values compared to both brown and black grain varieties (Table 11).

Similar results were also obtained by Krishnan *et al.* (2011) who reported FM seed coated with the L\* ranging from 34.0 to 51.2, a\* from 5.0 to 5.8 and b\* ranging from 7.6 to 11.1. Mandge

*et al.* (2014) reported the  $L^*$  - value of 53.6 for raw multigrain porridge and 41.6 for cooked multigrain porridge. Mean  $a^*$  and  $b^*$  values ranged from 5.0 to 5.8 and 15.8 to 18.4, respectively. The  $H^0$  values correspond to whether the object is red, orange, yellow, blue or violet.

The positive values noted in the  $H^0$  of the varieties showed that the product did not deviate from the colour, adding a positive factor to the current study because lightness and yellowness in the colour of flour are important factors in terms of consumer acceptance  $H^0$  value of 67.24 and the  $C^*$  value was 14.48 for 20 g wheat/100 g malted FM (Bhol & Bosco, 2014). The findings of this study were similar to those by Siroha *et al.* (2016) who studied five (5) PM varieties whose values ranged from 52.5 to 75.1.

### 3.4. Conclusion

The MC was significantly higher in moisture content,  $L^*$ ,  $b^*$  and  $C^*$  values, 1 000 kernel weight, true density, aspect ratio and sphericity than other FM grains on physical and dimensional properties. However, pearl millet varieties were significantly higher than FM varieties on all dimensional properties. The information from this study could be used by agricultural engineers, food engineers, food processors and food scientists. The information is potentially useful in the designing of equipment which is suitable for planting, harvesting, storage, processing and packaging of grains.

Moreover, the size and shape such as geometric mean diameter and sphericity properties of the FM grains need to be known by manufacturers as they may contributed in designing better equipment suitable for grain and other food processing operations. Therefore, data obtained on the physical properties of the grains was used in the fortification study of FM flour using vit B<sub>2</sub> and ZnO.

## CHAPTER 4 EFFECT OF FORTIFICATION ON NUTRITIONAL COMPOSITION OF PROCESSED FINGER MILLET (*ELEUSINE CORACANA*) FLOURS FORTIFIED WITH VITAMIN B<sub>2</sub> AND ZINC OXIDE

### Abstract

The aim of this study was to determine the effect of fortification on nutritional composition of finger millet (FM) flours fortified with vitamin (vit) B<sub>2</sub> and zinc oxide (ZnO). The milky cream (MC), brown and black and pearl millet (PM) flours were used for comparison. Flours were randomly arranged as a completely randomized design in three (3) replicates. Determination of some proximate compositions of FM flours and biochemical properties such as minerals, vitamins and pH values were conducted. The flours were randomly sampled in three (3) replicates. Data generated were analysed using SPSS version 23.0. Moisture content of brown instant fortified finger millet (IFFM) flour,  $8.63 \pm 1.59\%$  was significantly higher ( $p < 0.05$ ) from MC  $7.92 \pm 1.59\%$  and black,  $3.75 \pm 0.75\%$  IFFM flours while pH values of black IFFM flour were significantly higher from other flours. Ash content of brown IFM and IFFM flours were significantly higher than other flours. The MC raw finger millet (RFM) flour had the highest amount of ZnO,  $2.64 \pm 0.01$  mg/100 g and had significantly higher amount than brown ( $2.57 \pm 0.01$  mg/100 g) and black ( $2.62 \pm 0.04$  mg/100 g) flours. Both brown and black raw fortified finger millet (RFFM) flours had the highest amount of ZnO,  $9.72 \pm 0.08$  and  $9.72 \pm 0.03$  mg/100 g flour and had significantly higher ( $p < 0.05$ ) amount compared to MC flour, 9.44 mg/100 g. Pearl millet flour showed significantly higher ( $p < 0.05$ ) amount of ZnO as compared to both RFM ( $4.49 \pm 0.02$  mg/100 g) and RFFM ( $10.28 \pm 0.02$  mg/100 g) flours. The anticipation of the study was to produce and characterize FM flour with vit B<sub>2</sub> and ZnO that may be utilised for value added products.

**Key words:** Finger millet, fortification, micronutrient deficiencies, physico-chemical, minerals.

#### 4.1. Introduction

Food fortification is the addition of micronutrients to foods especially cereal grains which are consumed as dietary staple foods in developing countries such as South Africa and India (Shobana & Malleshi, 2007 and Akhtar *et al.*, 2011). The addition of vitamins, minerals and trace elements in foods after processing eliminate the micronutrient deficiencies (Ottaway, 2008 and Saleh *et al.*, 2013). About 815 million households suffer from vitamin and mineral deficiencies globally (Poletti *et al.*, 2004). The United States of America (USA) and European countries have been practicing the fortification of wheat flour for more than 50 years without any risk. Fortification is mostly used in developed countries where wheat flour is used as a staple foods (Wafula *et al.*, 2018). Wheat, rice, maize flours are generally fortified with vitamins B complex such as B<sub>1</sub>, B<sub>2</sub>, B<sub>6</sub>, niacin and minerals such as Fe and Zn (DoH, 2008, Sadighi *et al.*, 2008 and Beizadea, 2009).

These include African countries that are among low socioeconomic groups such as South Africa, Nigeria, Kenya, Tanzania and Ghana (Allen *et al.*, 2006 and Serna-Saldivar, 2010) and developed countries such as United Kingdom, Canada and most countries in Central America (Beizadea, 2009). However, the United States of America has also been fortifying milk with vit A and D since 1930 (Ottaway, 2008) while the South African government launched the fortification programme of wheat flour in 2003. Over 90% of wheat flour and 70% of maize flour are fortified in South Africa with vit A, B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, B<sub>6</sub> and B<sub>9</sub> as well as Fe and Zn (DoH, 2008 and Beizadea, 2009). Fortification of staple cereal foods such as maize, wheat and rice flours is widely practiced, few programmes has been launched regarding the fortification of cereal flours such as finger millet and pearl millet (Ottaway, 2008).

ZnO is the most useful chemical that is used for fortification and is generally regarded as safe (GRAS) for human consumption (Brown *et al.*, 2008). The chemical form of ZnO is fine particle, “light grade” compound that homogenises well with flour without clumping. The ZnO does not settle out or separate after homogenisation. It can also be used as a fortificant because of its

low cost, bioavailability of Zn and lack of undesirable organoleptic effects (Akhtar *et al.*, 2011 and Saleh *et al.*, 2013). The main problem of Zn deficiency is unlimited consumption of animal foods or fats in the developing countries (Tripathi & Platel, 2010 and Kunyanga *et al.*, 2013). Zn sulfate, Zn gluconate and Zn oxalate are also used to fortify cereal flour (Akhtar *et al.*, 2011) and Zn stearate (Tripathi & Platel, 2010). The Zn deficiency is documented worldwide for health complications particularly in developing countries. The subgroup of population that may have a risk of insufficient Zn intake and who can benefit by consuming food fortified with Zn are infants, young children, pregnant and lactating women, adolescents and elderly people (Biebinger *et al.*, 2008 and Brown *et al.*, 2008). The deficiencies may lead to cognitive function impairment, linear growth impairment, behavioural problems, mood changes, memory impairment problems with spatial learning, neuronal trophy (Tripathi *et al.*, 2012 and Gupta *et al.*, 2015) and cancer (Cakmak, 2008 and Lansakara *et al.*, 2016). Deficiencies of Zn can also cause diarrhea, pneumonia and it may leads to infant mortality in pregnant women (Upadhyaya *et al.*, 2011 and Singh *et al.*, 2016).

Deficiency of vit B<sub>2</sub> resulted in purplish tongue, retarded growth, dermatitis, sore throat, cracked lips, itching and burning eyes (Allen *et al.*, 2006; Ottaway, 2008 and Prom-u-thai *et al.*, 2010). Almost 60 - 80% of vit B<sub>2</sub> is removed during cereal grain milling (Tripathi & Platel, 2010). Allen *et al.* (2006), Tripathi & Platel (2010) and Akhtar *et al.* (2011) reported that little researches has been conducted in developing countries about finger millet flour fortified with vit B<sub>2</sub> and ZnO fortificants.

Most of the gluten-free cereal products do not contain adequate micronutrients needed for human health since they are lost during milling or sieving processes (Saleh *et al.*, 2013). Thus, fortification of instant FM flour gives an important attention to the public health strategy for combating vit B<sub>2</sub> and Zn deficiencies (Tripathi & Platel, 2011). Information regarding the fortification of instant finger millet (FM) flour with minerals and vitamins in developing countries is rare (Tripathi & Platel, 2010). Brown *et al.* (2008) and Ottaway (2008) reported that there were

minimal losses of vit B<sub>2</sub> and ZnO on fortified flour during storage, distribution and sales. Most of the research has been conducted on corn and wheat flours but not on finger millet flour. The main advantage of adding fortificants to flour is that it meets the nutritional requirements which also improves the health, productivity and well-being of humans (Serra-Majem *et al.*, 2002 and Gebremariam *et al.*, 2014). Therefore, the objective of this study was to determine the effect of fortification on nutritional compositions of FM flours fortified with vit B<sub>2</sub> and ZnO.

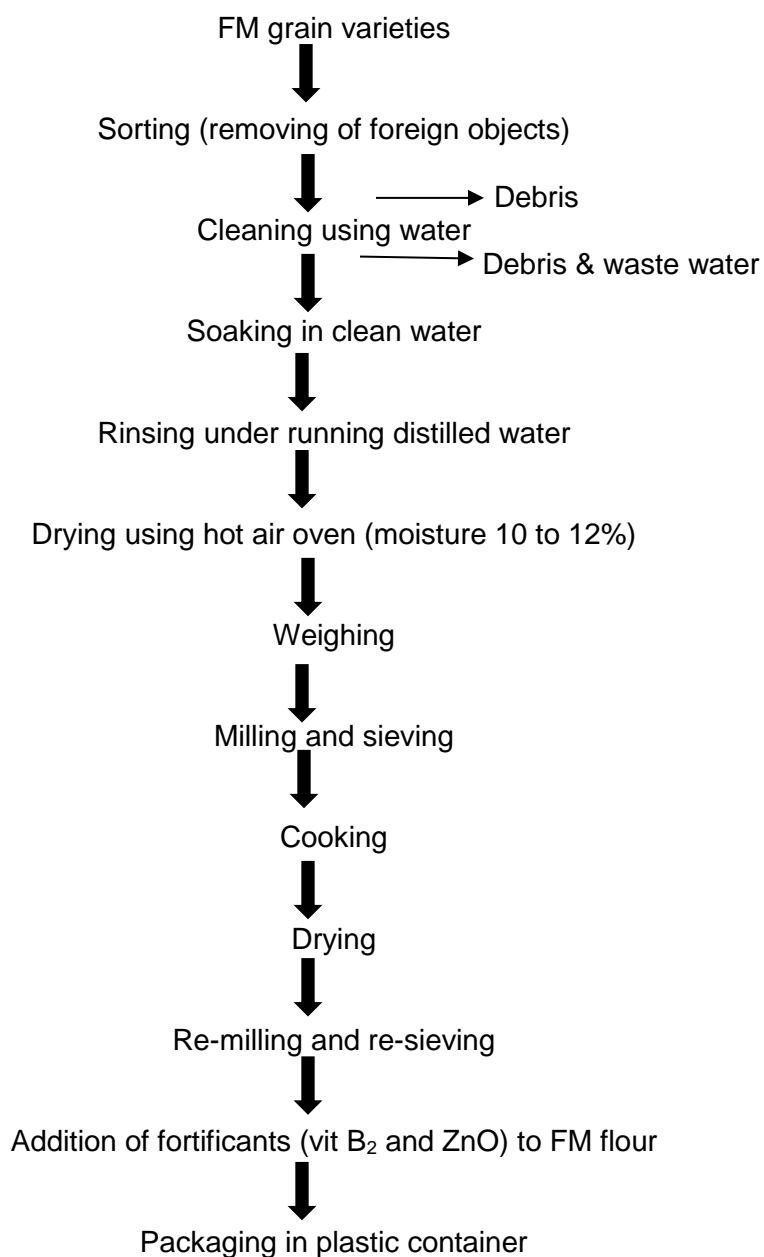
## 4.2. Materials and methods

### 4.2.1. Preparation of finger millet flours

Figure 6 shows the process flow diagram of FM flours fortified with vit B<sub>2</sub> and ZnO. Two hundred and fifty (250) gram of sorted FM grain varieties such as MC (80%), black (85%) and brown (97%) were soaked in cool water for 24 h at 30°C. The soaked grains were dried at 60°C for 24 h using hot air oven to a moisture content of 10 to 12%. The grains were milled into FM flour using a miller (Retsh ZM 200 miller, Germany) at 18 000 rpm for 3 min. The value of 100 g of FM flour was weighed and mixed with 200 ml of boiling water. The mixed flours were then cooked into porridge at 92°C for 25 min in stainless steel pan on an electric stove (Defy Kitchenaise 621, South Africa). After cooking, the porridge was cooled to a controlled temperature ranging from 20 to 25°C at a relative humidity of 35 to 50% depending on the laboratory environmental conditions (FDA, 2018) and later spread into the drying tray covered with aluminium foil.

The spread porridge was dried at 50°C for 8 h and milled into instant flour using miller at 18000 rpm for 3 min and sieved at 100 µm. The flours were packed and sealed in a polythene bag for further analysis (Roopa & Premavalli, 2008 and Saleh *et al.*, 2013). The dried grains were

remilled and resieved to make instant FM flour. Hundred (100) grams of each FM flours were fortified with vit B<sub>2</sub> (3 mg) and ZnO (5 mg), placed and sealed in a polythene bag for further analysis (Roopa & Premavalli, 2008 and Saleh *et al.*, 2013). All the reagents used in this study were purchased from Merck, Midrand, South Africa.



**Figure 6.** Process flow diagram of finger millet flours fortified with vitamin B<sub>2</sub> and zinc oxide (Saleh *et al.*, 2013).

Therefore, the FM flours were carried out in the following treatments:

- Raw finger millet flour (100 g) = RFM flour
- Raw fortified finger millet flour (100 g) + ZnO, 5 mg + vit B<sub>2</sub>, 3 mg = RFFM flour
- Instant finger millet flour (100 g) = IFM flour
- Instant fortified finger millet flour (100 g) + ZnO, 5 mg + vit B<sub>2</sub>, 3 mg = IFFM flour

#### 4.2.2. Determination of proximate compositions of finger millet flours

##### 4.2.2.1. Moisture content of finger millet flours using oven drying method

Moisture content was determined using an air oven. Dry coded, clean crucibles were placed in an oven for about 30 min, cooled and weighed using AACC, 2000: method 44-15.02. The weight of the crucibles was weighed and recorded. Four (4) grams of flours were weighed into the crucibles. The flours were dried at 105°C for 24 h. The result of moisture content (%) was calculated using equation 11.

$$\% \text{ moisture} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (11)$$

Where:  $W_1$  = weight of empty crucible

$W_2$  = weight of crucible + flour before drying

$W_3$  = final weight of crucible + flour after drying

##### 4.2.2.2. Ash content of finger millet flours using muffle furnace

A sample of 4.0 g of flour per treatment was weighed into a clean crucible AACC (2000): method 08-01.01. The crucibles were placed in a muffle furnace and ignited for 24 h at 550°C. The muffle furnace was turned off and left closed until the temperature dropped to at least 250°C

or lower. The door was opened carefully in order to avoid losing ash that may be fluffy. Tongs were used to transfer crucibles from the muffle furnace to desiccators with a porcelain plate and desiccant. The crucibles were placed inside a desiccator and cooled prior to weighing. The ash content was calculated using equation 12.

$$\% \text{ ash} = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \quad (12)$$

Where:  $W_1$  = weight of empty crucible

$W_2$  = weight of crucible + flour

$W_3$  = weight of crucible + ash

#### 4.2.2.3. Determination of crude protein of finger millet flours using Kjeldahl method

Total nitrogen and protein (N x 6.25) content of fortified FM flours were determined by the Kjeldahl using AOAC, 2007: method 985.33. One (1) gram of FM flour was transferred into a digestion tube. Two (2) tablets of selenium catalyst were poured and mixed with FM flour and 25 ml of sulphuric acid (96%) were added into the digestive tube. The tubes were then be heated slowly in the digestion apparatus, until the digest was clear. The digested flours and 100 ml conical flask containing two (2) drops of an indicator were placed under the condenser for distillation.

Ten (10) milliliters of clear supernatant was then transferred into the apparatus and 10 ml of 46% sodium hydroxide was added and then rinsed with distilled water. The colour changed from pink to yellow when the first distillation drops were added and mixed with the boric acid indicator solution. A total of 150 ml of the distillate was collected and titrated with 0.0174N sulphuric acids until the colour changed from yellow to pink. The titer volume was then red. Total nitrogen (N) was determined using equation 13.

$$\%N = \frac{(a \times N \times Mw \times 100)}{(b \times c)} \times 100 \quad (13)$$

Where: a = ml of sulphuric acid used for titration of the flour

N = Normality of sulphuric acid (0.0174)

a = Titer volume (10 ml)

Mw = Molecular weight of N<sub>2</sub> (0.014)

c = ml digest taken for distillation (10 ml)

b = g flour taken for analysis (0.1 g)

% crude protein = 6.35 x %N

#### 4.2.2.4. Crude fibre of finger millet flour using the enzymatic method

The crude fibre of the FM flour was analyzed using AOAC, 2007: method 985.33, where a value of 1.000 g flour was weighed in triplicate into 400 ml beaker. The flour was boiled under reflux for 30 min together with 200 ml solution containing 1.25 g H<sub>2</sub>SO<sub>4</sub> and potassium hydroxide per 100 ml of solution. The solution was filtered through line on a flauted funnel and washed with water. The residue was transferred to a beaker and boiled for 30 min with 100 ml of solution. It was dried in an oven drier at 105°C for 1 h and weighed. The residue was incinerated in a muffle furnace at 540°C for 3 h, cooled in a dessicator for 1 h and later weighed. The crude protein was calculated using equation 14.

$$\text{Crude fibre (\%)} = \frac{W_2 - W_3}{W_1} \times 100 \quad (14)$$

Where: W<sub>1</sub> = weight of flour used.

W<sub>2</sub> = weight of crucible + flour

W<sub>3</sub> = weight of flour + crucible + ash

#### 4.2.3. Determination of biochemical properties

##### 4.2.3.1. Determination of pH of finger millet flours using pH meter

The pH values of FM flours were measured using a Crison digital pH meter (Crison instrument, SA). Before using the pH, it was calibrated at a controlled temperature ranging from 20 to 25°C at a relative humidity of 35 to 50% depending on the laboratory environmental conditions (FDA, 2018) with three (3) different buffers pH meter 4, 7 and 9. The condition of the electrode was checked and cleaned before calibration. Thirty (30) milliliters of each buffer pH 4, 7 and 9 was poured into a clean, dry beaker and then calibrated. The meter was automatically stopped as soon as the reading was stable and then the pH reading was recorded.

The electrode was removed from the beaker and rinsed with distilled water for further use. Ten (10) grams of flour was placed in a beaker containing 100 ml distilled and deionized water and stirred for 15 min to homogenize the flour. The resulting suspension was left to stand for 15 min and the pH level was read in the supernatant liquid. The readings were taken in triplicates using the method of Cornejo-Villegas *et al.* (2010).

##### 4.2.3.2. Mineral content of finger millet flours using ICP-AES

Mineral contents were analysed using the method of Kunyanga *et al.* (2013). Flour digestion: In order to solubilise the acid-extractable element content of the flour, digestion was performed on a MARS microwave digester, using ultra-pure HNO<sub>3</sub> + H<sub>2</sub>O<sub>2</sub> at elevated temperature and pressure. After a cooling period, the extractant was diluted 10x with deionized water, then analysed by inductively coupled argon plasma atomic emission spectroscopy (ICP-AES, Jarrel-Ash). Minerals such as sodium (Na), potassium (K), Mg, Ca, manganese (Mn), Fe, Zn, copper

(Cu) and P were analysed (Kunyanga *et al.*, 2013). The flours were digested with nitric acid, sulphuric acid and perchloric acid. The mineral content were quantified against the standard solutions of known concentration which were analysed concurrently.

#### 4.2.3.3. *Vitamins B complex analysis of finger millet flours by UPLC-PDA detector*

The water soluble vitamins (WSV) were determined by the Southern African Grain Laboratory (SAGL) in-house method 002 (2017) using Ultra-Performance Liquid Chromatography with a Photo Diode Array Detector (UPLC-PDA). The method was suitable for determining vitamin B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub> and B<sub>6</sub> in RFM, RFFM, IFM and IFFM flours. All the vitamins were extracted with 0.1 N HCL (Hydrochloric acid), centrifuged and diluted. The flours were analysed with UPLC-PDA on reverse phase with the simultaneous separation of five (5) WSV. The vitamins were detected with PDA-detector with the following parameter PDA channel 1: 265 nm @ nm and PDA channel 2: 280 nm @ 4.8 nm. Water acuity H-class UPLC with empower 3 software and Acquity UPLC HSS T3 1.8 µm, 2.1 x 100 mm column (Waters, Millipore Corp., Milford, MA) were used. The column was operated at 30°C. The standard used were thiamine mononitrate DSM–South Africa, niacinamide Sigma-Aldrich (N5536), nicotinic acid Sigma ≥ 99.5% (72309), pyridoxine hydrochloric Sigma-Aldrich (P4722) and riboflavin Sigma ≥ 98% (R4500).

#### 4.2.4. Experimental design and data analysis

The generated data were subjected to analysis of variance using SPSS version 23 (SPSS, IBM, Chicago USA) and means were separated using the Duncan multiple range test (Kibar & Kibar, 2017). Significance was accepted at 95% confidence interval ( $p < 0.05$ ).

### 4.3. Results and discussion

#### 4.3.1. Some physical and chemical properties of finger millet flours

The physical and chemical properties of the four (4) flours such as RFM, RFFM, IFM and IFFM on dry weight basis were shown in Table 12. Moisture content of the RFM flour varied from  $7.60 \pm 2.35$  to  $11.67 \pm 1.44\%$  in which MC flour had the highest value,  $11.67 \pm 1.44\%$  and the lowest value was obtained from brown flour,  $7.60 \pm 2.35\%$ .

**Table 12.** Some proximate composition and pH values of finger millet flour treatments.

Cereal flours	Moisture	Ash	Crude fibre	Crude protein	pH values
<b>Raw finger millet</b>					
Milky cream	$11.67^a \pm 1.44$	$3.13^a \pm 0.29$	$1.90^c \pm 0.01$	$9.53^b \pm 0.02$	$6.15^c \pm 0.02$
Brown	$7.60^d \pm 2.35$	$2.77^b \pm 0.35$	$1.94^c \pm 0.00$	$8.06^c \pm 0.02$	$6.26^a \pm 0.02$
Black	$10.83^b \pm 1.44$	$2.27^d \pm 0.92$	$2.16^b \pm 0.51$	$7.91^d \pm 0.02$	$6.22^b \pm 0.01$
Pearl millet	$9.17^c \pm 1.44$	$2.73^c \pm 0.67$	$2.19^a \pm 0.53$	$11.23^a \pm 0.02$	$6.60^a \pm 0.01$
<b>Raw fortified finger millet</b>					
Milky cream	$2.95^b \pm 0.63$	$3.19^c \pm 0.65$	$1.90^d \pm 0.01$	$9.72^b \pm 0.02$	$6.18^b \pm 0.02$
Brown	$2.17^c \pm 1.13$	$2.80^d \pm 1.41$	$2.91^a \pm 0.00$	$6.23^a \pm 0.03$	$6.23^a \pm 0.03$
Black	$2.92^b \pm 1.18$	$4.82^b \pm 1.45$	$2.84^b \pm 0.06$	$9.41^c \pm 0.02$	$6.23^a \pm 0.02$
Pearl millet	$3.00^a \pm 2.14$	$5.17^a \pm 1.35$	$2.19^c \pm 0.53$	$11.06^a \pm 0.02$	$6.14^c \pm 0.01$
<b>Instant finger millet</b>					
Milky cream	$6.25^a \pm 1.25$	$5.83^b \pm 1.44$	$5.83^a \pm 2.89$	$5.83^b \pm 1.44$	$5.98^d \pm 0.02$
Brown	$3.57^b \pm 0.51$	$3.70^a \pm 1.37$	$3.17^b \pm 1.89$	$3.00^d \pm 1.13$	$6.26^c \pm 0.01$
Black	$1.87^d \pm 0.05$	$2.82^d \pm 0.03$	$2.91^c \pm 0.00$	$2.88^b \pm 0.03$	$6.39^b \pm 0.01$
Pearl millet	$9.88^b \pm 0.02$	$3.00^c \pm 0.03$	$2.88^c \pm 0.03$	$11.24^a \pm 0.02$	$6.48^a \pm 0.01$
<b>Instant fortified finger millet</b>					
Milky cream	$7.92^c \pm 0.80$	$3.71^c \pm 0.14$	$2.43^c \pm 0.53$	$9.73^b \pm 0.02$	$5.73^d \pm 0.04$
Brown	$8.63^b \pm 1.59$	$5.55^a \pm 3.47$	$2.91^b \pm 0.44$	$7.82^d \pm 0.03$	$5.98^c \pm 0.03$
Black	$3.75^d \pm 0.75$	$3.96^b \pm 0.60$	$2.93^b \pm 0.03$	$9.52^c \pm 0.03$	$6.08^b \pm 0.03$
Pearl millet	$8.00^a \pm 4.63$	$3.25^d \pm 0.59$	$2.21^d \pm 0.53$	$11.18^a \pm 0.02$	$6.15^a \pm 0.01$

Values are mean  $\pm$  standard deviation,  $n = 3$ . Values followed by the same letters in the same column are not significantly different ( $p < 0.05$ ).

The milky cream RFM flour showed significantly higher value as compared to other RFM flours. The MC had the highest moisture content of  $2.95 \pm 2.35\%$  while the brown flour had the lowest moisture content of  $2.17\% \pm 1.13\%$  on RFFM flours. The RFFM flour had significantly higher value when compared to RFFM flours. The highest moisture content was obtained from the milky cream IFM flour,  $6.25 \pm 1.25\%$  and brown,  $5.83 \pm 1.44\%$  and black,  $5.83 \pm 2.89\%$  for IFM flours both had the lowest values. Moisture content of IFFM ranged from 3.75 to 8.63% in which the highest value was obtained from the brown flour,  $8.63\% \pm 1.59\%$  and the lowest value on black flour  $3.75 \pm 0.75\%$ . Therefore, the MC showed significantly higher moisture content ( $p < 0.05$ ) as compared to brown and black flours. Brown flour showed significantly higher value on IFFM flour compared to the MC and black flours. Therefore, the addition of vit B<sub>2</sub> and ZnO did not show any effect on moisture content in all flours studied (Akhtar *et al.*, 2008).

Obadina *et al.* (2016) reported the moisture content on native PM flour of 12.39% on the dry basis. Similar results of moisture content, 10.46% on traditional instant corn flour were observed by Cornejo-Villegas *et al.* (2010). Siroha *et al.* (2016) reported the moisture content of PM flour from five (5) varieties (HC-10, HHB-67, HHB-223, HHB-226, W-445, GHB-732) which varied from 6.5 to 7.7%. The FM grains were also reported to have moisture content ranging from 7.15 -13.1% (Siwela, 2009; Shobana *et al.*, 2013) while Mirza *et al.* (2014) reported that with moisture content varied from 10.7-12.2% on FM grains. Similar results were obtained by David *et al.* (2014) who reported moisture content of 6.66% for FM flours. Moisture content of 8.83% on unfortified whole wheat (UWW) flour and 11.22% was reported for rice flour by Akhtar *et al.* (2008) and Chandra & Samsher (2013).

The addition of fortificants on instant flours increased the moisture content of fortified flours for MC and brown flour values (Table 12). The lower moisture content is an indication that the flours can be stored for a long period without spoilage and showed a better shelf stability. It is a good indicator of quality of the dry flour which contributes to low residual moisture content in baked products which is important because of the reduction of microbial growth which can be

stored in an appropriate packaging materials under good conditions (Adegunwa *et al.*, 2014). Falade *et al.* (2014) and Kajihaua *et al.* (2014), reported that low moisture content indicates better stability during milling and good storability.

Ash content is a reflection of the minerals contained in a flours (Obadina *et al.*, 2016). The ash content of RFM ranged from  $2.27 \pm 0.92$  to  $3.13 \pm 0.29\%$  where the MC contained the highest value of  $3.13 \pm 0.29\%$  and the lowest value of  $2.27 \pm 0.92\%$ , obtained from the black RFM flour. The MC showed significantly higher value than RFM flours. Black flour contained the highest value of ash content,  $4.82 \pm 1.45\%$  on RFFM while brown flour had the lowest value of  $2.80 \pm 1.41\%$ . The RFFM flour showed significantly higher ash content,  $5.17 \pm 1.35\%$  than RFFM flours. Brown flour of IFM had the highest value of  $3.70 \pm 1.37\%$  and the lowest value were found on the black flour ( $2.82 \pm 0.03\%$ ) and the IPM flour had significantly lower value of  $3.00 \pm 0.03\%$ .

The ash content of IFFM varied from  $3.71 \pm 0.14$  to  $5.55 \pm 3.47\%$ , where the highest value were found on brown flour and the lowest value on MC. The RPM had significantly lower ( $3.25 \pm 0.59\%$ ) values than all the FM flours (MC, brown and black). Ash content of fortified flours increased after adding fortificants as shown in Table 12. The addition of vit B<sub>2</sub> and ZnO on flours significantly increased the ash content of flours (Akhtar *et al.*, 2008). According to Saleh *et al.* (2013), FM grains have an ash content of 2.6% at a moisture content of 12% dry weight basis. For pearl millet flour, Obadina *et al.* (2016) reported an ash content of 1.68% on red amaranth seed. Saleh *et al.* (2013) and Verma & Patel, (2013) observed an ash content of 2.7% on FM grains. Krishnappa *et al.* (2009), Saleh *et al.* (2013) and Shobana *et al.* (2013) reported a mineral content of 2.05 to 3.5% in millets.

Siroha *et al.* (2016) reported an ash content of PM flour from different varieties (HC-10, HHB-67, HHB-223, HHB-226, W-445, GHB-732) that varied from 1.65 to 1.90%. Akhtar *et al.* (2008) and Mirza *et al.* (2014) reported similar results of ash content on UWW flour of 1.62% and FM grains which ranged from 2.3 to 2.7% were reported, respectively. Similar results were obtained by Krishnan *et al.*, 2011 who reported the FM seed coat with similar ash content which

ranged from 4.3 to 5.1%. Ash content indicates the amount of mineral content available in the FM flours (David *et al.*, 2014). That is the reason why the ash content increased after adding vit B<sub>2</sub> and ZnO fortificants.

The crude fibre content of RFM ranged from  $1.90 \pm 0.01$  to  $2.16 \pm 0.51\%$  where the highest value was obtained from black flour and the lowest value was from the MC flour and the PM  $2.19 \pm 0.53\%$  had significantly higher value than all FM flours. The RFFM had the highest value crude fibre on brown flour of  $2.91 \pm 0.00\%$  and the lowest value on MC of  $1.90 \pm 0.01\%$ . The crude fibre content of IFM was highest on MC flour of  $5.83 \pm 1.44\%$  and the lowest value of  $2.91 \pm 0.00\%$  in the black variety. Flour of the black variety had the highest value of  $2.93 \pm 0.03\%$  and the lowest value on MC of  $2.43 \pm 0.53\%$  for IFFM where the IFPM flour,  $2.21 \pm 0.53\%$  had significantly lower value as compared to other FM flours. Crude fibre was not affected by the technological process because the instant FM flours increased after adding the fortificants. FM is a rich source of dietary as compared to other millet species and this makes it a unique millet (Saleh *et al.*, 2013). Akhtar *et al.* (2008) reported that fibre content of wheat flours were not affected by the presence of fortificants. Similar results were obtained by David *et al.* (2014) who reported crude fibre of 3.10 % on FM flours.

Values obtained from this study were similar to those by Siroha *et al.* (2016) who reported the fibre of five (5) PM varieties (HC-10, HHB-67, HHB-223, HHB-226, W-445, GHB-732) ranging from 2.9 to 3.8%. The results of crude fibre showed a significant effect on flours after adding the fortificants because the fortified flours had the highest values as compared to unfortified flours. MC flours showed no significant difference when compared to the raw flour and raw fortified flour, which had the values of 1.90%. Akhtar *et al.* (2008) and Mirza *et al.* (2014) observed crude fibre content of 2.68% on UWW flour. This was an indication of the level of non-digestible carbohydrates and lignin in food. The values obtained are considered appropriate, because they aids in the absorption of glucose, poison, fat and also increase fecal bulk. Crude fibre is important

in the enhancement of digestibility. However, its presence in great quantities can cause intestinal irritation, lower digestibility and decrease nutrient usage (David *et al.*, 2014).

The crude protein of RFM varied from 7.91 to 9.53% where the MC had the highest crude protein while the black flour had the lowest crude fibre content. The RPM ( $11.23 \pm 0.02\%$ ) had significantly higher value than RFM flours. The RFFM had the highest crude protein on MC, 9.72% and lowest crude protein on 6.23%. The RFFM ( $11.06 \pm 0.02\%$ ) showed significantly higher value than RFFM flours. Crude protein of IFM varied from  $2.88 \pm 0.03$  to  $5.83 \pm 1.44\%$ , where the MC had the highest value of  $5.83 \pm 1.44\%$  compared to the brown ( $3.00 \pm 1.13\%$ ) and black ( $2.88 \pm 0.03\%$ ) IFM flours. The IFPM flour had significantly higher value  $11.24 \pm 0.02\%$  than IFFM flours. The IFFM had the highest crude protein value of  $9.73 \pm 0.02\%$  on the MC and the lowest value of  $7.82 \pm 0.03\%$  on brown flour. At  $11.18 \pm 0.02\%$ , the IFPM flour showed significantly higher value of crude protein than IFFM flours as shown on Table 12.

Therefore, RPM RFFM, IPM and IFPM flours that were used for comparison and had significantly higher value as compared to the MC, brown and black FM flours. Therefore, the addition of vit B<sub>2</sub> and ZnO did not show any effect on crude protein content in all treatments (Akhtar *et al.*, 2008) since there was no destruction of amino acids on the FM flours. However, the crude protein content of the brown and black IFM flours decreased likely due to the destruction of amino acids during cooking and redrying of flours (Sade, 2009). Obadina *et al.* (2016) reported the protein levels of 8.38% on PM flour. The FM grains have the protein content of 7.7% at a moisture content of 12% on a dry weight basis (Saleh *et al.*, 2013).

Cornejo-Villegas *et al.* (2010) observed protein levels of 9.49% for traditional instant corn flour and Amare *et al.* (2016) reported protein content of 15.15% on red amaranth seed. Similar results were reported by Siroha *et al.* (2016) on PM flour varieties (HC-10, HHB-67, HHB-223, HHB-226, W-445, GHB-732) whose protein content levels ranged from 9.7 to 11.3%. Akhtar *et al.* (2008) and Mirza *et al.* (2014) observed crude protein levels of 8.83% on UWW flour and FM grains which varied from 7.3 to 10.5%, respectively. The pH values of MC flours decreased from

6.22 to 6.06 for RFM flours with black flour having the highest pH values of 6.22 and the lowest values of 6.06 on brown flour.

Table 12 indicates that the RPM flour had a significantly lower pH value of 6.06. Both brown and black RFFM flours showed significantly higher value of 6.23 than the 6.18 value of the MC. The RFPM flour had significantly lower value of 6.14 than all RFFM flours (MC, brown and black). The IPM and black flours had significantly higher values of 6.48 and 6.39, respectively, compared IFM flours such as the MC which had 5.98 and brown with 6.26. The pH values of IFFM flours varied from 5.73 to 6.15 where the highest pH values were found on black flour with 6.08 and the lowest value on MC flour, 5.73. Pearl millet had significantly higher value of 6.15 than other IFFM flours. Therefore, the IFM flours decreased after adding the fortificants. Results revealed that fortification of FM flour with vit B<sub>2</sub> and ZnO decreased the pH values which contribute to lower microbial analysis and increased the ash content IFFM flours. Falade *et al.* (2014) reported a pH ranged between 6.54 and 6.74 for African rice. Similar findings of pH values of 6.42 were reported on pea flour by Soria-Hernández *et al.* (2015). Cornejo-Villegas *et al.* (2010) reported pH values which ranged from 7.03 to 7.44 on traditional instant corn and commercial instant corn flours. The decreased of pH values indicated the maintenance of quality of FM flour which inhibited the microbial growth and also contributed to flavour of processed fortified FM products (Singh *et al.*, 2012).

#### 4.3.2 Mineral content of finger millet flours

The mineral contents of different flours are presented in Table 13. The highest Ca value of  $385.49 \pm 2.83$  mg/100 g in black RFM flour, and the lowest value of  $118.68 \pm 0.21$  mg/100 g was found on milky cream RFM flour. The RPM showed significantly lower Ca value of  $27.37 \pm 0.13$  mg/ 100 g compared to RFM (MC, brown and black) flours. The results of RFFM flours indicated that Ca ranged from 132.76 to 372.15 mg/100 g.

**Table 13.** Mineral contents of finger millet flour treatments (mg/100 g).

Flours	Ca	Cu	Fe	K	Mg	Mn	Na	P	ZnO
<b>Raw finger millet</b>									
MCFM	118.68 <sup>c</sup> ± 0.21	0.46 <sup>c</sup> ± 0.04	4.02 <sup>d</sup> ± 0.08	279.75 <sup>d</sup> ± 1.41	140.57 <sup>c</sup> ± 0.56	5.23 <sup>c</sup> ± 0.02	1.28 <sup>d</sup> ± 0.05	262.06 <sup>d</sup> ± 0.97	2.64 <sup>b</sup> ± 0.01
BRFM	354.87 <sup>b</sup> ± 0.08	0.60 <sup>a</sup> ± 0.02	4.29 <sup>c</sup> ± 0.05	466.90 <sup>c</sup> ± 0.54	186.67 <sup>a</sup> ± 0.15	18.17 <sup>b</sup> ± 0.05	4.07 <sup>b</sup> ± 0.00	303.39 <sup>b</sup> ± 0.54	2.57 <sup>c</sup> ± 0.01
BLFM	385.49 <sup>a</sup> ± 2.83	0.59 <sup>a</sup> ± 0.01	6.21 <sup>b</sup> ± 0.07	530.84 <sup>a</sup> ± 16.33	183.82 <sup>b</sup> ± 2.15	20.64 <sup>a</sup> ± 0.15	4.78 <sup>a</sup> ± 0.12	293.18 <sup>c</sup> ± 4.92	2.62 <sup>b</sup> ± 0.04
PM	27.37 <sup>d</sup> ± 0.13	0.54 <sup>b</sup> ± 0.03	36.62 <sup>a</sup> ± 0.15	493.64 <sup>b</sup> ± 8.53	122.05 <sup>d</sup> ± 0.94	1.98 <sup>d</sup> ± 0.00	3.44 <sup>c</sup> ± 0.08	310.16 <sup>a</sup> ± 2.40	4.79 <sup>a</sup> ± 0.02
<b>Raw fortified finger millet</b>									
MCFM	132.76 <sup>c</sup> ± 2.70	0.51 <sup>b</sup> ± 0.00	3.94 <sup>c</sup> ± 0.07	300.06 <sup>d</sup> ± 18.30	147.80 <sup>c</sup> ± 5.18	5.85 <sup>c</sup> ± 0.13	1.22 <sup>d</sup> ± 0.09	283.41 <sup>c</sup> ± 5.75	9.44 <sup>c</sup> ± 0.12
BRFM	365.09 <sup>b</sup> ± 2.14	59 <sup>a</sup> ± 0.01	3.92 <sup>c</sup> ± 0.00	463.47 <sup>c</sup> ± 5.60	185.32 <sup>a</sup> ± 0.23	18.20 <sup>b</sup> ± 0.09	3.98 <sup>b</sup> ± 0.05	309.49 <sup>b</sup> ± 1.16	9.72 <sup>b</sup> ± 0.08
BLFM	372.15 <sup>a</sup> ± 0.04	0.56 <sup>a</sup> ± 0.01	6.89 <sup>a</sup> ± 0.08	482.36 <sup>b</sup> ± 2.10	174.93 <sup>b</sup> ± 0.55	18.20 <sup>b</sup> ± 0.09	4.08 <sup>a</sup> ± 0.02	309.49 <sup>b</sup> ± 1.65	9.72 <sup>b</sup> ± 0.03
PM	26.25 <sup>d</sup> ± 1.15	0.54 <sup>a</sup> ± 0.05	30.29 <sup>b</sup> ± 0.08	506.74 <sup>a</sup> ± 0.15	123.41 <sup>d</sup> ± 0.37	1.93 <sup>d</sup> ± 0.01	3.62 <sup>c</sup> ± 0.01	320.46 <sup>a</sup> ± 0.22	10.28 <sup>a</sup> ± 0.02
<b>Instant finger millet</b>									
MCFM	132.16 <sup>c</sup> ± 1.15	0.54 <sup>c</sup> ± 0.05	5.22 <sup>d</sup> ± 0.08	296.16 <sup>d</sup> ± 0.15	150.43 <sup>c</sup> ± 0.37	5.69 <sup>b</sup> ± 0.01	4.98 <sup>d</sup> ± 0.01	296.35 <sup>c</sup> ± 0.22	3.11 <sup>a</sup> ± 0.02
BRFM	379.81 <sup>b</sup> ± 1.66	0.71 <sup>a</sup> ± 0.02	5.29 <sup>c</sup> ± 0.06	493.17 <sup>c</sup> ± 11.16	199.66 <sup>a</sup> ± 1.68	19.11 <sup>a</sup> ± 0.00	12.28 <sup>a</sup> ± 0.26	332.84 <sup>b</sup> ± 1.02	2.89 <sup>b</sup> ± 0.02
BLFM	390.66 <sup>a</sup> ± 2.30	0.65 <sup>b</sup> ± 0.02	7.62 <sup>b</sup> ± 0.00	510.11 <sup>b</sup> ± 13.95	188.66 <sup>b</sup> ± 1.18	20.85 <sup>a</sup> ± 0.02	9.36 <sup>b</sup> ± 0.21	312.99 <sup>c</sup> ± 0.09	2.93 <sup>b</sup> ± 0.01
PM	41.28 <sup>d</sup> ± 0.27	0.66 <sup>b</sup> ± 0.02	46.84 <sup>a</sup> ± 0.67	527.46 <sup>a</sup> ± 2.16	129.93 <sup>d</sup> ± 0.66	2.35 <sup>d</sup> ± 0.01	8.81 <sup>c</sup> ± 0.11	336.05 <sup>a</sup> ± 0.09	5.29 <sup>c</sup> ± 0.00
<b>Instant fortified finger millet</b>									
MCFM	121.97 <sup>c</sup> ± 2.04	0.53 <sup>d</sup> ± 0.01	4.76 <sup>d</sup> ± 0.02	278.97 <sup>d</sup> ± 10.95	141.51 <sup>b</sup> ± 1.04	5.47 <sup>b</sup> ± 0.14	6.04 <sup>b</sup> ± 0.22	288.75 <sup>c</sup> ± 0.67	8.92 <sup>a</sup> ± 0.01
BRFM	339.25 <sup>b</sup> ± 1.53	0.61 <sup>b</sup> ± 0.00	5.02 <sup>c</sup> ± 0.00	432.41 <sup>c</sup> ± 0.92	177.39 <sup>a</sup> ± 0.15	5.39 <sup>c</sup> ± 0.03	6.04 <sup>b</sup> ± 0.22	288.75 <sup>c</sup> ± 0.67	8.92 <sup>a</sup> ± 0.01
BLFM	368.51 <sup>a</sup> ± 4.52	0.64 <sup>a</sup> ± 0.02	8.87 <sup>b</sup> ± 0.04	499.04 <sup>a</sup> ± 6.08	177.19 <sup>a</sup> ± 1.11	19.79 <sup>a</sup> ± 0.05	23.91 <sup>a</sup> ± 0.32	303.44 <sup>b</sup> ± 1.07	8.44 <sup>b</sup> ± 0.05
PM	34.00 <sup>d</sup> ± 0.07	0.57 <sup>c</sup> ± 0.01	41.32 <sup>a</sup> ± 0.17	475.57 <sup>b</sup> ± 10.39	118.93 <sup>c</sup> ± 1.13	2.28 <sup>d</sup> ± 0.01	5.27 <sup>c</sup> ± 0.11	321.79 <sup>a</sup> ± 0.38	8.37 <sup>c</sup> ± 0.02

Values are mean ± standard deviation, n = 3. Values followed by the same letters in the same column are not significantly different ( $p < 0.05$ ). Ca = calcium, Cu = Copper, Fe = Iron, K = potassium, Mg = magnesium, Mn = manganese, Na = Sodium, P = phosphorus and Zn = zinc. MCFM = milky cream finger millet, BRFM = brown finger millet, BLFM = black finger millet and PM = pearl millet.

The highest value of Ca was found in black RFFM flour and the lowest value was on milky cream RFFM flour. Black RFFM flour showed a significantly higher value than MC and brown RFFM flours. However, the RFFM flour had a significantly lower value than all RFFM flours with 26.25 mg/100 g. The calcium content of black IFM flour ranged from  $132.16 \pm 1.15$  to  $390.66 \pm 2.30$  mg/100 g where the RFFM flour had significantly lower value of  $41.28 \pm 0.27$  mg/100 g as compared to MC, brown and black IFM flours as shown on Table 13. Black IFFM flour had the highest Ca content,  $368.51 \pm 4.52$  mg/100 g while the lowest value was found on MC which had  $121.97 \pm 2.04$  mg/100 g. The IFPM flour had a significantly lower value of  $34.00 \pm 0.07$  mg/100 g. The addition of vit B<sub>2</sub> and ZnO decreased the Ca content of both fortified raw and instant fortified flours.

Takhellambam *et al.* (2016) reported similar results on ready-to-eat *ragi* flakes which had 222.67 mg/100 g. Swami *et al.* (2013) reported that FM grains are a rich source of Ca which varied from 300-350 mg/100 g. Devi *et al.* (2011) observed that at 344 mg/100 g, FM has the highest Ca content among all cereals. Saleh *et al.* (2013) and Muthamilarasan *et al.* (2016); Obadina *et al.* (2016) reported that FM grains contained 350 mg/100 g of Ca mg/100 g, 398.0 and 129.91 for native PM mg/ 100 g. Cornejo-Villegas *et al.* (2010) reported the mineral content (g/100 g) of traditional instant corn flour of 3.26 while commercial instant corn flour had the Ca of 0.12 mg/100 g. Amare *et al.* (2016) reported a Ca content of 102 to 215 mg/100 g on three (3) types of amaranth (white, red and brown) grains.

The grains are gluten-free and rich in fibre which helps to reduce incidents of celiac disease in people, and can be utilized as preventive drug entities for osteoporosis due to its exceptionally high Ca content (Mirza *et al.*, 2014). FM contains high value of Ca 162 to 358.0 mg/ 100 g (Chethan & Malleshi, 2007) and is also a good source of diet for growing children, pregnant women and elderly people (Jideani, 2012 and Chappalwar *et al.*, 2013) because it is important for normal growth of body tissue such as strengthening bone and teeth (Subastri *et al.*, 2015).

Thapliyal & Singh (2015), reported that the deficiency of Ca may lead to bone and teeth disorder and this can be addressed by daily consumption of FM foods. Table 13 shows that

the Cu content of RFM ranged from  $0.46 \pm 0.04$  to  $0.60 \pm 0.02$  mg/100 g where both brown and black RFM flours showed a significantly higher ( $p < 0.05$ ) value as compared to milky cream RFM flour. The brown RFM flour contained the highest Cu value of  $0.60 \pm 0.02$  mg/100 g while the lowest value was obtained from MC RFM flour at 0.46 mg/ 100 g. The brown RFFM flour showed a significantly higher value than other FM flours such as MC and black RFFM flours. The highest Cu value of  $0.71 \pm 0.02$  mg/100 g was obtained on brown IFM flour, while the lowest value on MC was  $0.54 \pm 0.05$  mg/100 g. Therefore, the brown flour had significantly higher value than the MC and black IFM flours (Table 13). A significantly higher Cu value of  $0.64 \pm 0.02$  mg/100 g was observed on black IFFM flour, compared to MC with  $0.53 \pm 0.01$  mg/100 g and brown,  $0.61 \pm 0.00$  mg/100 g IFFM flours as shown in Table 13. The addition of vit B<sub>2</sub> and ZnO decreased the Cu content of both and instant fortified flours. Siwela (2009) and Shimelis *et al.* (2009) reported the Cu content of 0.18 - 0.79 mg/100 g on FM grains.

The results of Fe content of 13.89 mg/ 100 g were similar to those obtained Takhellambam *et al.* (2016). The lack of Cu may leads to a decrease in Fe content in some tissues and Cu is associated with the growth and formation of bones (Mergedus *et al.*, 2015). Black RFM flour had the highest Fe value of  $6.21 \pm 0.07$  mg/100 g and the lowest value of  $4.02 \pm 0.08$  mg/100 g was observed on milky cream RFM flour. The RPM flour had significantly higher Fe content of  $36.62 \pm 0.15$  compared to RFM flour as shown in Table 13. Iron content of RFFM flours ranged from 3.92 to 6.98 mg/100 g, where black flour showed a significantly higher value compared to the MC and brown RFFM flours.

On the hand, at 30.29 mg/100 g the RFPM flour had a significantly higher value compared to all RFFM flours (Table 13). At  $7.62 \pm 0.00$  mg/100 g black IFM flour had significantly higher Fe content compared to IFM flours such as MC with  $5.22 \pm 0.08$  mg/100 g and brown with  $5.29 \pm 0.06$  mg/100 g. At  $46.84 \pm 0.67$  mg/100 g the IPM flour had a significantly higher value as compared to IFM flours as indicated in Table 13. The Fe content of black IFFM flour ranged from  $4.76 \pm 0.02$  to  $8.87 \pm 0.04$  mg/100 g. Black IFFM flour had significantly higher value of  $8.87 \pm 0.04$  mg/100 g than IFM flours with the MC at  $4.76 \pm 0.02$  and brown at  $5.02 \pm 0.00$  mg/100 g.

The IFPM flour showed a significantly higher Fe value of  $41.32 \pm 0.17$  mg/100 g than IFFM flours as indicated in Table 13. The addition of vit B<sub>2</sub> and ZnO decreased the Fe content of both raw and instant fortified flours. Saleh *et al.* (2013) and Shobana *et al.* (2013) obtained a Fe content of 3.3 to 14.89 mg/100 g on FM grains and Obadina *et al.* (2016) reported a Fe content of 178.28 mg/100 g on native PM grains. Similar results of Fe content were reported by Sade (2009) and Amare *et al.* (2016) on the PM flour, 8.8 mg/100 g and three (3) types of amaranth grains which ranged from 12.29 - 21.15 mg/ 100 g. The availability of Fe in human body may help to prevent anemia, especially among low socioeconomic groups (Allen *et al.*, 2006 and Serna-Saldivar, 2010) in African countries such as South Africa, Nigeria, Kenya, Tanzania and Ghana.

Potassium content of RFM flours ranged from  $279.75 \pm 1.41$  to  $530.84 \pm 16.33$  mg/100 g, where the black flour showed a significantly higher value compared to the MC and brown RFM flours as presented in Table 13. The K content of RFFM varied from 300.06 to 482.36 mg/100 g, where the black flour had the highest value and the lowest value was found on the milky cream RFFM flour. Black RFFM flour showed a significantly higher value than that of the MC and brown RFFM flours. The RFFM flour had the highest value of K which was 506.74 mg/100 g as shown in Table 13. The highest value of K was obtained from the black IFM flour,  $510.11 \pm 13.95$  mg/100 g while the lowest value of  $296.16 \pm 0.15$  mg/100 g was obtained from the milky cream IFM flour,

The IPM flour showed significantly higher value of K as compared to IFM flours as shown on Table 13. Black IFFM flour had the highest value K of  $499.04 \pm 6.08$  mg/ 100 g while the lowest value of  $278.97 \pm 10.95$  mg/ 100 g was found on milky cream IFFM flour. Significantly higher value was observed on black flour as compared to other IFFM flours. The addition of vit B<sub>2</sub> and ZnO decreased the K content of both raw and instant fortified flours. Obadina *et al.* (2016) reported a K content of 3926.99 mg/100 g in native PM grains and Shobana *et al.* (2013) found a K content of 0.43 - 0.49 mg/100 g in FM grains. Table 13 shows the highest value of Mg on brown RFM flour and the lowest value on the MC flour. The RPM showed a significantly lower value as compared to MC, brown and black RFM flours. Brown

RFFM flour had the highest value of Mg which was 185.32 mg/100 g and the lowest value of 147.80 mg/100 g from MC flour.

Therefore, brown flour showed a significantly higher value on Mg compared to the MC and black flours. The raw fortified pearl millet (RFPM) 123.41 mg/100 g had a significantly lower value as compared to RFFM flours as shown in Table 13. The brown IFM flour had significantly higher Mg value of  $199.66 \pm 1.68$  mg/100 g as compared to IFM flours where MC had  $150.43 \pm 0.37$  mg/100 g and black had  $188.66 \pm 1.18$  mg/100g. The IPM flour showed a significantly lower Mg value of  $129.93 \pm 0.66$  mg/100 g as compared to IFM flours. Magnesium content of IFFM flours which included the brown at  $177.39 \pm 0.15$  mg/100 g and at black,  $177.19 \pm 1.11$  mg/100 g showed significantly higher values than the milky cream IFFM flour which had  $141.51 \pm 1.04$  mg/00 g. The IFPM flour had significantly lower  $118.93 \pm 1.13$  mg/100 g value than IFFM flours as presented in Table 13. The addition of vit B<sub>2</sub> and ZnO increased the Mg content of both raw and instant fortified flours. Shimelis *et al.* (2009) reported an Mg content of 78 - 201.0 mg/ 100 g on FM grains and an Mg content of 1171.77 mg/100 g (Obadina *et al.*, 2016) in native PM. Magnesium content was reported by Amare *et al.* (2016) on three (3) types of amaranth which varied between 292 - 341 mg/100 g.

FM flours are a good source of Mg which has been shown to reduce the severity of asthma and the frequency of migraines, lower high blood pressure and reduce the risk of heart attack. Other benefits of millet are development and repair of body tissue, prevention of gallstones, protection against breast cancer and protection against postmenopausal problems in women, and childhood cancer (Verma & Patel, 2013; Amadou *et al.*, 2013 and Emmanuel *et al.*, 2013).

Black RFM flour contained the highest Mn value of  $20.64 \pm 0.15$  mg/100 g and the lowest value from milky cream RFM flour of  $5.23 \pm 0.02$  mg/100 g. The RPM flour had significantly lower Mn values of  $1.98 \pm 0.00$  mg/100 g compared to RFM flours (Table 13). The results of Mn on RFFM flours on ranged from 18.20 to 5.85 mg/100 g where brown and black flours had significantly higher values than that the MC and brown RFFM flours. The RFPM flour had significantly lower 1.93 mg/100 g value than RFFM flours.

The black IFM flour contained the highest Mn value of  $20.85 \pm 0.02$  mg/100 g while the lowest value was obtained from milky cream IFM flour which had  $5.69 \pm 0.01$  mg/100 g. At  $2.35 \pm 0.01$  the IFPM flour had a significantly lower value Mn than IFM flours as shown in Table 11. The highest value of Mn was found on milky cream IFFM flour at  $5.47 \pm 0.14$  mg/100 g while the lowest was observed on black IFFM flour at  $19.79 \pm 0.05$  mg/100 g as indicated in Table 13. Shimelis *et al.* (2009) and Siwela (2009) reported the manganese content of 17.61-48.43 mg/100 g. The sodium content of RFM flours varied from  $1.28 \pm 0.05$  to  $4.78 \pm 0.12$  mg/100 g where the black RFM flour had a significantly higher value as compared to MC and brown RFM flours.

The black RFFM flour contained the highest Na value of 4.08 mg/100 g while the lowest value was obtained from milky cream RFFM flour at 1.22 mg/100 g (Table 13). The highest Na value of  $12.28 \pm 0.26$  mg/100 g was found in the brown IFM flour while at  $4.98 \pm 0.01$  mg/100 g, MC had the lowest value. Therefore, the brown IFM flour showed significantly higher Na value compared to MC and black IFM flours. At  $6.04 \pm 0.22$  mg/100 g, the sodium contents of the MC and brown IFFM flours increased, with black IFFM flour showing a significantly higher value of Na,  $23.91 \pm 0.32$  mg/100 g compared to other IFFM flours. The IFPM flour had significantly lower Na value of  $5.27 \pm 0.11$  mg/100 g IFFM flours (Table 13). The addition of vit B<sub>2</sub> and ZnO decreased the Mg content of both raw and instant fortified flours. Sade (2009) and Shimelis *et al.* (2009) and Siwela (2009) reported the Na content, 9.2 mg/100 g on PM flour and 17.61 - 48.43 and 49.0 mg/100 g on FM grains.

The phosphorus content of brown RFM flours had the highest value of  $303.39 \pm 0.54$  mg/100 g on P and the lowest value of  $262.06 \pm 0.97$  mg/100 g on MC RFM flour and the brown flour had a significantly higher value compared to the MC and black RFM flours. At  $310.16 \pm 2.40$  mg/100 g, the RPM flour had a significantly higher value than RFM flours (Table 13). The mean value of P ranged from 283.41 to 309.49 mg/100 g where the highest value of 320.46 mg/100 g was found on the RFFM flour. The RFFM flour also showed a significantly higher value compared to other RFFM flours.

The phosphorus content of the brown IFM flour had a significantly higher value of  $332.84 \pm 1.02$  mg/100 g compared to the IFM flours of MC which had  $296.35 \pm 0.22$  mg/100 g and black which had  $312.99 \pm 0.09$  mg/100 g. The IPM flour showed significantly higher value on P compared to IFM flours. Both the MC and brown IFFM flours had the same value of P,  $288.75 \pm 0.67$  mg/100 g. The black IFFM showed significantly higher value of P,  $303.44 \pm 1.07$  mg/100 g, with the IFPM showing a significantly higher value,  $321.79 \pm 0.38$  mg/100 g. The grains are a rich source P which stands 283 mg/100 g (Swami *et al.*, 2013).

Cornejo-Villegas *et al.* (2010) reported a P content of 1.32 mg/100 g on traditional instant corn flour and 0.25 mg/100 g on commercial instant corn flour. Shobana *et al.* (2013) found a P content of 130 to 250.0 mg/100 g in FM grains. Sade (2009) reported the P content of 360 mg/100 g on PM flour. Phosphorus is important for human diet (Cornejo-Villegas *et al.*, 2010). The milky cream RFM flour had the highest ZnO value of 2.64 mg/100 g and had a significantly higher value than the RFM flours of brown which was 2.57 mg/100 g and black which was 2.62 mg/100 g). The RPM showed a significantly higher ( $p < 0.05$ ) value of ZnO than to RFM (4.79 mg/100 g) as shown in Table 13.

Both brown and black RFFM flours had the highest ZnO value of 9.72 mg/100 g and had a significantly higher ( $p < 0.05$ ) value compared to the milky cream RFFM flour which had 9.44 mg/100 g. The RFPM 10.28 mg/100 g showed a significantly higher value as compared to RFFM flours. ZnO content of IFM flours ranged from  $2.89 \pm 0.02$  to  $3.11 \pm 0.02$  mg/100 g. The milky cream flour which had  $3.11 \pm 0.02$  mg/100 g showed a significantly higher value of ZnO compared to the brown which had  $2.89 \pm 0.02$  mg/100 g and the black IFM flours which had  $2.93 \pm 0.01$  mg/100 g.

The IPM had a significantly higher value of  $5.29 \pm 0.00$  mg/100 g as compared to IFFM flours which had  $8.92 \pm 0.01$  mg/100 g. At  $8.44 \pm 0.05$  mg/100 g, the black IFFM flour, showed significantly lower value while the IFPM had significantly lower value of ZnO as compared to IFFM flours. The addition of vit B<sub>2</sub> and ZnO increased the Zn content of fortified flours both raw and instant flours fortified flours. Gibson *et al.*, (2016) reported the daily recommended amounts of Zn ranged from 2 -14 mg/day on different age groups including pregnant and

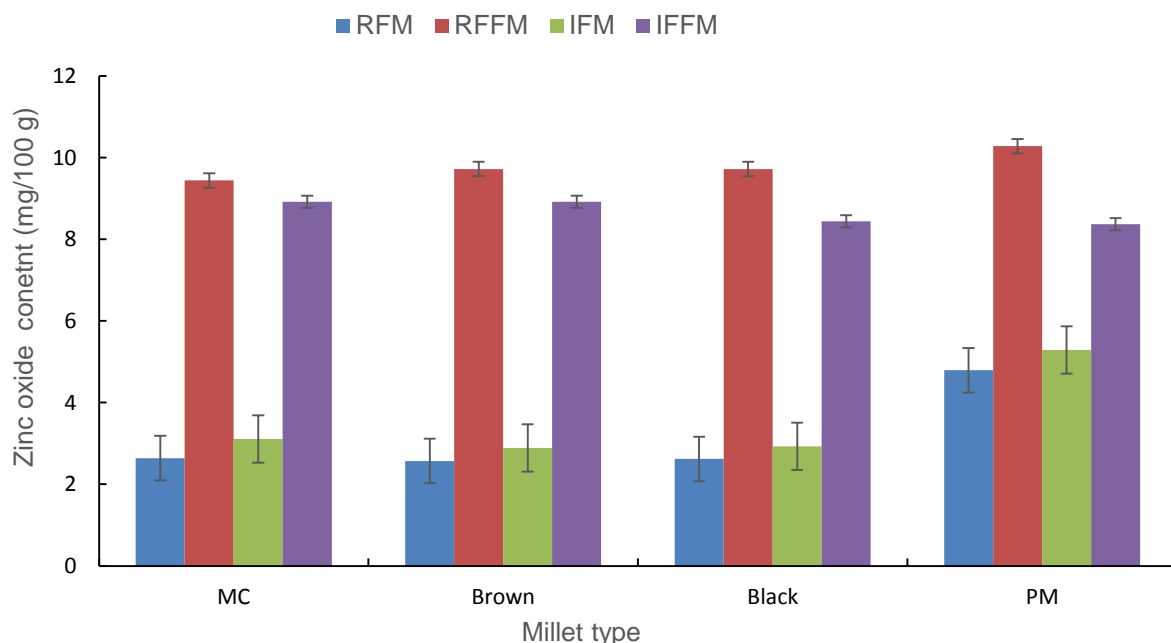
lactating women. The results of ZnO fortificant obtained from this study were within this specified range. The results were similar to those by Amare *et al.* (2016) and Takhellambam *et al.* (2016). They reported the Zn content of 2.57 on RTE flakes which ranged from 2.73 to 3.43 mg/100 g. The Zn content of 0.97 - 2.56 on FM grains has been reported by Dharmaraj & Malleshi (2011) and Singh & Raghuvanshi (2012) and Shobana *et al.* (2013). Tripathi *et al.* (2010) reported the fortification of sorghum and PM with Zn. Ca and Zn content of sorghum and PM flour in mg/100 g where sorghum had the Zn content of 0.66 on roti and 0.65 on dumpling. On the other hand PM had the Zn content of 4.0 on roti and 0.93 on dumpling.

Akhtar *et al.* (2008) conducted a study on whole wheat fortified with ZnO and iron. Moreover, the physico-chemical properties and microbiological stability of WWFF were studied. Tripathi *et al.* (2012) reported the Zn content of roti made FM flour of was 0.28 mg/100 g and dumpling from FM flour was 0.30 mg/100 g. The Zn content of roti produced from unfortified FM flour was 0.73 mg/100 g and dumpling was 0.76 mg/100 g. Zn deficiency is recognized as a global health problem particularly in developing countries. It is a major public problem in developing countries, especially in Africa and India. Although animal foods are rich sources of Zn, food grains can also contribute as a source of Zn because they are rich in Zn. Zn is normally lost during milling process as a result of heat (Hemalatha *et al.*, 2007). Zinc deficiency is a burden disease that lead to a high death rate especially in infants and children.

FM flours fortified with ZnO may help to reduce the child death rate globally by 63% in sub-Saharan Africa (Shrimpton *et al.*, 2005) and 95.4% in South East Asia (Tripathi & Platel, 2010). ZnO deficiencies could lead to cognitive function impairment, linear growth impairment, behavioural problems, mood changes, memory impairment problems with spatial learning and neuronal trophy (Tripathi *et al.*, 2012 and Gupta *et al.*, 2015). New innovative approaches may be implemented to boost fortification of foods with ZnO. However, food prepared in the house-hold applying technological process such as fermentation, soaking and sprouting may increase the availability of zinc in FM flours (Shrimpton *et al.*, 2005).

The Zn deficiency also causes diarrhea, pneumonia and may leads to infant mortality in pregnant women (Brown *et al.*, 2008 and Upadhyaya *et al.*, 2011). Allen *et al.* (2006); Tripathi & Platel (2010) and Akhtar *et al.* (2011) reported that there is little information or experience in developing countries about cereal grains flour fortified with vit B<sub>2</sub> and Zn fortificants. The main issue of Zn deficiency is unlimited consumption of animal foods or fats in the developing countries (Tripathi & Platel, 2010; Akhtar *et al.*, 2011 and Kunyanga *et al.*, 2013). ZnO is the most important fortificant for cereal based foods due to its chemical stability and cost effectiveness (Allen *et al.*, 2006; Prom-u-thai *et al.*, 2010 and Akhtar *et al.*, 2011).

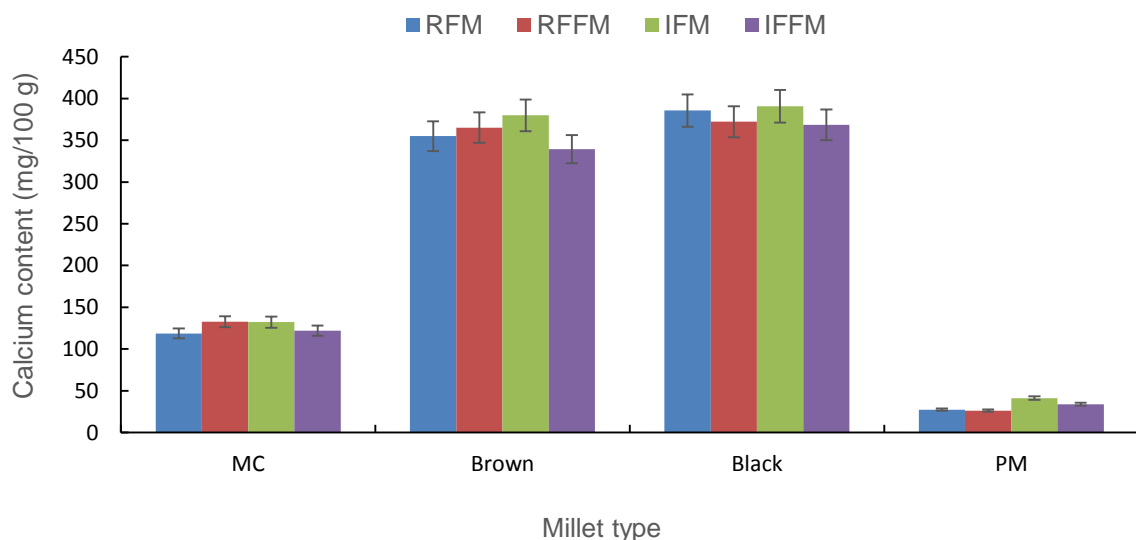
Zn sulfate and Zn gluconate are also used to fortify cereal flour (Akhtar *et al.*, 2011). Organoleptic problems related to Zn fortification of foods have not been reported and do not cause a major problem in food products (Akhtar *et al.*, 2011; Saleh *et al.*, 2013). Figure 7 shows the value of Zn content for each FM flours. They milky cream RFM and IFM flours showed a significant higher ( $p < 0.05$ ) value on Zn content as compared to other flours. Brown and black RFFM flours had the same ZnO content and showed significantly higher values.



**Figure 7.** Zinc oxide content in mg/100 g of finger millet flours. Error bars indicate the standard deviation. MC = milk creamy, PM = pearl millet, RFM = raw finger millet, RFFM = raw fortified finger millet, IFM = instant finger millet and IFFM = instant fortified finger millet.

MC and brown RFFM flours had similar ZnO content and showed a significant higher value. The addition of ZnO increased the concentration of Zn in fortified flours. Addition of ZnO increased the Zn intake on fortified FM flours. There is a need for fortification of FM flours with Zn in order to replace the Zn content which is lost during food processing. The availability of ZnO on FM flours may reduce deficiencies which leads to diseases such as diarrhea and pneumonia which could lead to infant mortality in pregnant women. Figure 8 shows the value of Ca content for each FM flour.

Fortified RFM flours increase the concentration of Ca in MC from 118.68 to 132.76 mg/100 g and brown flours from 354.87 to 365.09 mg/100 g but decreased this concentration in the black flour variety to 385.49 to 372.15 mg/100 g. The addition of ZnO decreased concentration of Ca content in IFFM flours. It ranged from 162 - 358.00 mg/100 g (Dharmaraj & Malleshi, 2011; Upadhyaya *et al.*, 2011 and Saleh *et al.*, 2013). MCFM flour contains low value of Ca (118.68 mg/100 g) as compared to other flours. For example, RFM flours range from 354.87 to 385.49 mg/100 g. Ca content decreased after adding ZnO on IFFM but it did not cause a negative effect on fortified flours.



**Figure 8.** Calcium content in mg/100 g of finger millet flours. Error bars indicates the standard deviation. MC = milky cream, PM = pearl millet, RFM = raw finger millet, RFFM = raw fortified finger millet, IFM = instant finger millet and IFFM = instant fortified finger millet.

#### 4.3.3 Vitamins B complex of finger millet flours

Black RFM flour had the highest value of vit B<sub>1</sub> ( $0.43 \pm 0.01$  mg/100 g) and the lowest values were found in both MC ( $0.27 \pm 0.24$  mg/100 g) and brown RFM flours ( $0.27 \pm 0.24$  mg/100 g) (Table 14). The RFM flour showed significantly higher value of vit B<sub>1</sub> ( $0.60 \pm 0.03$  mg/100 g). The RFFM flours had the highest value of vit B<sub>2</sub> in MC flour of  $114.82 \pm 8.56$  mg/100 g) while the lowest value was obtained in brown flour of  $26.24 \pm 5.84$  mg/100 g.

**Table 14.** Vitamins B complex of finger millet flour treatments.

Cereal flours	Vitamin B <sub>1</sub>	Vitamin B <sub>2</sub>	Vitamin B <sub>3</sub>	Vitamin B <sub>6</sub>
<b>Raw finger millet</b>				
Milky cream	$0.27^c \pm 0.24$	ND	ND	ND
Brown	$0.27^c \pm 0.23$	ND	ND	ND
Black	$0.43^b \pm 0.01$	ND	ND	ND
Pearl millet	$0.60^a \pm 0.03$	$0.27^a \pm 0.03$	ND	ND
<b>Raw fortified finger millet</b>				
Milky cream	ND	$114.82^a \pm 8.56$	ND	ND
Brown	ND	$26.24^c \pm 5.84$	ND	ND
Black	ND	$68.77^b \pm 13.19$	ND	ND
Pearl millet	ND	$27.27^c \pm 0.03$	ND	ND
<b>Instant finger millet</b>				
Milky cream	ND	ND	ND	ND
Brown	ND	ND	ND	ND
Black	ND	ND	ND	ND
Pearl millet	ND	$0.08^a \pm 0.07$	ND	ND
<b>Instant fortified finger millet</b>				
Milky cream	ND	$1.41^b \pm 0.19$	ND	ND
Brown	ND	$1.20^d \pm 0.03$	ND	ND
Black	ND	$0.85^c \pm 0.03$	ND	ND
Pearl millet	ND	$4.50^a \pm 0.03$	ND	ND

Values are mean  $\pm$  standard deviation, n = 3. Values followed by the same letters in the same column are not significantly different ( $p < 0.05$ ). ND = not detected.

Vitamin B<sub>2</sub> of IFFM flours ranged from  $0.85 \pm 0.03$  mg/100 g to  $1.41 \pm 0.19$  mg/100 g where the highest value was obtained from MC flour and the lowest value on black flour. The MC flour showed significantly higher ( $p < 0.05$ ) values of vit B<sub>1</sub> and vit B<sub>2</sub> in both RFFM and IFFM flours when compared to other flours. Vitamin B<sub>2</sub> was also obtained on the RPM and IPM flours which had the following values  $0.27 \pm 0.03$  mg/100 g and  $0.08 \pm 0.07$  mg/100 g, respectively. Kumar *et al.* (2016) reported the vit B<sub>1</sub> in FM and PM flours which were 0.42 and 0.33 mg/100 g.

Vit B<sub>2</sub> was also found in fortified flours such as RPM and IPM and was not obtained on RFM and IFM flours. The daily recommended vit B<sub>2</sub> intake ranged from 0.4 – 1.8 mg/day in all age groups including pregnant and lactating women (Zieliński *et al.*, (2005). The results were similar to those obtained by Kumar *et al.* (2016) who reported that the FM and PM flours had the vit B<sub>2</sub> of 0.19 and 0.25 mg/100 g. Vit B<sub>2</sub> content of buckwheat flour, groats, corn flour, rice flour, rice instant and barley were 0.210, 0.132, 0.067, 0.028, 0.024, mg/100 g, respectively (Lebiedzńska & Szefer, 2006).

Vit B<sub>2</sub> is very sensitive to processing conditions, especially light, heat, oxidizing and reducing agents and other physical and chemical stress. Vit B<sub>2</sub> is stable when added to FM flours and the addition of fortificant may not reduce its shelf-life (Zieliński *et al.*, 2005). The losses according to Kumar *et al.* (2016) reach 66%, may be due to the technological processes involved such as soaking, cooking, drying and milling. Other vitamins such as vit B<sub>3</sub> and B<sub>6</sub> were not found in all FM flours. Kumar *et al.* (2016) also studied the concentration of vit B<sub>3</sub> in FM and PM flours of 1.1 and 2.3 mg/100 g and the concentration of vit B<sub>6</sub> in FM and PM flours was 18.3 and 45.5 mg/100 g.

Vitamins B complex are important micronutrients that helps to maintain the health of the human body. The deficiencies of vit B<sub>2</sub> are serious problem in many developing countries especially in Africa (Akhtar *et al.*, 2011). Vitamins B complex are water-soluble vitamins and can be used to fortify food products such as cereal flours which include FM and wheat flour and baked products such as bread. Lack of vitamins may causes micronutrient deficiencies such as pellagra, beri-beri and hair loss. Other cause of deficiencies are smoking and alcohol

abuse (Serna-Saldivar, 2010). Vitamins B complex are normally lost during processing, especially during drying, milling and storage. These are the reasons that encourage the food industries to add vitamins in food in order to reduce micronutrient deficiencies.

Currently, there is a growing demand for consuming fortified foods such as cereal, flours and bread in the world including Africa. Vitamin B<sub>2</sub> and B<sub>3</sub> are added on maize in United States of America, South Africa, Australia and Nigeria (Tripathi & Platel, 2010). Vitamins B complex have no side effect and have low risk factor after consuming fortified food products (Liberato & Pinheiro-Santa´ana, 2006). There is little information available about fortification of FM flour with vitamin B<sub>2</sub> (Tripathi & Platel, 2010).

#### 4.4. Conclusion

The ash content on MC flours increased after adding the fortificants. This indicated the availability of mineral contents contained in the FM flours. Moisture content decreased after adding the fortificants which shows that the flour may have a long shelf-life during storage. Black RFM, RFFM, IFM and IFFM flours showed significantly higher values of Ca, K, Mn and Na compared to MC and brown flours. Brown RFM, RFFM, IFM and IFFM flours had the highest Cu content. The RPM, RFPM and IPM flours had significantly higher P content among the flours of RFM, RFFM and IFM. ZnO showed significantly higher value on MC flours on all flours tested. The addition of ZnO increased on MC for both RFFM and IFFM flours which showed a positive effect on fortified flours.

Both brown and black RFFM flours had the significantly higher value of ZnO. The PM flour showed significantly higher ( $p < 0.05$ ) value of ZnO compared to other RFFM flours. The MC flour showed significantly higher ( $p < 0.05$ ) values of vit B<sub>2</sub> in both RFFM and IFFM flours, compared to other flours. Vitamin B<sub>1</sub> was also found in all RFM flours. The levels of vit B<sub>2</sub> and ZnO obtained in MC both RFFM and IFFM flours demonstrated that the fortification process of flours resulted in increasing the concentrations. Among three (3) FM flours studied, MC and

brown RFFM and IFFM flours showed that they could be suitable for value-addition. People also prefer the fortified RTE breakfast cereals such as instant porridge and corn flakes that are on current trends especially in urban areas where the majority of the people are suffering from chronic diseases. The grains are underutilized in many developing African countries, then they can be processed into fortified value-added foods and beverages. FM flours fortified with vitamin B<sub>2</sub> and ZnO should be recommended to be added in daily consumed meals in order to reduce micronutrient deficiencies.

## CHAPTER 5 EFFECT OF VITAMIN B<sub>2</sub> AND ZINC OXIDE FORTIFICATION ON THE COLOUR ATTRIBUTES AND FUNCTIONAL PROPERTIES AND COLOUR ATTRIBUTES OF FLOURS OF FINGER MILLET (*ELEUSINE CORACANA*) VARIETIES

### Abstract

The objective of this study was to determine the effect of fortification on functional properties of finger millet (FM) flours using a completely randomized design in three (3) replications. The milky creamy (MC), brown and black varieties were sorted, milled, cooked into porridge, dried, remilled into instant flours and fortified with vit B<sub>2</sub> and ZnO. Functional properties of flours, pasting properties of flours, thermal properties of starches and microscopic structure were analysed. Colour attributes were also measured. Data generated were collected and analysed using SPSS version 23.0. MC from different treatments showed significantly ( $p < 0.05$ ) higher in L\*, b\*, C\*, H°, YI and ΔE values as compared to other flours. Foaming capacity of MC showed significantly higher as compared to other flours. Viscosities of hot raw black and hot raw fortified brown flour was significantly different from other flours. Viscosities of hot instant black and instant fortified black flour were significantly different from other flours. Pasting properties of milky cream raw finger millet (RFM) and raw fortified finger millet (RFFM) flours showed significantly higher in peak viscosity (3518 cP), final viscosity (6554 cP), breakdown viscosity (703 cP) and setback viscosity (3868 cP) as compared to other RFM and RFFM flours. Thermal properties of black RFM and RFFM starches were significantly higher in onset temperature (T<sub>o</sub>), peak temperature (T<sub>P</sub>) and conclusion temperature (T<sub>c</sub>). The milky cream instant finger millet starch showed significantly higher values in T<sub>o</sub>, T<sub>P</sub>, T<sub>c</sub> and enthalpy of gelatinisation (7.63°C) compared to other starches. The results obtained from this study showed that there is a significant variation of functional properties after adding the fortificants which may contribute to physical, chemical and/or organoleptic properties of food produced from fortified flours. Microscopic results revealed that raw flours had oval, smooth surfaces and formed clusters while instant flours had some few holes, dents and rough surfaces.

**Key words:** Finger millet, colour attributes, functional properties, pasting properties, thermal properties, microscopic structure.

## 5.1. Introduction

The functional properties of cereal grains are physico-chemical properties that show the complex interaction among the composition, molecular components, and structure and physico-chemical properties of food components Chandra & Samsher (2013). The functional property of cereal food is defined as physical, chemical and/or organoleptic properties of food. Examples of functional properties of food include colour attributes, viscosity, FC, foaming solubility, WAC, OAC, gelatinisation temperature, BD and SC (Ubwa *et al.*, 2012; Kumari & Raghuvanshi, 2015 and Kaur *et al.*, 2016).

The Rapid Visco Analyser (RVA) is used to measure the pasting properties of flour/starch. RVA consist of the following characteristics: peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BDV), setback viscosity (SV) and peak time (PT) and time The pasting behaviour of flour/ starch is governed by amylose content and degree of amylose leaching (Sharma *et al.*, 2015).

Differential scanning calorimeter (DSC) is used to determine the thermal properties associated with starch gelatinisation. It is the process in which granules absorb a large value of water and swell to shows the internal structure of the granules as it disintegrates, releasing polysaccharide into the surrounding medium and accompanied by a variety of changes. When starch granules are heated in water beyond a critical temperature range, the starch granules undergo an irreversible process marked by crystalline melting and loss of birefringence and starch solubilisation (Kaur *et al.*, 2007 and Kaur *et al.*, 2016).

The Scanning Electron Microscopy (SEM) is used to form a morphological image of the food surface and is conducted in a vacuum environment. It is also used to study the morphological structure of food components that changes during food processing and their

physical effects. Another purpose of using SEM is to understand the relationship between food processing conditions and their structure (Russel *et al.*, 2001). Microscopy and image techniques are very most appropriate in evaluating food structure because they are the only analytical methods that produce results in the form of image rather than numbers (Kalab *et al.*, 1995).

Micrographs of flour plays an essential role in flavour, storage, texture, the nutritional composition and overall quality of processed flours. Commercialisation of food production can affect the microstructure of food processing parameters such as foaming, emulsion, freezing, heating, milling and baking and in a person's mouth prior to chewing and swallowing (Anyasi *et al.*, 2017).

Little information has been reported on the study of functional properties of FM flour. Most studies were conducted on wheat, maize, sorghum and rice (Chandra *et al.*, 2015) and oats (Kumar *et al.*, 2016). The objective of this study was to determine the effect of fortification on functional, thermal and microstructural properties of FM flour fortified with vit B<sub>2</sub> and ZnO.

## 5.2. Materials and methods

5.2.1. Sample preparation refer to Chapter 4 section 4.2.1 page 44.

5.2.2. Colour attributes of finger millet flours

Colour attributes of FM flour were determined using Lovibond LC 100 spectrophotometer and SV 100 test kit (Thilagavathi *et al.*, 2015). They were measured and expressed as positive and negative colour space values, where  $L^*$  indicated lightness of the product from 0 for black to 100 for perfect white. Chromaticity coordinates of  $a^*$  corresponds to  $+a$  = red and  $-a$  = green and  $b^*$  correspond to  $+b$  = yellow and  $-b$  = blue. The  $C^*$  was expressed as either grey or the pure hue and  $H^\circ$  was recorded using different colours such as

yellow, green and blue values. The method of Pathare *et al.* (2013) was used in the determination of whiteness index (WI), yellowness index (YI) and total colour difference ( $\Delta E$ ) were calculated using equations 15 - 17.

$$\text{Whiteness index} = \sqrt{(100 - L^2) + a^2 + b^2} \quad (15)$$

$$\text{Yellowness index} = \frac{142.86b}{L} \quad (16)$$

$$\text{Total colour difference } (\Delta E) = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (17)$$

### 5.2.3. Water absorption capacity of finger millet flours

One (1) gram FM flour was transferred into weighing 50 ml centrifuge tubes in triplicate to which 10 ml of distilled water was added, stirred homogeneously with a glass rod and incubated in waterbath at 30°C for 30 min. The centrifuge tubes were centrifuged as expressed x g at 3000 rpm for 15 min using a Model T-8BL Laby™ centrifuge (Laboratory Instruments, Ambala Cantt India). The supernatants were discarded and the residues were weighed using equation 18. Two (2) different heights of the centrifuge tubes gave water absorbance using the method of Sawant *et al.* (2013).

$$\text{Water absorption capacity (\%)} = \frac{V_1 - V_2}{V_2} \times 100 \quad (18)$$

Where: V1 = initial volume

V2 = final volume

### 5.2.4. Oil absorption capacity of finger millet flours

OAC of the FM flour was determined using the method of Jagannadham *et al.* (2014). One (1) gram of the flour was mixed with 10 ml of vegetable oil (commercial) in preweighed centrifuge tubes. The contents were stirred for 1 min with a glass rod to disperse the flour in

oil and incubated in a water-bath at 30°C for 30 min in triplicate centrifuge tubes. The flour was centrifuged for 25 min expressed as x g at 3000 rpm using a Model T-8BL Laby™ centrifuge (Laboratory Instruments, Ambala Cantt, India). The separated oil layer was then be removed with a pipette and the tubes were inverted for 25 min to drain any remaining oil prior to reweighing. The OAC was expressed as gram of oil bound per gram of the flour on a dry weight basis using equation 19 (Shrestha & Srivastava, 2017)

$$\text{OAC} = \frac{\text{Volume of oil absorbed (ml)}}{\text{Weight of sample (g)}} \quad (19)$$

#### 5.2.5. Bulk density of finger millet flours

BD was determined by measuring 10 ml capacity graduated cylinder, weighed and recorded. The cylinder was filled with the flour and tapped gently from the bottom 30 times until there was no further dimension of the flour level and calculated through the methods of Jagannadham *et al.* (2014) and Mandge *et al.* (2014) using equation 20.

$$\text{Bulk density (g/ml)} = \frac{\text{Weight of FM flour}}{\text{Volume of FM flour after tapping}} \quad (20)$$

#### 5.2.6. Swelling capacity and swelling index of finger millet flours

One (1) gram of the flour was weighed into a centrifuge tube and the weight of the tube plus the flour were recorded. Ten (10) ml of the distilled water was added and stirred with a glass rod for about a minute. The contents were centrifuged expressed as x g at 3 000 rpm for 25 min. The suspension was left to stand for 30 minutes at a controlled temperature ranging from 20 to 25°C at a relative humidity of 35 to 50% depending on the laboratory environmental conditions (FDA, 2018). The free water was decanted after which the new weights were recorded. The supernatant was transferred into a preweighed petri plate and evaporated to

dryness on a water bath to circulate the solubility index. The weights and volume of the wet residue in the centrifuge tube were noted to determine the SI. The SI was also calculated using equation 21 by (Dharmaraj *et al.*, 2015).

$$\text{Swelling capacity (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \quad (21)$$

Where:  $W_1$  = weight of FM flour after decanting water

$W_2$  = weight of FM flour before water was added

Swelling index was calculated using equation 22 as follows:

$$\text{Swelling index (g/g)} = \frac{\text{Weight of flour paste}}{\text{Weight of dry flour}} \quad (22)$$

#### 5.2.7. Determination of dispersibility of finger millet flours

Ten (10) grams of the flours were weighed into 100 ml measuring cylinder, water was added to each volume of 100 ml. The set up was stirred vigorously and allowed to stand for 3 h (Jagannadham *et al.*, 2014). The difference was calculated as the percentage dispersibility using equation 23.

$$\% \text{ Dispersibility} = 100 - \text{volume of settled particles} \quad (23)$$

#### 5.2.8. Foaming capacity and foaming solubility of finger millet flours

Two (2) ml of flours were transferred into a 50 ml distilled water in a graduated cylinder and mixed thoroughly using a glass rod. The foam volume in the cylinder was recorded. The volume was recorded after whipping and measured as % of volume increase due to whipping (Kamara *et al.*, 2009). The FC was calculated using equation 24 as follows:

$$\text{Foaming capacity (\%)} = \frac{W2-W1}{W1} \times 100 \quad (24)$$

Where: W1 = volume of foam before FM flour whipping

W2 = volume of foam after FM flour whipping

#### 5.2.9. Viscosity of finger millet flours

Ten (10) grams of flours were mixed with 90 ml of distilled water at 30°C and allowed to hydrate for 30 min with occasional stirring. The viscosity of the slurry was measured in Brookfield viscometer (Model RV, Brookfield Engineering, Inc., USA) using spindle number Q3 rotating expressed as x g at 100 rpm and the cool paste viscosity was measured in centipoise (cP). Subsequently, the slurry was heated to boiling in a water bath at 95 ± 1°C for 20 min, cooled to 30°C and hot paste viscosity was measured in cP (Krishnan *et al.*, 2011 and Ramashia *et al.*, 2018).

#### 5.2.10. Pasting properties of finger millet flours using Rapid Visco-Analyzer

The viscosity on FM flour was determined through a Rapid Visco-Analyzer (RVA-4, Australia) with a thermocline version 3.0. The paste consistency profile for each flour was measured in which, 2.5 g dry flour (adjusted to 14% moisture content) and distilled water was added to keep the total weight of water and flour constant at 25 ± 0.01 g. Each flour was held at 50°C for 1 min while heating at 50 to 90°C and was held to a constant temperature of 95°C for 2.50 min.

The flour was then cooled down at 50°C for 2 min. RVA indicates starch viscosity by measuring the resistance of flour slurry to the stirring action paddle. The RVA plot of viscosity (cP) versus time (s) values were used to determine PV, BDV), FV and SV (Yadar *et al.*, 2014).

#### 5.2.11. Starch isolation from finger millet flours

Starch was isolated from FM flours by following the method of Sandhu & Singh (2007). About 20 g/100 g of flours were added to 1.25 L of distilled water contained sodium meta-bisulphite (0.1 g/100 g). The starch – protein slurry was the allowed to stand for 4-5 h. The supernatant was removed by suction and the settled starch layer was re-suspended in distilled water and centrifuged expressed as x g at 1 000 rpm/10 min in a centrifuge. The white layer was re-suspended in distilled water and re-centrifuged 3-4 times. The starch was then collected and dried in a hot air oven at 45°C for 12 h.

#### 5.2.12. Thermal properties of finger millet starches using differential scanning calorimetry

The gelatinisation temperature of FM flour was determined using a Differential Scanning Calorimetry (DSC). Indium was used to calibrate the instrument. Four (4) milligrams of dry starches were weighed into aluminum pans and distilled water was added using a micro-syringe in order to obtain the starch-water suspension. The FM starch was hermetically sealed and allowed to stand for 1 h at a controlled temperature ranging from 20 to 25°C at a relative humidity of 35 to 50% depending on the laboratory environmental conditions (FDA, 2018) before heating. The pan was heated from 20 to 125°C at the rate of 10°C/min. An empty pan was used as a control.

Thermal analyses (onset, end set, peak temperature and enthalpy of gelatinisation) were carried out using the software provided with the equipment. Onset temperature ( $T_o$ ), peak temperature, ( $T_p$ ), conclusion temperature ( $T_c$ ) and enthalpy of gelatinisation ( $\Delta H_{gel}$ ) were calculated automatically (Kaur *et al.*, 2007 and Dharmaraj *et al.*, 2015).

### 5.2.13. Microscopic structure of finger millet flours using SEM

#### 5.2.13.1. Microscopic structure using Joel instrument

The microscopic structure of finger millet flour was conducted using a SEM Joel (JSM IT 300, Japan). A dried FM flour was separately mounted on the holder with double sided carbon tape and coated with a thin layer of gold in Quorum Q150RES Tescom coating system. The flours were observed under SEM and accelerated at 20 kV with a spot size ranged between 10.6 to 10.8 mm and the diameter of the starch particle pore size of 20  $\mu\text{m}$  at the magnification of x950 (Sun *et al.*, 2014).

#### 5.2.13.2. Microscopic structure using Energy Dispersive X-ray detector

Microscopic structure of FM flour was mounted on a sample holder using double-sided scotch tape and was coated with a thin layer of gold in a sputter coating instrument. All examinations were observed at an accelerated voltage of 5.000 kV using a scanning electron microscope coupled with electron probe microanalysis Energy Dispersive X-ray detector (Mervlin/ Evo Germany) (Anyasi *et al.*, 2017).

### 5.2.14. Experimental design and data analysis

The generated data were subjected to analysis of variance using SPSS version 23 (SPSS, IBM, Chicago USA) and means were separated using the Duncan multiple range test (Kibar & Kibar, 2017). Significance was accepted at 95% confidence interval ( $p < 0.05$ ).

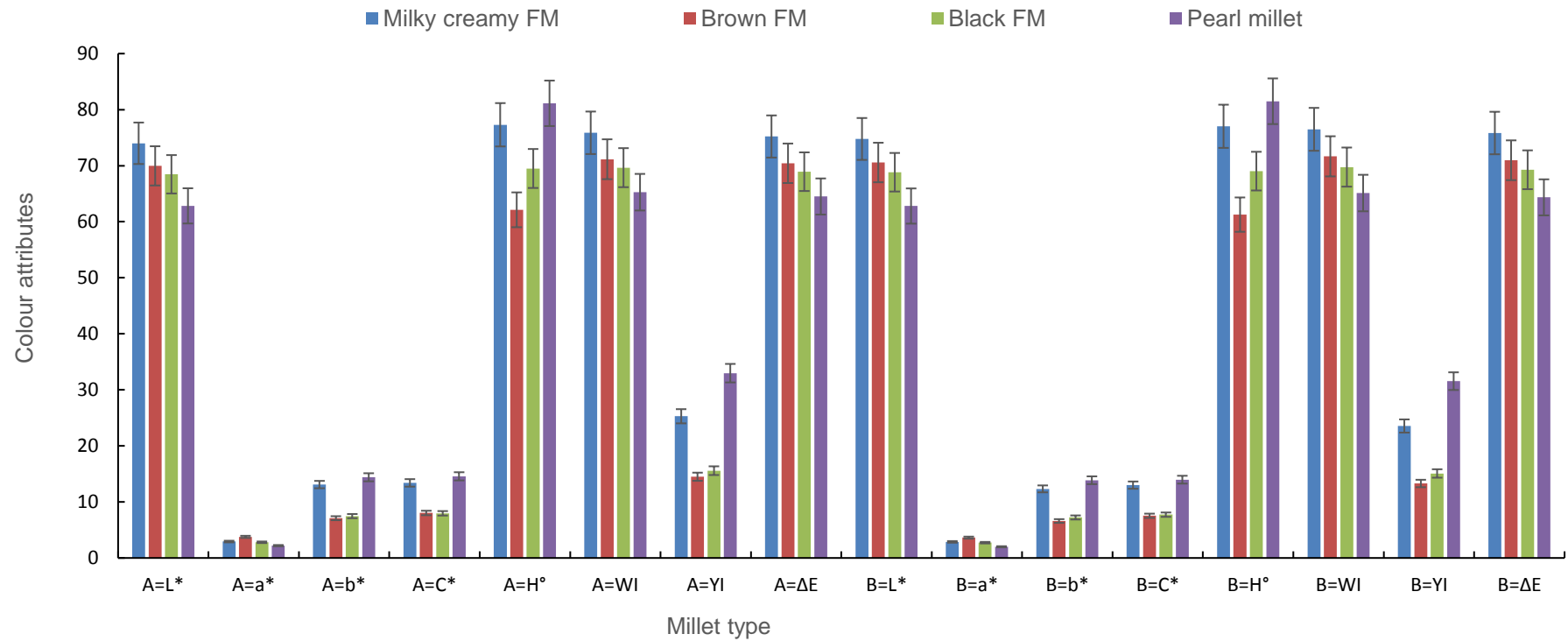
### 5.3. Results and discussion

#### 5.3.1. Colour attributes of finger millet flours

Figure 9 indicates the results of colour attributes of FM flours as recorded in terms of  $L^*$ ,  $a^*$ ,  $b^*$ ,  $C^*$ ,  $H^\circ$ ,  $WI$ ,  $YI$  and  $\Delta E$ .  $L^*$  values of RFM and RFFM varied between  $68.47 \pm 0.85$  to  $74.00 \pm 0.62$  and  $68.83 \pm 0.83$  to  $74.77 \pm 1.46$ , respectively. The milky cream RFM and RFFM flours showed significant higher  $L^*$  values as compared to brown and black flours, where the RPM flour had significantly lower values when compared to RFM and RFFM flours. The addition of fortificants onto RFM increased the  $L^*$  values. Figure 10 showed that the  $L^*$  values of IFM and IFFM flours ranged from  $51.8 \pm 0.10$  to  $67.2 \pm 0.35$  and  $50.10 \pm 0.17$  to  $67.13 \pm 0.59$ , respectively where MC flours also showed significantly higher ( $p < 0.05$ ) values.

The addition of fortificants to instant flours decreased the  $L^*$  values. The reason may be that IFM flours had undergone several processes such as re-cooking, re-drying, re-milling and re-sieving compared to RFM flours. These results are similar to those by Dharmaraj *et al.* (2015) which varied from 67.11, 57.9 and 76.3 for native, hydrothermally treated and decorticated FM whole meals. Bhol & Bosco (2014) also reported the  $L^*$  value of 59.88 for 20 g wheat/ 100 g Malted FM. The findings of this study were also in agreement with the results reported by Siroha *et al.* (2016) who studied five (5) pearl millet varieties and reported that their  $L^*$  values ranged from 75.1 to 78.4.

Positives values obtained for coordinates  $a^*$  ranged from  $2.8 \pm 0.10$  to  $3.77 \pm 0.06$  and  $2.73 \pm 0.06$  to  $3.63 \pm 0.25$  for RFM and RFFM flours, respectively. The  $a^*$  values indicated that all the flours had different concentration of red pigmentation.



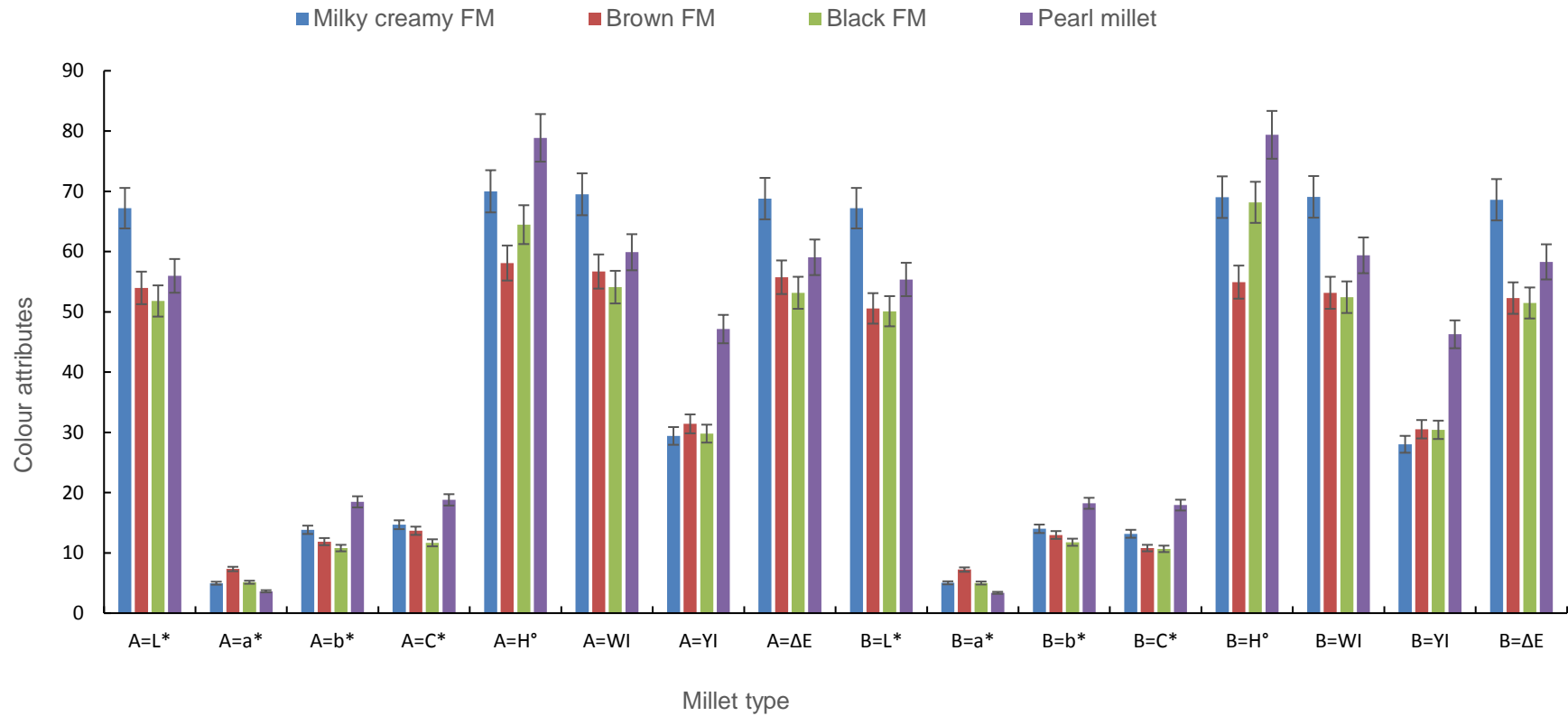
**Figure 9.** Colour attributes raw finger millet and raw fortified finger millet flours. Error bars indicate standard deviation. RFM (A) and RFFM (B) (milky creamy, brown, black) and pearl millet flours. L\* = yellowness/ blueness, a\* = redness/ greenness, C\* = chroma, H° = hue angle, WI = whiteness index, YI = yellowness index, ΔE = total colour different.

Brown flours showed significantly higher ( $p < 0.05$ )  $a^*$  values compared to MC and black flours with the highest recorded values of  $3.77 \pm 0.06$  and  $3.63 \pm 0.25$ , respectively. The RPM had significantly lower  $a^*$  values of  $2.20 \pm 0.17$  and  $2.00 \pm 0.00$ , respectively (Figure 9). The  $a^*$  values of IFM and IFFM flours varied from  $4.97 \pm 0.12$  to  $7.33 \pm 0.06$  and  $5.00 \pm 0.10$  to  $7.23 \pm 0.12$ , respectively, where brown flours showed significantly higher  $a^*$  values as compared to other flours (Figure 10). Therefore, the IPM and IFPM had significantly lower  $a^*$  values of  $3.63 \pm 0.12$  and  $3.37 \pm 0.06$ , respectively.

The  $a^*$  values for all flours decreased after adding the fortificants. The findings of this study was in agreement with the results reported by Siroha *et al.*, 2016 who studied five (5) pearl millet varieties and their values ranged from 0.32 to 1.64. On the other hand, Dharmaraj *et al.* (2015) obtained the following results 3.1, 3.1 and 1.2 from native, hydrothermally treated and decorticated FM whole meals. The  $a^*$  values for 20 g wheat/ 100 g Malted FM  $a^*$  value was 5.60 reported by Bhol & Bosco (2014).

The  $b^*$  value indicates the concentration of yellow colour on the flours. The results from RFM and RFFM flours ranged from  $7.1 \pm 0.20$  to  $13.1 \pm 0.20$  and  $6.60 \pm 0.10$  to  $12.33 \pm 0.40$ , respectively. The MC showed significantly higher  $b^*$  value of  $13.1 \pm 0.20$  and  $12.33 \pm 0.40$ , respectively as compared to brown and black flours (Figure 9). The RPM and RFPM flours had significantly higher  $b^*$  values of  $14.4 \pm 0.26$  and  $14.4 \pm 0.26$ , respectively, when compared to FM flours. The IFM and IFFM milky cream flours showed significantly higher  $b^*$  values of  $13.85 \pm 0.31$  and  $13.17 \pm 0.32$ , respectively, when compared to other FM flours (Figure 10).

The IPM and IFPM flours showed significantly higher  $b^*$  values of  $18.47 \pm 0.25$  and  $17.93 \pm 0.25$ , respectively. The addition of fortificants decreased the  $b^*$  values. Similar results of  $b^*$  values of 8.5, 8.7 and 10.8 were obtained by Dharmaraj *et al.* (2015) the native, hydrothermally treated and decorticated FM whole meals. Bhol & Bosco (2014) obtained  $b^*$  value of 13.35 from 20 g wheat/100 g malted FM. The findings of this study were in agreement with the results reported by Siroha *et al.* (2016) who studied five (5) pearl millet varieties whose values varied from 9.9 to 13.5.



**Figure 10.** Colour attributes instant finger millet and instant fortified finger millet flours. Error bars indicate standard deviation. IFM (A) and IFFM (B) (milky creamy, brown, black) and pearl millet flours. L\* = yellowness/ blueness, a\* = redness/ greenness, C\* = chroma, H° = hue angle, WI = whiteness index, YI = yellowness index, ΔE = total colour different.

The chroma values for RFM flours ranged from  $7.97 \pm 0.23$  to  $13.4 \pm 0.20$  while RFFM flours varied from  $7.53 \pm 0.06$  to  $13.00 \pm 0.38$ . The RPM and RFPM flours showed significantly higher  $C^*$  values of  $14.57 \pm 0.25$  and  $13.97 \pm 0.31$ , respectively (Figure 9). The Milky cream IFM and IFFM flours showed significantly higher  $C^*$  values of  $14.67 \pm 0.25$  and  $14.00 \pm 0.42$ , respectively, compared to other FM flours (Figure 10). The IPM and IFPM flours showed the significantly higher  $C^*$  values of  $18.80 \pm 0.30$  and  $8.23 \pm 0.25$ , respectively when compared to all FM flours. Chroma increased with increasing colour concentration and became darker when the  $C^*$  decreased. The intensity of  $C^*$  was higher in the MC flours. Pathare *et al.* (2013) reported that colour is an important quality factors in the food processing industry and it attracts the consumer's choice and preferences.

The  $H^0$  values ranged from  $62.13 \pm 0.98$  to  $77.3 \pm 0.36$  for RFM, while RFFM flours varied from  $61.27 \pm 1.97$  to  $77.03 \pm 1.39$ . The MC flours had significantly higher  $H^0$  values compared to other FM flours. The RPM and RFPM flours showed significantly higher  $H^0$  values for both RFM and RFFM flours of  $81.13 \pm 0.98$  and  $81.50 \pm 0.20$ , respectively (Figure 9). The milky cream IFM and IFFM flours had the highest  $H^0$  values of  $70.27 \pm 0.12$  and  $69.03 \pm 0.92$  (Figure 10).

The lowest  $H^0$  values of  $58.10 \pm 0.17$  and  $54.93 \pm 2.40$  on brown IFM flours, respectively. However, the IPM flour showed significantly higher  $H^0$  values of  $78.87 \pm 0.12$  and  $79.37 \pm 0.15$ , respectively, compared to all FM flours. Bhol & Bosco (2014) reported similar results of  $C^*$  and  $H^0$  values of 67.24 and 14.48, respectively, for 20 g wheat/100 g malted FM. The positive values in the  $H^0$  of the flours showed that the product does not deviate from the colour adding a positive factor to the current study because lightness and yellowness in the colour of flour are important factors so far as consumer acceptance is concerned.

The milky cream RFM flour had the highest value of  $75.87 \pm 0.64$  and the lowest value was obtained from the RPM flour,  $65.27 \pm 1.05$  on WI. The highest WI was obtained from milky cream RFFM flour,  $76.49 \pm 1.48$  and the lowest value was obtained from the RFPM  $65.12 \pm 0.71$ . The milky cream IFM and IFFM flours had the highest value of 69.51 and 76.49. The lowest value was obtained from black IFM and IFFM flours,  $54.10 \pm 0.08$  and  $52.43 \pm 0.15$ ,

respectively. Therefore, the MC showed significantly higher ( $p < 0.05$ ) values on WI for flour treatments measured (Figure 9).

The yellowness index was highest in the RPM flour at  $32.98 \pm 1.27$  which showed a significantly higher value as compared to milky cream, brown and black RFM flours. However, the milky cream RFM flour had the highest value of  $25.29 \pm 0.19$  and the lowest value was obtained from brown black RFM flour at  $14.50 \pm 0.20$ . The RFFPM showed significantly higher value of  $31.55 \pm 1.06$  as compared to RFFM flours. Black IFM had the highest value of  $29.79 \pm 0.31$  as compared to other IFM flours. Brown IFFM flour showed significantly higher value of  $30.52 \pm 0.63$  as compared to MC and brown IFFM flours. The IPM and IFPM flours showed significantly higher values of  $47.14 \pm 0.46$  and  $46.27 \pm 0.81$ , respectively on YI (Figure 9).

Total colour difference ( $\Delta E$ ) of RFM and RFFM flours ranged between  $68.93 \pm 0.84$  to  $70.43 \pm 1.28$  and  $69.27 \pm 0.83$  to  $75.83 \pm 1.50$ , respectively. The MC had significantly higher ( $p < 0.05$ )  $\Delta E$  compared to brown and black flours (Figure 9). Instant finger millet varied from  $53.16 \pm 0.90$  to  $68.79 \pm 0.40$ . The highest value  $\Delta E$  was found in the milky cream IFM flour ( $68.79 \pm 0.40$ ) and the lowest value was obtained from the black IFM flour ( $53.74 \pm 0.09$ ). The milky cream IFFM flour had the highest amount of  $\Delta E$  ( $68.60 \pm 0.49$ ) and the lowest value was found on the black IFFM ( $51.47 \pm 0.14$ ) (Table 10). The MC flour for both FM flours showed significantly higher ( $p < 0.05$ )  $\Delta E$  compared to brown and black flours.

The addition of fortificants decreased the  $\Delta E$  of wheat. The findings of this study were in agreement with the results of Siroha *et al.* (2016) who studied five (5) pearl millet varieties and their  $\Delta E$  values ranged from 52.5 to 75.1. Similar results were also obtained by Krishnan *et al.* (2011) who reported FM seed  $\Delta E$  ranging from 41.4 to 57.5. The addition of fortificants on instant flours decreased the colour attributes. The reason may be that IFM flours had been exposed to several technological processes such as re-cooking, re-drying, re-milling and re-sieving compared to RFM flours.

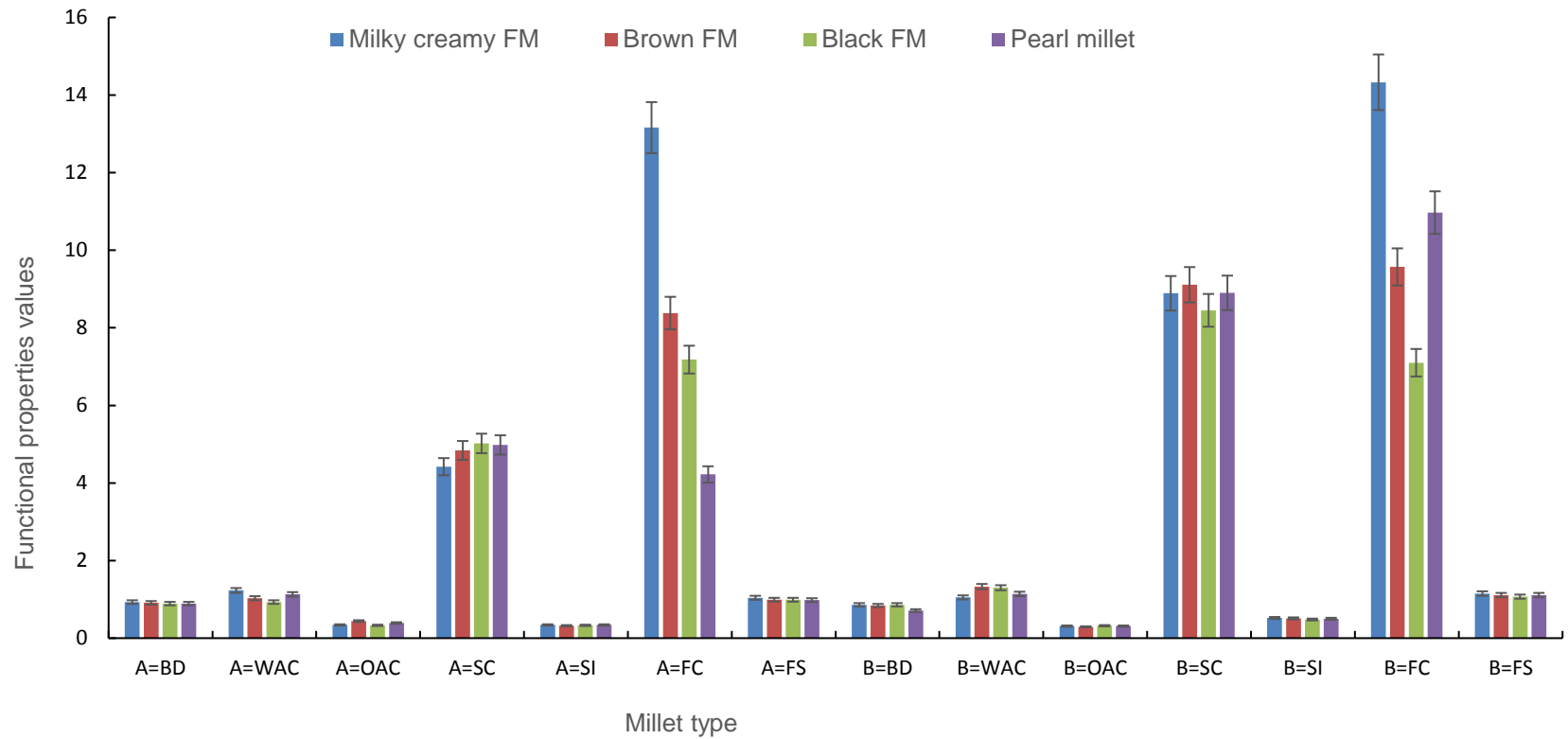
### 5.3.2. Functional properties of finger millet flours

Bulk density (BD) was found to be highest on milky cream RFM flour ( $0.93 \pm 0.02$  g/ml) and lowest density on the black RFM flour ( $0.89 \pm 0.01$  g/mL). The milky cream RFM flour had significantly higher BD value compared to brown and black RFM flours. The BD ranged from  $0.84 \pm 0.02$  to  $0.86 \pm 0.01$  g/mL. Both the MC and black RFFM flours showed a significantly higher ( $p < 0.05$ ) value of BD as compared to the brown RFFM flour. The RFFM flour had a significantly lower value of BD ( $0.71 \pm 0.01$  g/mL) (Figure 11).

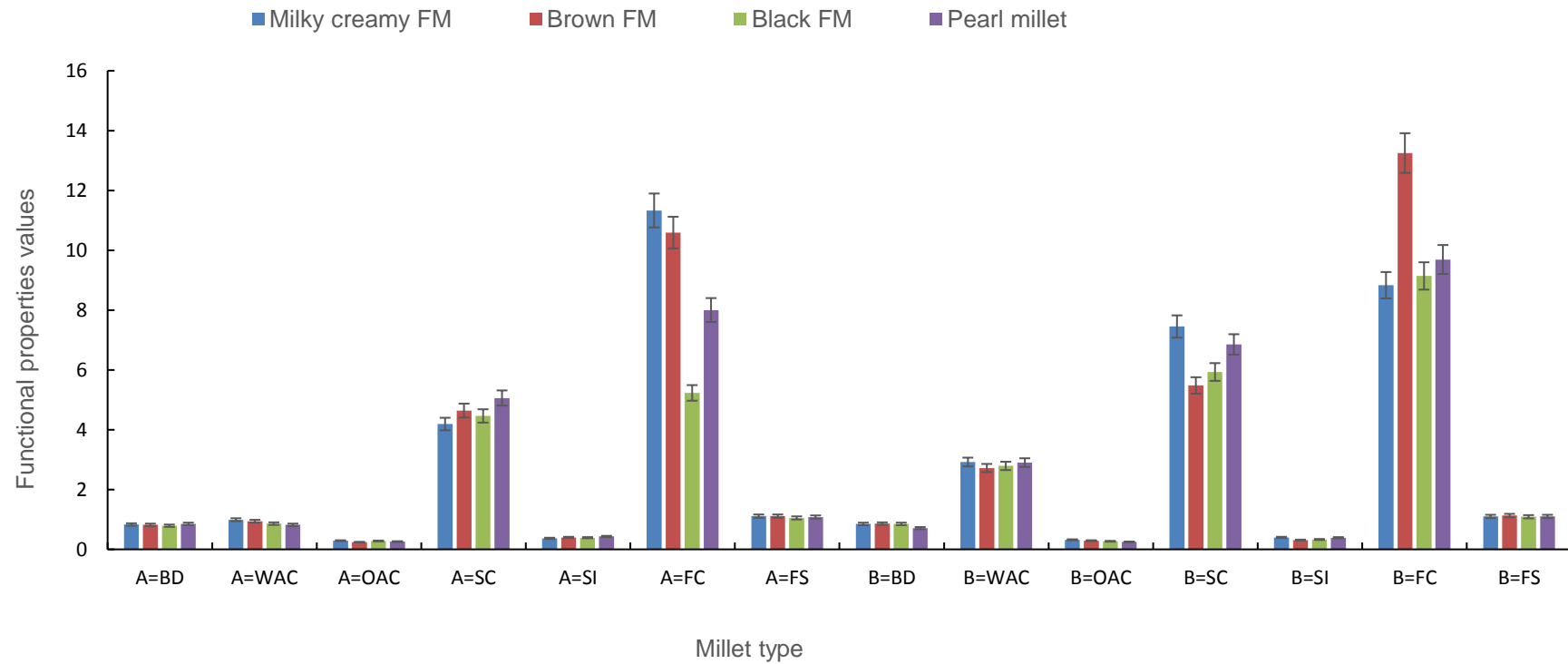
The BD of instant finger millet flour are shown in Figure 12 with the MC showing the highest value of  $0.83 \pm 0.02$  g/mL whereas the black flour had the lowest values of  $0.79 \pm 0.02$  g/mL. The IPM flour showed significantly higher value of BD ( $0.85 \pm 0.02$  g/mL) than IFM flours. The IFPM flour had significantly lower BD value of  $0.71 \pm 0.01$  g/mL than IFFM flours. Brown IFFM flour had significantly higher value of  $0.86 \pm 0.01$  g/ml compared to the MC and black IFFM flours which both had a similar BD value of  $0.85 \pm 0.01$  g/mL.

The BD values on the RFM decreased after adding the fortificants while that of instant flours increased. Similar findings were observed by Dharmaraj *et al.* (2015) who reported on native, hydrothermally treated and decorticated whole meal FM and obtained values of 0.83, 0.77 and 0.80 g/ml, respectively. Mandge *et al.* (2014) reported a BD that ranged from 1.30 to 1.47 g/mL for raw and cooked multigrain porridge. Similar results of BD were reported by Chandra *et al.* (2015) on wheat flour (0.76 g/mL).

The BD is a reflection of the load the flours can carry, if allowed to rest directly on one another. The density of processed products dictates the characteristics of its container or packaged product density influences the value and strength of packaging material, texture or mouth feel (Adebowale *et al.*, 2012a). Akpata & Akubor (1999) reported that low a BD of FM flour would be an advantage in the preparation of instant foods.



**Figure 11.** Functional properties of raw finger millet and raw fortified finger millet flours. Error bars indicate standard deviation. RFM (A) and RFFM (B) (milky creamy, brown, black) and pearl millet flours. BD = bulk density, WAC = water absorption capacity, OAC = oil absorption capacity, SC = swelling capacity, SI = swelling index, FC = foaming capacity and FS = foaming solubility.



**Figure 12.** Functional properties of instant finger millet and instant fortified finger millet flours. Error bars indicate standard. IFM (A) and IFFM (B) (milky creamy, brown, black) and pearl millet flours. BD = bulk density, WAC = water absorption capacity, OAC = oil absorption capacity, SC = swelling capacity, SI = swelling index, FC = foaming capacity and FS = foaming solubility.

The higher BD indicated that the flour could be used in as a thickener in foods and also used in preparation of foods since it helps to reduce pasting thickness which is an essential factor in child feeding while a low BD flour is used in the formulation of complementary foods (Chandra *et al.*, 2015).

Water absorption capacity (WAC) of RFM flours varied from  $0.93 \pm 0.06$  to  $1.23 \pm 0.06\%$ . The MC showed a significantly higher value of WAC of  $1.23 \pm 0.06 \%$  as presented in Figure 11. The RFFM flours had the highest value of WAC on brown flour ( $1.33 \pm 0.02\%$ ) whereas the RFFM flour had a significantly higher value of WAC,  $1.14 \pm 0.01\%$ . Figure 12 showed that milk cream IFM flour had a significantly higher value of WAC ( $0.99 \pm 0.01\%$ ) while the IPM flour had a significantly lower value of  $0.82 \pm 0.08\%$ . IFFM had the highest value of WAC which ranged from  $2.72 \pm 0.03$  to  $2.92 \pm 0.02\%$  where the MC flour had the highest value and the brown flour had the lowest value. The milky cream showed a significant ( $p < 0.05$ ) difference WAC value compared to other IFFM flours. The WAC increased after adding the fortificants. The results of water absorption capacity were similar to findings of Siroha *et al.* (2016) who studied three (3) pearl millet varieties which ranged between 153 to 177%.

The WAC is a useful indication of flour or isolates whether it can be incorporated into aqueous food formulation especially those involving dough handling. Lower WAC was suitable for making thinner gruels and also indicated the value of water available for gelatinisation (Giami, 1993). Adebowale *et al.* (2012a) reported high WAC values to loose structure of starch polymers while low values indicate the compactness of the structure. The WAC of flours may be utilised in food products that need viscosity such as gravies and soup (Chandra *et al.*, 2015). Oil absorption capacity (OAC) of the brown RFM flour had the highest value of  $0.44 \pm 0.02$  mL/g and showed a significantly higher value of OAC as compared to MC and black RFM flours. The black RFFM flour showed significantly higher ( $p < 0.05$ ) OAC value of  $0.32 \pm 0.00$  mL/g (Figure 11).

Figure 12 indicated that the MC for IFM and IFFM flours had the highest value  $0.29 \pm 0.01$  and  $0.32 \pm 0.00$  mL/g as compared to other IFM and IFFM flours. Some flours increased or decreased after adding the fortificants and this shows that there were great variations

amongst the flours studied. These results were in agreement with Obadina *et al.* (2016) who reported an OAC which ranged from 0.33 to 0.68 mL/g in native and roasted whole grain pearl millet. Mbaeyi-Nwaoha & Obetta (2016) reported an OAC which ranged from 1.24 to 1.87% in unfermented and fermented pearl millet flour. Obadina *et al.* (2016) also stated that the OAC is the ability of flour to absorb oil and it also act as flour retainer which improves the mouth feel. The higher OAC of FM flour suggested that the flour could be useful in the formulation of foods while an oil absorption property may be used in the production of sausage. These properties make proteins a functional ingredient in foods such as whipped toppings, chiffon dessert, angels and sponge cakes (Kaushal *et al.*, 2012).

Adebowale & Lawal (2004) reported that flours with good OAC are essential and useful in flavour retention, improvement of palatability and increased shelf-life particularly in baked or meat products where fat absorption is required. Yadahally *et al.* (2008) mentioned that there was an advantage for best organoleptic characteristics of flour that has high water and that OAC could positively influence the moisture, fat contents and flavor in food products.

The swelling capacity (SC) of the RFM flours ranged from  $4.42 \pm 0.75$  to  $5.02 \pm 0.29\%$ . The black RFM flour showed significantly higher value of  $5.02 \pm 0.29\%$  compared to the MC ( $4.42 \pm 0.75$ ) and brown ( $4.84 \pm 0.14\%$ ) RFM flours. The brown RFFM flour ( $9.11 \pm 0.03\%$ ) had significantly higher value of SC compared to MC ( $8.89 \pm 0.09$  g/mL) and black ( $8.45 \pm 0.08\%$ ) RFFM flours (Figure 11). Figure 12 showed that the swelling capacity of IFM flours varied from  $4.19 \pm 0.13$  to  $4.64 \pm 0.60\%$  and the highest value of SC was found in the brown IFM flour and the lowest on milky cream IFM flour. Brown IFM flour showed significantly higher value of SC as compared to other IFM flours. At  $5.06 \pm 0.13\%$ , the IPM flour showed a significantly higher value of SC compared to all IFM flours. The milky cream IFFM flour showed a significantly higher value of SC ( $7.45 \pm 0.08\%$ ) compared to other IFM flours (Figure 12).

Both milky cream RFM and RPM flours showed significantly higher SI values of  $0.34 \pm 0.01\%$  and  $0.34 \pm 0.00\%$ , respectively, in which the lowest value was found in the brown RFM flour ( $0.32 \pm 0.01\%$ ). The milky cream RFM flour had the highest value of SI ( $0.52 \pm 0.01\%$ ) while the black RFM flour had the lowest value ( $0.48 \pm 0.01\%$ ). The MC had a

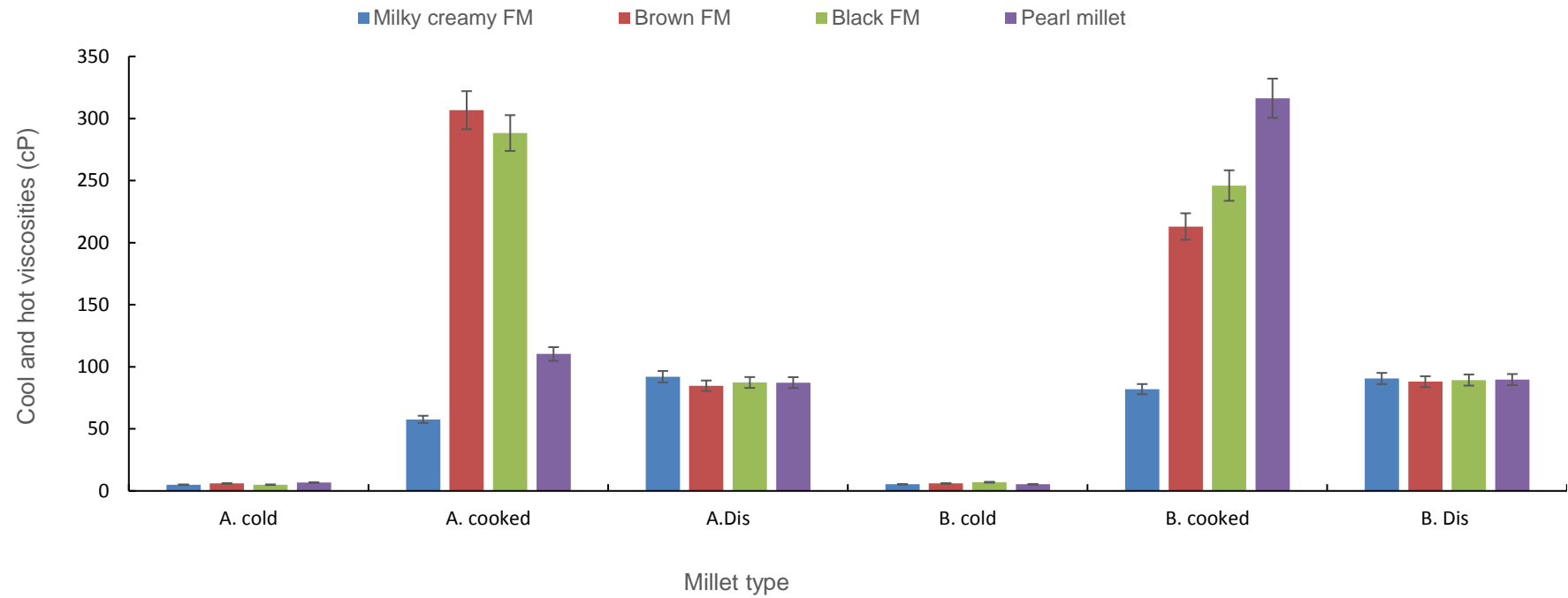
significantly higher SC value than the brown and black RFFM flours (Figure 11). The mean results of SI varied from  $0.37 \pm 0.01$  to with the black IFM flour having the highest value of  $0.79 \pm 0.16\%$  and the lowest value of  $0.37 \pm 0.01\%$  was obtained from milky cream IFM flours. The black IFM flour had a significantly higher value as compared to other IFM flours (Figure 12). Figure 12 shows the SI of IFFM flours which ranged from  $0.31 \pm 0.00$  to  $0.40 \pm 0.01$  g/g. The MC showed a significantly higher value of  $0.40 \pm 0.01$  g/g of SI as compared to other IFFM flours. There was a gradual increase of SC and SI after adding fortificants RFFM flours. These findings were similar to the report of Shiihii *et al.* (2011) who showed an SC of 7.1 g/g in FM dry milling (normal seed). Mbaeyi-Nwaoha & Obetta (2016) reported an SI range between 1.57 and 1.89 g/g in unfermented and fermented pearl millet flours.

Adegunwa *et al.* (2014) reported that the swelling power of flour granules is an indication of the extent of associative forces within the granules. It could also be related to the water absorption index of the starch-based flour during heating. The FC for the milky cream for both RFM flours which was  $13.16 \pm 1.22\%$  and RFFM which was  $14.33 \pm 3.51\%$  flours showed significantly higher value compared to other flours (Figure 11). The milky cream IFM had the highest value of  $11.33 \pm 1.15$  while the lowest value of  $1.05 \pm 0.01$  was obtained from the black IFM. The brown IFFM flour had a significantly higher value of  $13.25 \pm 1.48\%$ , compared to the MC flour which was ( $8.83 \pm 1.07\%$ ) and the black IFFM flour which was  $9.14 \pm 1.15\%$  (Figure 12).

The RFM flours showed that the highest FS was obtained from the MC flour ( $1.04 \pm 0.03$ ). The highest FS was observed in the RFFM milky cream which stood at  $1.15 \pm 0.03$  g/ml and the lowest FS was obtained from the black RFFM flours with  $1.07 \pm 0.01$  g/ml, respectively. The milky cream RFM and RFFM flours showed significantly higher value as compared to the brown and black RFFM flour (Figure 11). Both the MC and brown IFM flours had a significantly higher value of  $1.11 \pm 0.01\%$  compared to the black IFM flour. The mean results of FS on IFFM flours varied from  $1.09 \pm 0.01\%$  to  $1.13 \pm 0.01\%$ , with the brown IFFM flour ( $1.13 \pm 0.01\%$ ) having a significantly higher FS value compared to the MC ( $1.10 \pm 0.02\%$ ) and the black, ( $1.09 \pm 0.01\%$ ) IFFM flours (Figure 12).

Both FC and FS milky cream RFFM flour showed a significant difference compared to other flours. The FC increased after adding fortificant to IFFM flours and FS also increased on RFFM flours. Siroha *et al.* (2016) reported an FC of three (3) pearl millet flour varieties which ranged from 18 to 25%. The RFFM milky cream flour contained the highest FC due to higher protein (Chandra & Samsher, 2013). The FC and solubility depend on the interfacial film produced by proteins, which maintains the air bubbles in suspension and decrease the rate of coalescence (Siroha *et al.*, 2016). Adebowale & Maliki (2011) reported that foam formation and stability depend on the type of pH values, protein, surface retention, viscosity and processing method. They also stated that it is essential since it is useful as whipping agents which rely on their ability to maintain the whipping process. The dispersibility (%) of FM flour was higher on the milky cream FM ( $92.03 \pm 0.38$ ), while lower values were obtained from the brown flour ( $84.73 \pm 0.64$ ). The MC flours had an RFM of  $92.03 \pm 0.38\%$  and an RFFM of  $90.57 \pm 0.51\%$  which were significantly higher values in dispersibility as compared to both brown and black flours (Figure 13).

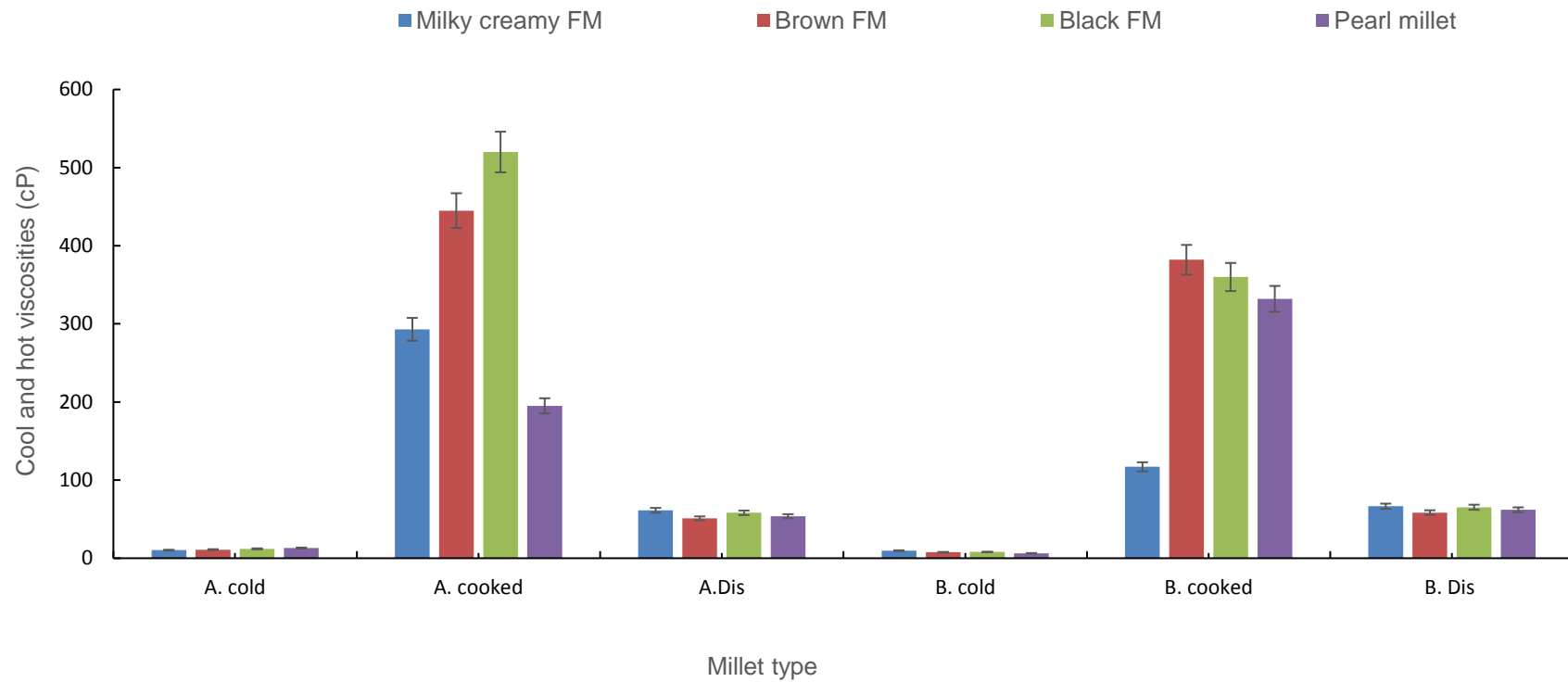
The milky cream flours had an IFM of  $61.37 \pm 0.55\%$  and an IFFM of  $66.57 \pm 2.00\%$  which were significantly higher values in dispersibility compared to both brown and black flours (Figure 14). The RFFM and IFFM flours increased after adding the fortificants. The findings of this study were similar to those by Olapade *et al.* (2014) who reported dispersibility ranging from 68 to 70.67% in cassava-bambara flours. According to Adebowale *et al.* (2012a) and Olapade *et al.* (2014), the values of dispersibility may help produce fine constituent dough during mixing. Adegunwa *et al.* (2014) reported the dispersibility values which ranged from 73.50 to 78.00%. The cool paste viscosity of the RFM flour ranged from  $5.00 \pm 0.00$  to  $6.00 \pm 0.00$  cP while hot viscosity ranged from  $57.67 \pm 1.15$  to  $306.7 \pm 3.51$  cP. Brown RFM flours for cool and hot paste viscosities were significantly higher ( $p < 0.05$ ) compared to MC and black RFM flours. The brown RFM flour showed a significantly higher value of  $306.7 \pm 3.51$  cP on hot paste viscosity for brown and black RFM flours. The RFPM ( $316.33 \pm 1.53$  cP) had a significantly higher value of hot paste viscosity as compared to all RFFM flours.



**Figure 13.** Cool and hot paste viscosities of raw finger millet (RFM) and raw fortified finger millet (RFFM). Error bars indicate standard deviation. FM = finger millet, RFM (A) and RFFM (B) (milky creamy, brown, black) and pearl millet flours. Viscosity cool, hot and dis = dispersibility.

Black hot paste viscosity showed significantly higher value of  $7.00 \pm 0.00$  and  $246 \pm 3.61$  cP as indicated on Table 13. The mean results of IFM flours for cool and hot paste viscosities ranged from  $10.33 \pm 0.58$  to  $12.00 \pm 0.00$  cP and  $293.3 \pm 3.51$  to  $519.7 \pm 3.51$  cP, respectively. Brown IFM flour showed significantly higher value of  $12.00 \pm 0.00$  cP compared to MC and black IFM flours, while the IPM flour had significantly higher value of  $13.00 \pm 0.00$  cP as compared to all IFM flours (Table 14).

Cool paste viscosity of the milky cream IFFM flour showed a significantly higher value of  $9.67 \pm 0.58$  cP while the IFPM flour showed a significantly lower value of  $6.33 \pm 0.58$  cP. The brown IFFM flour showed significantly higher viscosity of  $382.00 \pm 3.21$  cP on hot paste (Table 14). These results are similar to those of Dharmaraj *et al.* (2015) who studied the cool and hot paste viscosities on native, hydrothermal and decorticated FM.



**Figure 14.** Cool and hot paste viscosities of instant finger millet and instant fortified finger millet. Error bars indicate standard deviation. FM = finger millet, IFM (A) and IFFM (B) (milky creamy, brown, black) and pearl millet flours. Viscosity cool, hot and dis = dispersibility.

Dharmaraj *et al.* (2015) indicated that cool viscosity paste measured on hydrothermally treated and decorticated FM were 11 and 22 cP, respectively. The PM flour varied significantly in cool viscosity compared to other FM flours with the highest value of 6.67 cP. The hot paste viscosity of native, hydrothermally treated and decorticated FM were 1717, 350 and 463 cP, respectively. Krishnan *et al.* (2011) obtained results ranging from 12.0 to 21.0 cP for cool viscosity paste on FM seed coat, while the hot viscosity ranged from 48.0 to 248.0 cP.

The cool and hot paste viscosities showed that they contained unprocessed carbohydrates. These low molecular weight of carbohydrates contribute to reduced viscosity, possess less water-binding ability and may be more easily digested and absorbed as required by infants. Therefore, reduced viscosity is a good indicator for the appropriateness of a weaning food blend for infants (Usman, 2016). It was observed that cool paste viscosity of the flours gradually increased while hot paste viscosity decreased after adding the fortificants

These results were similar to the findings of Dharmaraj *et al.* (2015) who studied the cool and hot paste viscosities of native, hydrothermal and decorticated FM which indicated that cool paste viscosity measured only on hydrothermally treated and decorticated FM were 11 and 22 cP. The hot viscosity pastes of native, hydrothermally treated and decorticated FM were 1717, 350 and 463 cP, respectively.

Another study by Krishnan *et al.* (2011) on FM seed coat obtained results ranging from 12.0 to 21.0 cP for cool viscosity paste, while the hot viscosity ranged from 48.0 to 248.0 cP showing that it contained unprocessed carbohydrates. Carbohydrates contribute to reduced viscosity, have less water-binding qualities and may be more easily digested and absorbed as required by infants. Reduced viscosity is a good indicator for the appropriateness of a weaning food blend for infants (Usman *et al.*, 2016).

### 5.3.3. Pasting properties of finger millet flours

Pasting properties are used to determine whether the FM flours are suitable and desirable to be utilised for baking FM products in the food industry (Isibhakhomen *et al.*, 2013).

Moisture content is a critical control factor in the RVA analysis, since the value of flour used in the analysis was weighed according to its moisture content. Moisture content values of RFM and RFFM flours ranged from 10.3 to 12.0% and 10.2 to 12.1%, respectively. The IFM and IFFM flours, moisture content ranged between 6.6 to 8.6% and 6.9 to 8.6%, respectively. The highest moisture content value was obtained from RFM, 12.1% and the IFM had the lowest moisture content of 6.6%, respectively.

The results of pasting properties of the RFM, RFFM, IFM and IFFM flours are shown in Table 15. The experiment was conducted at a temperature of 91°C. PT is an indication of the cooking time and it varied from 5.69 to 6.38 min and 5.73 to 6.82 min, respectively for RFM and RFFM flours. The RPM flour showed significantly higher time of 6.56 min than all RFM flours. The highest PT was observed on the black RFM flour at 6.38 min while the lowest PT was found on the milky cream RFM flour at 5.69 min. At 6.82 min, black RFFM flour had significantly higher peak time as compared to the MC RFFM flour at 5.73 min and the brown at 6.16 min. The PT of IFM and IFFM flours varied from 6.00 to 7.00 min and 6.16 to 6.98 min, respectively. The milky cream IFM flour showed significantly lower minutes of 6.00 as compared to brown and the black which had the same PT of 7.00 min for IFM flours. The highest PT was obtained from black IFFM flour and the lowest PT was found on milky cream IFFM flours as shown in Table 15. Both the brown IFFM flour and IFPM showed significantly higher PT values than the milky cream IFFM flour. Sade (2009) reported similar results of 4.86 min on the PT of RFM flour.

Falade *et al.* (2014) observed the PT of two (2) rice varieties which ranged from 5.40 to 5.43 min. The PT is an indication of the gelatinisation time during processing. It is the temperature at which the first detectable increase in viscosity is noted and is an index associated with the initial change due to the swelling of the starch (Adegunwa *et al.*, 2014). Pasting properties of flour are essential in the food industry because they tend to affect the texture, uses and digestibility of starchy foods (Adegunwa *et al.*, 2014).

**Table 15.** Pasting temperature of finger millet flour treatments.

FM flours	PT (min)	PV (cP)	TV (cP)	FV (cP)	BDV (cP)	SV (cP)
<b>Raw millet flours</b>						
Milky cream FM	5.69 <sup>d</sup> ± 0.03	3518.0 <sup>a</sup> ± 60.77	2815.0 <sup>c</sup> ± 125.61	6554.3 <sup>a</sup> ± 130.24	703.00 <sup>a</sup> ± 65.82	3868.3 <sup>a</sup> ± 255.57
Brown FM	6.18 <sup>c</sup> ± 0.04	3254.0 <sup>b</sup> ± 61.61	3089.0 <sup>a</sup> ± 67.73	3444.3 <sup>b</sup> ± 80.39	165.00 <sup>c</sup> ± 7.21	355.3 <sup>c</sup> ± 36.67
Black FM	6.38 <sup>b</sup> ± 0.31	3010.0 <sup>c</sup> ± 43.27	2942.3 <sup>b</sup> ± 50.95	3163.7 <sup>c</sup> ± 53.11	72.33 <sup>d</sup> ± 28.54	226.00 <sup>d</sup> ± 28.69
Pearl millet	6.56 <sup>a</sup> ± 0.10	1556.7 <sup>d</sup> ± 22.85	1331.3 <sup>d</sup> ± 24.91	1970.0 <sup>d</sup> ± 23.58	225.7 <sup>b</sup> ± 2.52	639.33 <sup>b</sup> ± 9.07
<b>Raw fortified millets flours</b>						
Milky cream FM	5.73 <sup>d</sup> ± 0.07	3656.3 <sup>a</sup> ± 252.44	2917 <sup>c</sup> ± 151.61	6716.7 <sup>a</sup> ± 569.07	732.67 <sup>a</sup> ± 125.51	3793 <sup>a</sup> ± 449.62
Brown FM	6.16 <sup>c</sup> ± 0.10	3224.7 <sup>b</sup> ± 36.64	3060 <sup>a</sup> ± 48.77	3461.3 <sup>b</sup> ± 34.53	164.7 <sup>c</sup> ± 12.74	401.00 <sup>c</sup> ± 79.08
Black FM	6.82 <sup>a</sup> ± 0.25	3030.7 <sup>c</sup> ± 52.79	2970.7 <sup>b</sup> ± 94.71	3284 <sup>c</sup> ± 30.81	103.67 <sup>d</sup> ± 37.43	357.00 <sup>d</sup> ± 17.78
Pearl millet	6.62 <sup>b</sup> ± 0.27	1567.3 <sup>d</sup> ± 17.39	1331.3 <sup>d</sup> ± 9.81	1989.7 <sup>d</sup> ± 24.58	236.00 <sup>b</sup> ± 27.07	658.33 <sup>b</sup> ± 32.08
<b>Instant millet flours</b>						
Milky cream FM	6.00 <sup>b</sup> ± 0.07	191.00 <sup>d</sup> ± 3.21	179.00 <sup>d</sup> ± 2.00	310.70 <sup>d</sup> ± 3.79	12.33 <sup>d</sup> ± 1.53	131.70 <sup>d</sup> ± 2.52
Brown FM	7.00 <sup>a</sup> ± 0.00	712.00 <sup>a</sup> ± 10.44	641.3 <sup>a</sup> ± 7.09	970.70 <sup>a</sup> ± 16.77	70.67 <sup>b</sup> ± 4.04	268.00 <sup>b</sup> ± 96.15
Black FM	7.00 <sup>a</sup> ± 0.00	304.00 <sup>c</sup> ± 2.08	287.70 <sup>c</sup> ± 3.06	422.70 <sup>c</sup> ± 3.06	16.00 <sup>c</sup> ± 1.00	135.00 <sup>c</sup> ± 0.00
Pearl millet	7.00 <sup>a</sup> ± 0.00	614.00 <sup>b</sup> ± 9.24	477.7 <sup>b</sup> ± 9.50	839.00 <sup>b</sup> ± 9.85	330.00 <sup>a</sup> ± 8.54	362.00 <sup>a</sup> ± 13.11
<b>Instant fortified millet flours</b>						
Milky cream FM	6.16 <sup>b</sup> ± 0.08	176.00 <sup>d</sup> ± 1.53	164.7 <sup>d</sup> ± 1.15	294.3 <sup>d</sup> ± 2.52	11.67 <sup>d</sup> ± 0.58	129.67 <sup>d</sup> ± 1.53
Brown FM	7.00 <sup>a</sup> ± 0.00	723.00 <sup>a</sup> ± 9.02	655.3 <sup>a</sup> ± 8.74	983.3 <sup>a</sup> ± 17.50	67.33 <sup>b</sup> ± 1.53	328.00 <sup>b</sup> ± 13.11
Black FM	6.98 <sup>a</sup> ± 0.04	311.00 <sup>c</sup> ± 3.79	296.7 <sup>c</sup> ± 4.51	435.7 <sup>c</sup> ± 4.93	14.67 <sup>c</sup> ± 1.53	139.00 <sup>c</sup> ± 2.65
Pearl millet	7.00 <sup>a</sup> ± 0.00	603.00 <sup>b</sup> ± 3.61	472.7 <sup>b</sup> ± 3.51	817.7 <sup>b</sup> ± 37.51	131.00 <sup>a</sup> ± 3.61	346.00 <sup>a</sup> ± 6.00

Values are mean ± standard deviation, n = 3. Values followed by the same letters in the same column are not significantly different ( $p < 0.05$ ) at the moisture content ranged (10.3 to 12.0%). PT = peak time, PV = peak viscosity, TV = trough viscosity, FV = final viscosity, BDV = breakdown viscosity, SV = setback viscosity, FM = finger millet, min = minutes and cP = centipoise

The PV for both RFM and RFFM flours ranged from 3010.0 to 3518.0 and 3030.7 to 3656.3 cP, respectively as indicated on Table 15. The RPM and RFFM flours had significantly lower cP of 1556.7 and 1567.3, respectively, compared to all RFM and RFFM flours. Milky cream for RFM and RFFM flour showed significantly higher PV of 3518.0 and 3656.3 cP, respectively, as compared to the brown and black for RFM and RFFM flours. The RFFM flour had significantly lower PV of 1567.3 cP on PV. The mean results of PV on IFM flour varied from 191.00 to 712.00 cP in which the brown IFM flour had a significantly higher PV of 712.00 than all RFM flours.

Table 15 shows that the PV for IFFM flours ranged from 176 to 723 cP. The highest cP of  $176 \pm 1.53$  was obtained from brown IFFM flour while the lowest cP of 723 cP was found in the milky cream IFFM flour. Brown IFFM flour showed significantly higher cP compared to MC and black IFFM flours. The low PV of flours is an indication that the flour could be utilised in the production of food products that need low gel strength and elasticity (Adegunwa *et al.*, 2014). Sandhu & Singh (2007) observed the PV of 152 to 222 cP for corn starches.

Moreover, Bhupender *et al.* (2013) reported that the PV of starches from different pearl millet varieties ranged from 1665 to 1998 cP. Falade *et al.* (2014) studied the PV of two (2) rice varieties which ranged from 4204 to 4308 cP. The low PV flours is an indication that the flour can be utilised in the production of food products that need low gel strength and elasticity. PV is the ability of the starch to swell freely before it physically breaks down (Adegunwa *et al.*, 2014).

The TV ranged from 2815 to 3089 and 2917 to 2970.7 cP, respectively for both RFM and RFFM flours. Both The brown RFM, RFFM and IFM flours had the significantly higher cP of 3089.0, 3060, 641.3 and 655.3, respectively, compared to the MC and black for all flours tested. The RFFM flour showed a significantly lower cP of 1331.3 than RFFM flours. Sandhu & Singh (2007) observed a TV of 594 to 727 cP for corn starches and Sade (2009) reported the TV of 35.67 cP from the PM.

The TV is the minimum viscosity value that measures the ability of paste to withstand breakdown during cooling (Isibhakhomen *et al.*, 2013 and Adegunwa *et al.*, 2014). It indicates

the ability of the flour to form a gel or viscous paste after cooking and cooling as well as the resistance of the viscous paste to shear stress during stirring (Adegunwa *et al.*, 2014). Pasting properties studied on instant flours decreased after adding the fortificants as the moisture level of the flour decreased.

The final viscosity (FV) of raw finger millet and raw fortified finger millet flours ranged from 3163.7 to 6554.3 and 3284 to 6716.7 cP, respectively. The milky cream RFM and RFFM flours showed significantly higher cP of 6554.3 and 6716.7, respectively. The RPM and RFFM flours showed significantly lower values of 1970.0 and 1989.7 cP, compared to the brown with 3444.3 and the black with 3163.7 cP for RFM and RFFM flours. The brown flours showed significantly higher cP for IFM at 970.70 and IFFM at 983.3 (Table 15).

The FV indicates the ability of the flour to form a gel or viscous paste after cooking and cooling as well as the resistance of the viscous paste to shear stress during stirring (Adegunwa *et al.*, 2014). Onyango (2014) reported the FV which ranged from 530.0 to 1925.0 cP from white maize meal and Sade (2009) observed the FV of 91.50 on PM. Falade *et al.* (2014) reported the FV of two (2) rice varieties which ranged from 5417 to 5456 cP. FV indicates the ability of the flour to form a gel or viscous paste after cooking and cooling as well as the resistance of the viscous paste to shear stress during stirring (Adegunwa *et al.*, 2014).

The BDV (final viscosity – trough viscosity) of RFM and RFFM flours varied from 72.33 to 703.00 and 103.67 to 732.67 cP, respectively. MC for both RFM and RFFM flours showed significantly higher values ( $p < 0.05$ ) compared to other RFM and RFFM (brown and black) flours. The mean BD ranged from 12.33 to 70.67 cP where brown IFM flour had the highest cP of  $70.67 \pm 4.04$  and lowest cP was found on milky cream IFM flour, 12.33 (Table 15).

The IPM had a significantly higher cP, 330.00 than all IFM flours. At 67.33 cP, the brown IFFM flour had a significantly higher cP than MC and black IFFM flours. The highest cP obtained from brown IFFM flour was 67.33 and the lowest cP of 11.67 was found on milky cream IFFM flour. The IFPM flour had a significantly higher cP of 131. Sandhu & Singh (2007)

reported a BDV which varies from 113 to 579 cP from different corn starches. On the other, Sade (2009) reported a BDV of 35.75 cP in pearl millet.

Onyango (2014) studied the a BDV which ranged from 385 to 974 cP from white maize meal Falade *et al.* (2014) studied the BDV of two (2) rice varieties which ranged from 2095 to 2200 cP. Bhupender *et al.*, (2013) reported that BDV is caused by the disintegration of gelatinised starch granules structure, which happens during the continuous stirring and heating and indicates the shear thinning property of starch. The low BDV values indicated the stability of starches under hot conditions. Bhupender *et al.* (2013) studied the BDV of starches from different pearl millet varieties that ranged from 414 to 769 cP. The SV (final viscosity – trough viscosity) of RFM and RFFM flours ranged from 226.00 to 3868.33 and 357.00 to 3793 cP, respectively.

The highest SV value was obtained from milky cream RFFM flour, 3868.33 cP and the lowest value of 357.00 cP on the black RFM flour. For both RFM and RFFM, milky cream flours showed a significantly higher SV ( $p < 0.05$ ) compared to brown and black flours. Setback viscosity of the IFM flours ranged from 131.7 to 268 cP, where brown IFM flour had significantly higher cP than milky and black IFM flours. The IPM flour showed significantly higher cP of 362 (Table 15). The setback viscosity of IFFM flours ranged from 129.67 to 328 cP. The brown IFFM flour had significantly higher than MC and black IFFM flours. The IFPM had significantly higher cP of 346. Sandhu & Singh (2007) studied an SV of corn starches ranged from 141 to 726 cP, Sade (2009) found an SV of 55.83 cP from the PM and Onyango (2014) obtained the SV which ranges from 0.0 to 173.0 cP from white maize meal. Falade *et al.* (2014) observed that the SV of two (2) rice varieties which ranges from 3309 to 3347 cP. SV is an index of retrogradation. Bhupender *et al.* (2013) reported that SV reveals the gelling ability or the measure of recrystallisation of gelatinised starch during cooling. The low SV indicates the low rate of starch retrogradation and syneresis. Low SV may be caused by low degree of amylose leaching.

#### 5.3.4. Thermal properties of starch from different finger millet (FM) varieties

The results of thermal analysis for starches from different FM varieties were summarised in Table 16. The onset temperature ( $T_o$ ) ranged between 67.91 to 76.35°C and the milky cream RFM starches showed a significantly higher  $T_o$  of 76.35°C. Pearl millet had significantly lower  $T_o$  of 67.91°C. The peak ( $T_p$ ) and conclusion ( $T_c$ ) temperatures ranged from 69.21 to 81.94°C and 72.71 to 89.64°C, respectively.

The black RFM starch showed significantly higher  $T_p$ , 81.94°C and  $T_c$ , 89.64°C as compared to milky cream ( $T_p$  - 77.80°C and  $T_c$  - 80.17 °C) and brown ( $T_p$  - 76.57°C and  $T_c$  - 87.12°C). The RPM had significantly lower  $T_p$  and  $T_c$  temperatures compared to RFM starches. Enthalpy of gelatinisation ( $\Delta H$  gel) of starches from different starches of FM varieties varied from 5.74 to 7.13°C. The black RFM starch had significantly higher  $\Delta H$  (gel) compared to the MC and brown RFM starches.

Significantly higher value for peak height index (PHI) was found on the pearl millet starch 3.11°C where the highest value was observed on pearl millet and the lowest value of 2.34°C on brown RFM starches. The brown RFM starch showed significantly higher gelatinisation temperature range (GTR) of 13.25°C. The transition temperatures ( $T_o$ ,  $T_p$  and  $T_c$ ) of black RFFM starches ranged from 71.41 to 81.80°C, 74.46 to 84.22°C and 78.29 to 83.81°C, respectively (Table 16). The black RFFM starches showed significantly higher values compared to MC and brown RFFM starches on the parameters stated above.

**Table 16.** Thermal properties of starch from finger millet (FM) variety treatments.

FM starches	T <sub>o</sub> (°C)	T <sub>p</sub> (°C)	T <sub>c</sub> (°C)	ΔH (J/g)	PHI (°C)	GTR (°C)
<b>Raw millet starches</b>						
Milky cream FM	76.35 <sup>a</sup> ± 1.72	77.80 <sup>b</sup> ± 1.43	80.17 <sup>c</sup> ± 0.56	5.74 <sup>c</sup> ± 0.59	2.55 <sup>c</sup> ± 0.48	3.82 <sup>d</sup> ± 2.02
Brown FM	73.89 <sup>c</sup> ± 1.06	76.57 <sup>c</sup> ± 1.26	87.12 <sup>b</sup> ± 1.68	6.11 <sup>b</sup> ± 0.77	2.34 <sup>c</sup> ± 0.26 <sup>c</sup>	13.22 <sup>a</sup> ± 2.45
Black FM	74.31 <sup>b</sup> ± 5.09	81.94 <sup>a</sup> ± 7.96	89.64 <sup>a</sup> ± 1.72	7.13 <sup>a</sup> ± 1.03	2.63 <sup>b</sup> ± 0.33	6.65 <sup>b</sup> ± 8.55
Pearl millet	67.91 <sup>d</sup> ± 8.62	69.21 <sup>d</sup> ± 6.81	72.71 <sup>d</sup> ± 3.97	5.89 <sup>c</sup> ± 0.51	3.11 <sup>a</sup> ± 0.56	5.36 <sup>c</sup> ± 4.36
<b>Raw fortified millets starches</b>						
Milky cream FM	77.96 <sup>c</sup> ± 4.10	79.82 <sup>b</sup> ± 4.09	81.58 <sup>c</sup> ± 4.23	7.19 <sup>a</sup> ± 0.80	7.40 <sup>a</sup> ± 2.09	2.68 <sup>d</sup> ± 2.09
Brown FM	79.39 <sup>b</sup> ± 2.51	78.72 <sup>c</sup> ± 1.41	80.74 <sup>b</sup> ± 2.72	6.18 <sup>c</sup> ± 0.67	2.31 <sup>b</sup> ± 0.40	3.86 <sup>c</sup> ± 4.85
Black FM	81.80 <sup>a</sup> ± 10.58	84.22 <sup>a</sup> ± 9.23	83.81 <sup>a</sup> ± 12.20	6.90 <sup>b</sup> ± 1.85	2.10 <sup>c</sup> ± 0.85	5.47 <sup>b</sup> ± 4.25
Pearl millet	71.41 <sup>d</sup> ± 4.11	74.46 <sup>d</sup> ± 4.14	78.29 <sup>d</sup> ± 1.19	5.72 <sup>d</sup> ± 2.34	1.42 <sup>d</sup> ± 0.48	6.88 <sup>a</sup> ± 4.02
<b>Instant millet starches</b>						
Milky cream FM	84.57 <sup>a</sup> ± 2.04	87.27 <sup>a</sup> ± 2.08	92.81 <sup>a</sup> ± 2.63	7.63 <sup>a</sup> ± 2.95	3.93 <sup>b</sup> ± 0.85	8.22 <sup>c</sup> ± 2.09
Brown FM	69.49 <sup>d</sup> ± 5.42	76.65 <sup>b</sup> ± 0.28	87.66 <sup>b</sup> ± 9.93	6.89 <sup>d</sup> ± 2.54	4.63 <sup>a</sup> ± 1.05	13.50 <sup>a</sup> ± 3.53
Black FM	74.31 <sup>c</sup> ± 5.09	70.80 <sup>c</sup> ± 1.71	86.21 <sup>c</sup> ± 4.18	7.37 <sup>c</sup> ± 1.67	3.56 <sup>c</sup> ± 1.09	11.90 <sup>b</sup> ± 3.53
Pearl millet	80.66 <sup>b</sup> ± 1.11	82.84 <sup>b</sup> ± 1.71	85.67 <sup>d</sup> ± 2.33	7.55 <sup>b</sup> ± 3.00	3.92 <sup>b</sup> ± 0.47	4.94 <sup>d</sup> ± 2.59
<b>Instant fortified millet starches</b>						
Milky cream FM	81.94 <sup>c</sup> ± 1.07	83.57 <sup>c</sup> ± 0.64	85.46 <sup>c</sup> ± 0.87	6.03 <sup>b</sup> ± 2.62	2.31 <sup>b</sup> ± 0.61	3.53 <sup>a</sup> ± 2.09
Brown FM	85.88 <sup>a</sup> ± 0.92	87.14 <sup>a</sup> ± 1.84	87.13 <sup>b</sup> ± 1.86	6.14 <sup>b</sup> ± 2.62	2.05 <sup>c</sup> ± 0.61	1.26 <sup>d</sup> ± 1.17
Black FM	85.17 <sup>b</sup> ± 3.58	86.37 <sup>b</sup> ± 3.52	88.52 <sup>a</sup> ± 3.39	5.70 <sup>c</sup> ± 1.20	2.14 <sup>c</sup> ± 0.04	2.27 <sup>b</sup> ± 1.95
Pearl millet	81.48 <sup>c</sup> ± 2.94	83.23 <sup>c</sup> ± 2.79	84.59 <sup>d</sup> ± 2.69	6.91 <sup>a</sup> ± 2.29	2.94 <sup>a</sup> ± 1.18	2.50 <sup>b</sup> ± 1.70

Values are mean ± standard deviation, n = 3. Values followed by the same letters in the same column are not significantly different ( $p < 0.05$ ). T<sub>o</sub> = onset, T<sub>p</sub> = peak temperature, T<sub>c</sub> = conclusion temperature, ΔH J/g = enthalpy of gelatinisation, PHI = peak height index, GTR = gelatinisation temperature range

The Milky cream RFFM flour had significantly higher value on  $\Delta H$  gel and PHI while the RFFM starch had the least enthalpy of gelatinisation starch. The RFFM flour showed significantly higher value of GTR when compared to FM starches. The addition of vit B<sub>2</sub> and ZnO on raw flours from different FM varieties increased the T<sub>o</sub> and T<sub>p</sub> values. The  $\Delta H$  gel and PHI of milky cream RFFM starch increased after adding the fortificants.

The T<sub>o</sub>, T<sub>p</sub>, T<sub>c</sub> and  $\Delta H$  gel of milky cream IFM starches ranged from 69.49 to 84.57 °C, 70.80 to 87.27°C, 85.67 to 92.81°C and 6.89 to 7.63°C, respectively. The milky cream IFM starch had significantly higher value on T<sub>o</sub>, T<sub>p</sub>, T<sub>c</sub> and  $\Delta H$  gel compared to other IFM starches from different FM varieties. The brown IFM had significantly higher value on PHI and GTR, 4.63°C and 13.50°C, respectively (Table 16).

The IFM starch had the least T<sub>c</sub> and GTR of 85.67°C and 4.94°C, respectively. The T<sub>o</sub> and T<sub>p</sub> of brown IFFM starches which varied from 81.48 to 85.88°C and 83.23°C to 87.14°C, respectively. Brown IFFM had significantly higher value on T<sub>o</sub> and T<sub>p</sub> compared to MC and black IFFM starches while the IFPM starches had significantly lower value on the same parameters of 81.48 °C and 83.23°C, respectively.

The black IFFM flour showed a significantly higher value on T<sub>c</sub> of 88.52°C. The IFPM flour had significantly higher value on  $\Delta H$  gel and PHI, 46.91°C and 2.94°C, respectively. The GTR varied from 1.26 to 3.53°C where milky cream IFFM had significantly higher value of 3.53°C compared to the brown and black IFFM starches. The T<sub>o</sub> and T<sub>p</sub> values increased on the brown and black IFFM starches after adding the fortificants while T<sub>c</sub>, PHI and GTR decreased after adding the fortificants (Table 16).

Ubwa *et al.* (2012) a T<sub>o</sub> results of 74.0°C FM starch. Sandhu & Siroha (2017) observed that the T<sub>o</sub> ranges from 63.4 to 67.7°C in six (6) pearl millet varieties (HC-10, HHB-67, HHB-223, HHB-226, W-445 & GHB-732). Sandhu & Siroha (2017) also reported a range of T<sub>p</sub> and T<sub>c</sub> of 69.3 to 71.6°C and 74.5 to 76.3°C, respectively in six (6) pearl millet starches from different varieties. Ubwa *et al.* (2012) observed a T<sub>p</sub> of 86.0°C on finger millet starch.

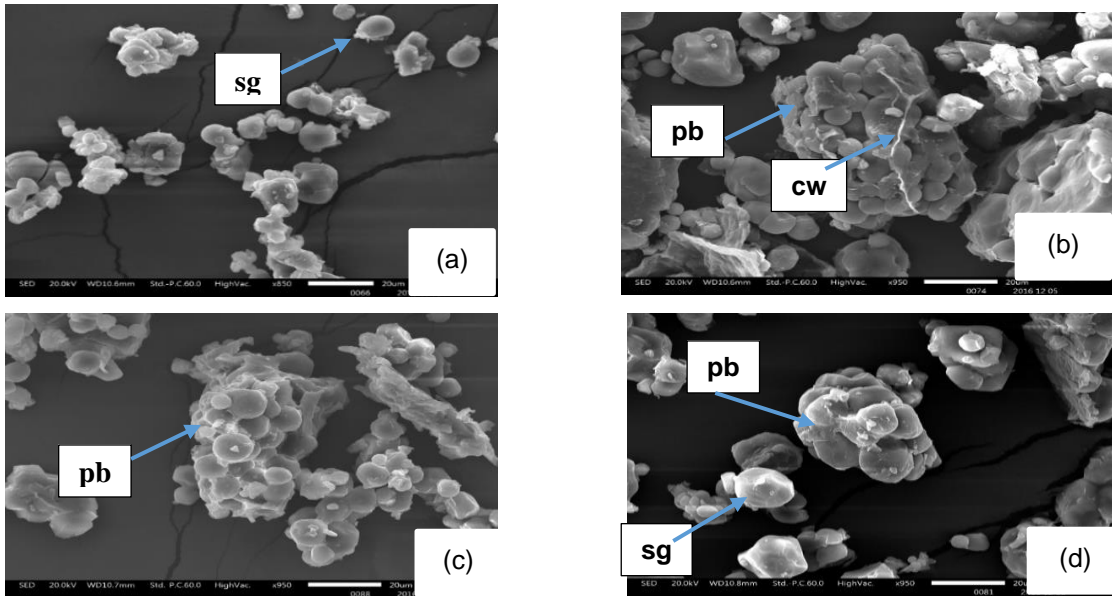
Sandhu & Siroha (2017) studied  $\Delta H$  gel which varied from 10.6 to 11.9°C in six (6) pearl millet starches from different varieties. Higher values of  $\Delta H$  (gel) of black RFM indicates its more energy requirements for gelatinisation of starch. The higher value of  $\Delta H$  gel starches may be possible due to starches rich in amylopectin as starch are composed mainly of amylopectin. Gelatinisation involves melting and uncoiling of the external chains of amylopectin that are packed together as double helices in clusters (Sandhu & Siroha 2017).

The PHI studied by Sandhu & Siroha (2017) varies from  $1.83 \pm 0.02$  °C to  $3.16 \pm 0.04$  °C which are similar to that of the present study. Sandhu & Siroha (2017) also reported the GTR which varies from 7.4 to 11.7°C in six (6) pearl millet starches from different varieties. Starches granule size affects its physico-chemical properties namely, pasting, gelatinisation, enzyme susceptibility, crystallinity and solubility. The findings were in agreement with those by Ubwa *et al.* (2012) who reported a GTR of 13.1°C on finger millet starch.

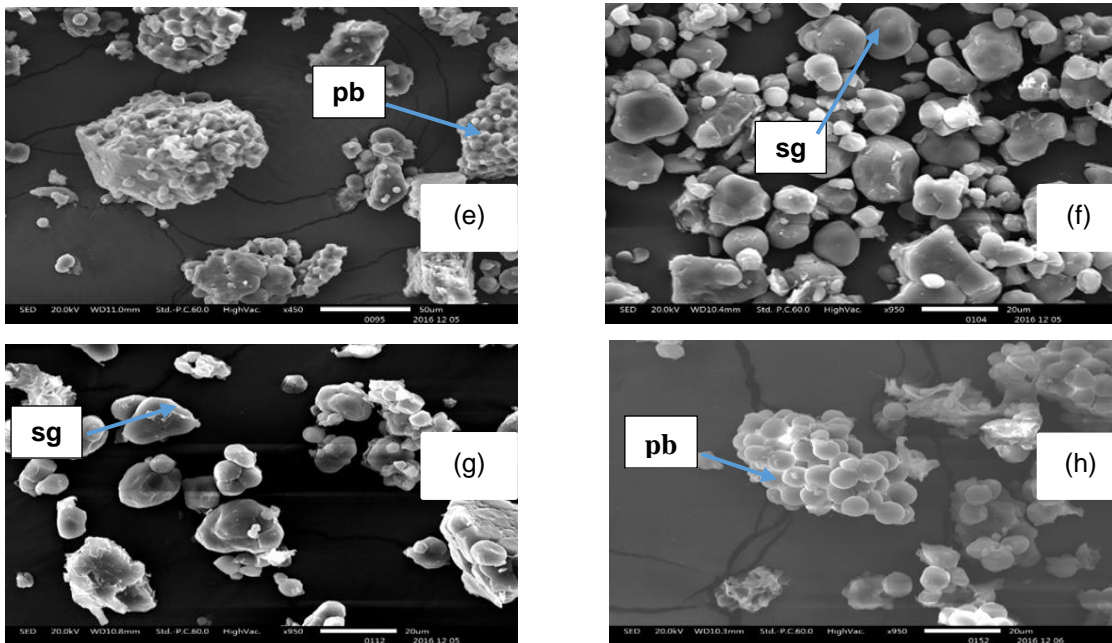
### 5.3.5. Microscopic structure of finger millet flours

Two (2) microscopic structure instruments were used to determine the microscopic structures of FM flours namely: Joel SEM (JSM IT 300, Japan) and Energy Dispersive X-ray detector (Mervlin/ Evo Germany). The SEM showed that the starch granules (SG) of RFM flours such as the MC, brown and black had oval and smooth surfaces. The size of the SG were identical to each other and ranged from small to large for all FM flours (Figure 15). Gull *et al.* (2016) reported that the SG should be oval or polygon. The brown and black RFM flours formed clusters in which most of the SG were attached to each other. The cell wall and the protein bodied of SG were visible as shown in Figure 15. The RPM and RFPM flours also had spherical and smooth SG which were found in the form of clusters.

Figure 16 showed that SG on brown flours had different shapes and sizes which appeared to be small to large. Some SGs had oval and smooth surfaces. The milky cream RFFM had small granules that formed clusters. The RPM and RFPM flours also had spherical and smooth SG which were also found in the form of clusters.



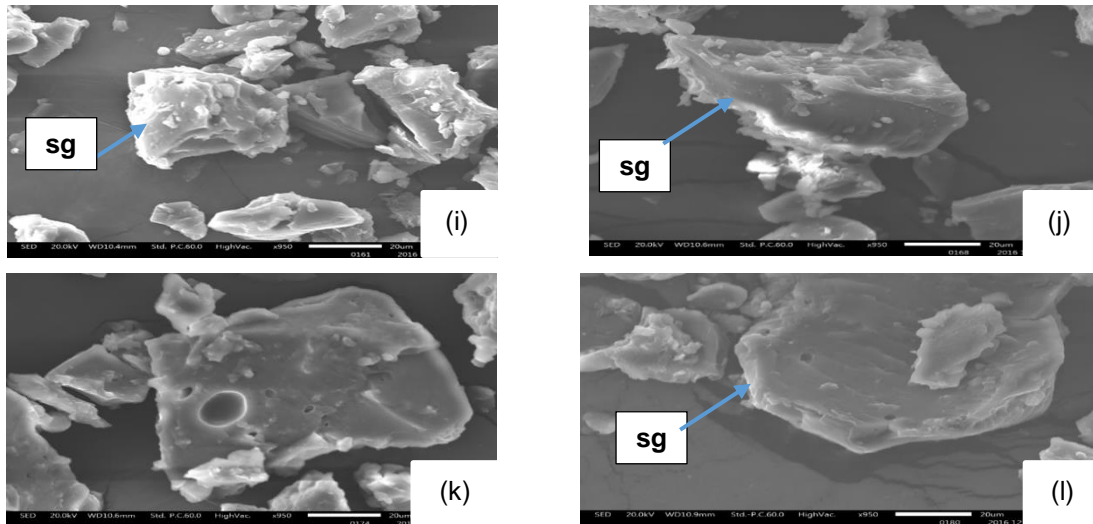
**Figure 15.** Microscopic structures of raw finger millet flours using Joel instrument. (a) = milky cream, (b) = brown, (c) = black and (d) = pearl millet. Scale bar 20 µm at magnification of x950. pb = protein bodies, cw = cell wall and sg = starch granules.



**Figure 16.** Microscopic structures of raw fortified finger millet flours using Joel instrument. (e) = milky cream, (f) = brown, (g) = black and (h) = pearl millet. Scale bar 20 µm at magnification. pb = protein bodies and sg = starch granules.

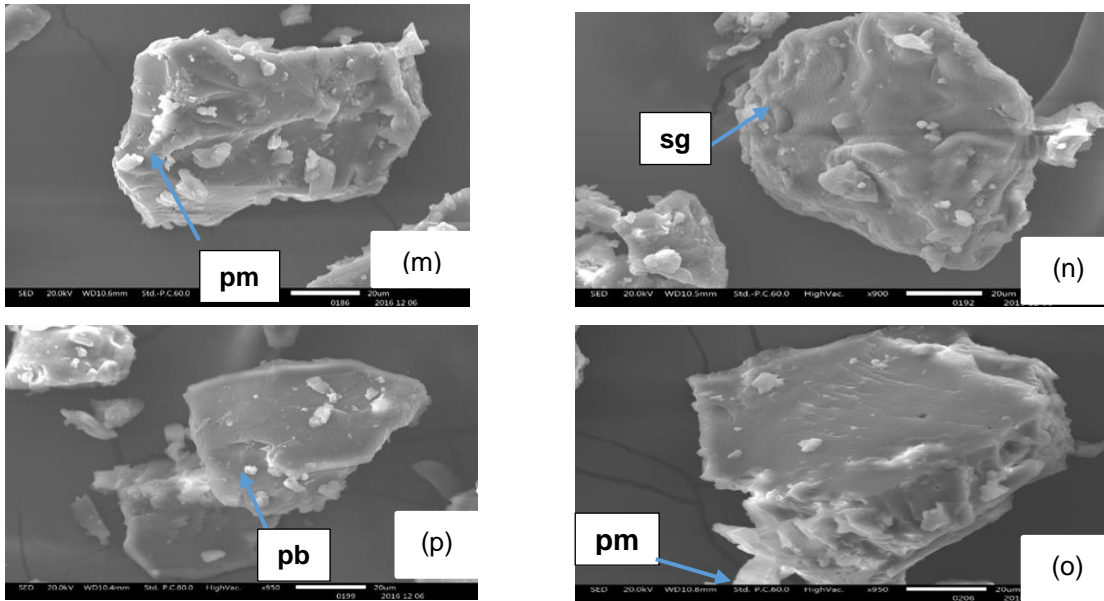
Figure 17 shows that IFM flours had irregular shapes that varied from small to large SG. The SG also had rough, dents and few small pores on brown IFM and in the IPM flours.

The milky cream IFM flour had several structure where some of the SGs were attached to each structures. The black IFM had one (1) big stone like structure which had a big pore and surrounded by small pores due to the rearrangement of molecular structure. Instant fortified finger millet flours had several rough like stone structures all over the surface with small SG attached to each stone.



**Figure 17.** Microscopic structures of instant finger millet flours using Joel instrument. (i) = milky cream, (j) = brown, (k) = black and (l) = pearl millet. Scale bar 20  $\mu$ m at magnification of x950. sg = starch granules.

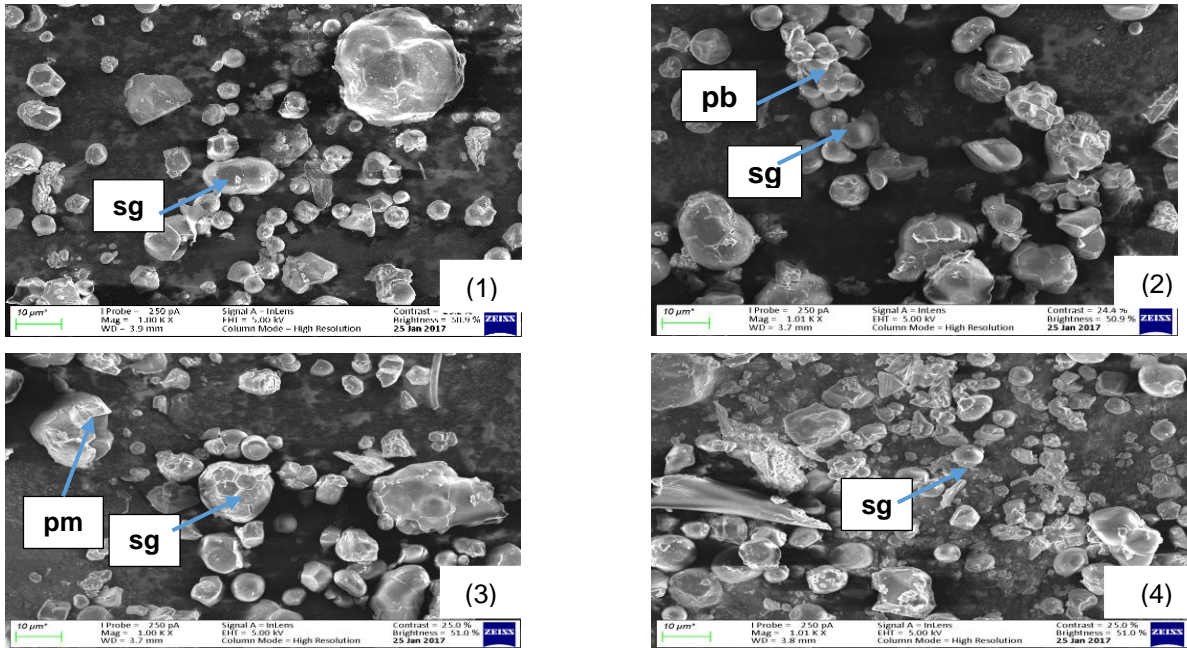
The IFPM flours had identical features as compared to other IFFM flours though they had small pores (Figure 18). The main causes of rough, dents and pores on the SG could have been caused by technological processes such as cooking the flour to porridge with the onset gelatinisation setting on flour (Sun et al., 2014). Raw fortified finger millet flours showed a positive effect after adding vit B<sub>2</sub> and ZnO as compared to IFFM flours from the MC, brown and black varieties.



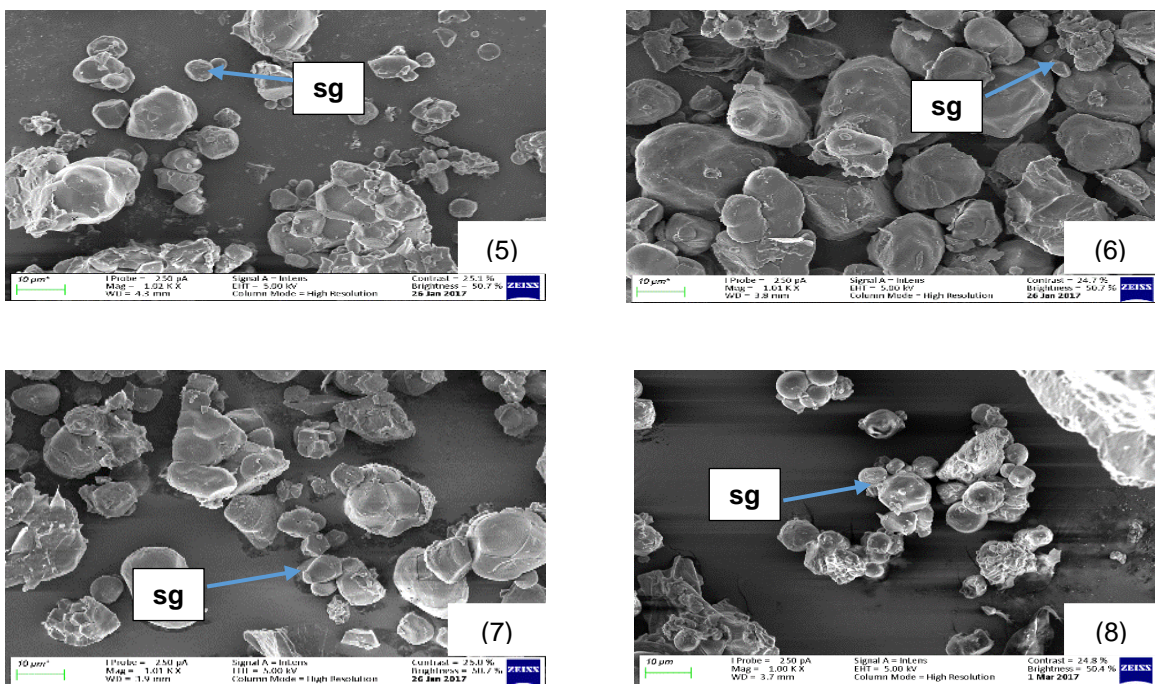
**Figure 18.** Microscopic structures of instant fortified finger millet flours using Joel instrument. (m) = milky cream, (n) = brown, (o) = black and (p) = pearl millet. Scale bar 20  $\mu\text{m}$  at magnification of x950. pb = protein bodies; pm = protein matrix and sg = starch granules.

An Energy Dispersive X-ray detector (Mervlin/ Evo Germany) instrument was used to observe the microscopic structures of FM flours studied. The majority of SG on RFM and the RPM flours had oval, shiny and smooth surfaces that individually stood out. The SG had different shapes and sizes that varied from small to large (Figure 19). The MC had one (1) SG that was identical to a ball. The proteins bodies and matrix on SG were clearly visible on the flours. The brown RFFM flour had totally different SG as compared to the brown RFM flour.

The SG granules were bigger and closer to each other. They also had different shapes and sizes that ranged from small to large. The RFPM had few small SG that were attached to each other and formed the clusters. The SGs of all FM flours appeared and only differed only in sizes and shapes. Most of the SG were attached to each other (Figure 20).

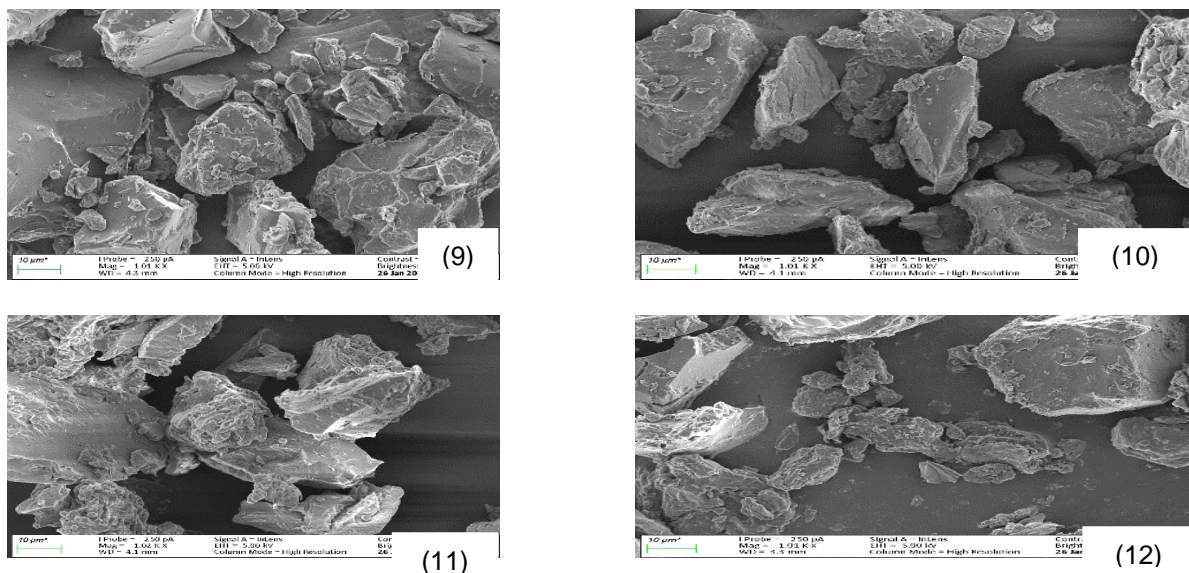


**Figure 19.** Microscopic structures of raw finger millet flours using Energy Dispersive X-ray detector. (1) = milky cream; (2) = brown; (3) = black and (4) = pearl millet. Scale bar 10 µm. pb = protein bodies; pm = protein matrix and sg = starch granules.

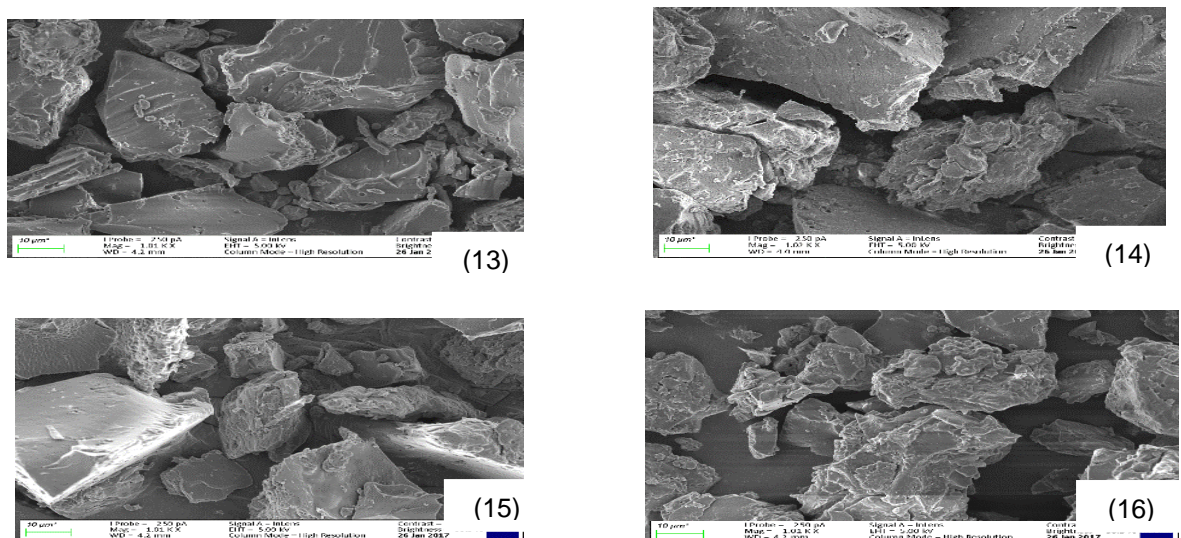


**Figure 20.** Microscopic structures of raw fortified finger millet flours using Energy Dispersive X-ray detector. (5) = milky cream; (6) = brown; (7) = black and (8) = pearl millet. Scale bar 10 µm pm = protein matrix and sg = starch granules.

The IFM flours had dents and rough surface with several structures that looked like stone including the IPM flours (Figure 21). Identical observations were showed made in IFFM flours which had different irregular shapes and sizes (Figure 22). The addition of fortificants showed a negative effect on IFM and IFFM flour due to gelatinisation of starch.



**Figure 21.** Microscopic structures of instant finger millet flours using Energy Dispersive X-ray detector. (9) = milky cream; (10) = brown; (11) = black and (12) = pearl millet. Scale bar 10  $\mu$ m.



**Figure 22.** Scanning electron microscopic structures of instant fortified finger millet flours using Energy Dispersive X-ray detector. (13) = milky cream; (14) = brown; (15) = black and (16) = pearl millet. Scale bar 10  $\mu$ m.

Both microscopic structure instruments used that is, the Joel SEM and Energy Dispersive X- ray detector had identical SGs especially on RFM and RFFM flours. The SGs observed using the Energy Dispersive X- ray detector had smooth and shiny SGs while most of the SGs observed using the Joel formed clusters on RFM and RFFM flours. The instant flours showed identical features such as rough surface, irregular shapes, dents and pores for the Joel SEM while the Energy Dispersive X- ray detector had no SG only structures that only looked like stones.

Anyasi *et al.* (2017) also reported the microstructures of unripe banana which were irregular shaped when compared to different varieties. The relationship between food processing conditions and microstructure changes of food components may influence the nutritional value of food and help to retain the quality of the flour.

#### 5.4. Conclusion

Pasting properties (cP) of the milky cream RFM and RFFM flours had significantly higher values in PV, FV, BDV and SV as compared to other RFM and RFFM flours. The brown IFM and IFFM flours had significantly higher values in PV, TV and FV. The IPM and IFPM showed significantly higher values in BDV and SV flours. PT and PV on the brown and black RFFM flours decreased after the adding of vit B<sub>2</sub> and ZnO. The addition of fortificants lead to a decreased in the pasting properties of milky cream IFFM flours on PV, TV, FV, BDV and SV as the moisture level of the flours decreased. The decreased of moisture content lead to an increase in the shelf-life of flour during storage at controlled temperature ranging from 20 to 25°C at a relative humidity of 35 to 50% depending on the laboratory environmental conditions (FDA, 2018) Thermal properties of the black RFM flours had significantly higher values in T<sub>o</sub>, T<sub>p</sub> and T<sub>c</sub> and RFFM starches had significantly higher values in T<sub>o</sub>, T<sub>p</sub> and T<sub>c</sub>. Milky cream IFM flour was significantly higher values in T<sub>o</sub>, T<sub>p</sub>, T<sub>c</sub> and ΔH. The brown IFFM starch showed significantly higher T<sub>o</sub> and T<sub>p</sub>. The IFPM had significantly higher values in ΔH and PHI as

compared to other FM starches. The thermal properties shows that MC and black FM starches showed significantly higher values as compared to other flours on  $T_o$ ,  $T_p$  and  $T_c$ . Thermal properties ( $^{\circ}\text{C}$ ) of the milky cream IFFM starches decreased after adding the fortificants on  $T_o$ ,  $T_p$ ,  $T_c$ ,  $\Delta H$ , PHI and GTR.

The morphology of RFM and RFFM flours were spherical and had smooth surfaces while instant FM flours had holes, dents and rough surfaces. The addition of fortificants on RFM and RFFM flours showed a positive effect while the IFM and IFFM flours showed a negative effect. The relationship between food processing conditions and microstructure changes of food components may influence the nutritional value of food and help to retain the quality of the products. Functional properties showed that the MC and brown flours may be utilised for commercial purpose to produce value-added products that can be consumed by all age groups.

## CHAPTER 6. GENERAL CONCLUSION AND RECOMMENDATIONS.

### 6.1. Conclusion

Three (3) different finger millet (FM) varieties were studied including the pearl millet (PM) variety that was used to compare the results of FM flours as most of the studies were conducted on the PM. FM grains were sorted from mixed FM samples. Technological challenges were encountered during sorting as FM grains were tiny and similar to sand or stones especially the brown and black FM varieties. The brown variety was found in large quantities as compared to the black and milky cream FM varieties.

Physical properties of the FM varieties were determined in order to help know the size and shape such as geometric mean diameter. These may help the manufacturer to design better equipment used for harvesting, processing, storage and packaging.

Moisture content values were low which shows that low values indicate the long shelf-life of FM. The milky cream FM variety showed significantly higher ( $p < 0.05$ ) values on moisture content, 1 000 kernel weight, true density, aspect ratio and sphericity. The grains had significantly higher values in terms of width, thickness and colour attributes ( $L^*$ ,  $b^*$ ,  $C^*$  and  $H^0$ ) as compared to the brown and black FM grains.

The milky cream FM flour showed significantly higher ( $p < 0.05$ ) values on moisture content and ash content. There is no negative effect on moisture content as the values obtained were within the specified range of  $<12\%$ . Ash content increased which showed an increase in the mineral concentrations of the FM flours.

Crude protein and crude fibre did not indicate a negative effect on FM flours because the values obtained for all flours were within the specified values. The ZnO increased on the milky cream for RFM and IFM flours after adding the fortificant as compared to brown and black FM flours. Milky cream RFFM and IFFM flours showed significantly higher values and vit B<sub>2</sub> was also obtained from RPM and IPM flours.

MCFM flours showed significantly higher values on colour attributes ( $L^*$ ,  $b^*$ ,  $C^*$  and  $H^0$ ) as compared to other FM flours. The MCFM flours showed significantly higher values for BD, WAC, OAC, SI, FC, dispersibility pasting properties and thermal properties as compared to the brown and black FM flours. Raw flours showed a positive effect after adding the fortificants, the starch granules were oval, spherical in shape and formed clusters. Instant flours had a negative effect after adding the fortificants because of technological process such as cooking that formed starch to gelatinised.

The MCFM flours showed significantly higher values in most of the parameters studied. Consumers may also prefer MC and brown FM flours since they have similar colour as compared to maize and sorghum flours which are staple foods to most African countries which include South Africa and Zimbabwe. The MC and brown FM flours may be used to produce food products and ready-to-eat products that can be consumed by all age groups.

The addition of vit B<sub>2</sub> and ZnO to FM flours indicate the excellent source of riboflavin, zinc, crude fibre, calcium and other minerals. Therefore, fortified FM flours could be the best option in reducing the prevalence of vit B<sub>2</sub> and Zn and hunger in developing countries as it can be used to produce ready-to-eat food products which are essential in the human diet.

## **6.2. Recommendation for future research**

Future studies that need to be conducted on three (3) FM flours include sensory evaluation, rheological properties, farinogram, extensigram, falling number, antioxidant activities, phenolic compounds, amino acids and optimisation using response surface methodology. A survey on consumer wellness study need to be conducted in order to promote the use of finger millet food products in South Africa and other African countries. There is also a need of the commercialisation and innovation of new product development produced from fortified FM flours in the developing and developed countries using three varieties (milky cream, brown and black as discussed in this study).

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## APPENDIX I TYPES OF MILLET SPECIES



(a) = Finger millet



(b) = Foxtail millet and (c) = Pearl millet



(d) = Proso millet and (e) = Banyard millet



(f) = Teff millet and (g) = Kodo millet

## APPENDIX II LIST OF ARTICLE IN CONFERENCE PROCEEDING/ PUBLICATIONS

Results from this thesis have been presented at conferences, submitted for publication and published as review and original research articles.

### Conference.

Ramashia, S.E., Jideani, A. I. O., & Gwata, E. T. (2015). Research gaps on scientific investigation of finger millet (*Eleusine coracana*) grain. 21st SAAFoST Biennial Congress and Exhibition, Durban, 06 - 09 September 2015. SAAFoST Publication. [www.saafost.org.za/Events/BRANCH-All/2015/Sep6-9SAAFoST](http://www.saafost.org.za/Events/BRANCH-All/2015/Sep6-9SAAFoST).

### Journals.

Ramashia, S. E., Gwata, E. T., Meddows-Taylor, S., Anyasi T. A., & Jideani, A. I. O. (2018). Some physical and functional properties of finger millet (*Eleusine coracana*) obtained in sub-Saharan Africa. *Food Research International*, 104, 113-118.

Ramashia, S. E., Gwata, E. T., Meddows-Taylor, S., Anyasi T. A., & Jideani, A. I. O. (2017). Processing, nutritional composition, and health benefits of finger millet in sub-Saharan Africa. *Food Science and Technology*. *Submitted manuscript*.

### Food Science and Technology Magazine.

Ramashia, S. E., Gwata, E. T., Meddows-Taylor, S. & Jideani, A. I. O. (2018). Fortification of finger millet flours with vitamin B<sub>2</sub> and zinc oxide. *Food Science and Technology Magazine*, South African Association for Food Science and Technology will be published in November 2018 issue.

### APPENDIX III LIST OF CONFERENCES ATTENDED

Ramashia, S. E., Jideani, A. I.O. & Gwata, E. T. (2015). Research gaps on scientific investigation of finger millet (*Eleusine coracana*) grain/ flour. 21<sup>st</sup> SAAFoST Biennial International Congress and Exhibition, 06-09 September 2015, Durban, KwaZulu-Natal province, South Africa.

Ramashia, S. E., Jideani, A. I. O. & Gwata, E. T. (2015). Fortification of finger millet (*Eleusine coracana*) flour with vitamin B<sub>2</sub> and zinc oxide. 21<sup>st</sup> SAAFoST Biennial International Congress and Exhibition, 06-09 September, Durban, KwaZulu-Natal province, South Africa.

Ramashia, S. E., Jideani, A. I. O. & Gwata, E. T. (2016). Some physical properties of finger millet (*Eleusine coracana*) grain cultivars grown in sub-Sahara Africa. Autumn International Conference in Food Safety and Safety, 16-18 May, University of Johannesburg, Doornfontein Campus, Gauteng, South Africa.

Ramashia, S. E., Gwata, E. T., Meddows-Taylor, S. & Jideani, A. I. O. (2017). Effect of fortification on functional properties of fortified finger millet (*Eleusine coracana*) flours with vitamin B<sub>2</sub> and zinc oxide. (2017). 22<sup>nd</sup> SAAFoST Biennial International Conference and Exhibition, 3-6 September, Century City, Cape Town, South Africa.

Ramashia, S. E., Gwata, E. T., Meddows-Taylor, S. & Jideani, A. I. O. (2017). Influence of vitamin B<sub>2</sub> and zinc oxide fortification on the microstructure of finger millet (*Eleusine coracana*) flour. 22<sup>nd</sup> SAAFoST Biennial International Conference and Exhibition 3-6 September 2017, Century City, Cape Town, South Africa.

Ramashia, S. E., Gwata, E. T., Meddows-Taylor, S. & Jideani, A. I. O. (2018). Assessment of mineral contents in finger millet flours fortified with zinc oxide. 21<sup>st</sup> Century: A Global Sorghum Conference, "Feed, Fuel in a Rapid changing the world", 9-12 April 2018, Century City Conference Centre, Cape Town, South Africa.



Ramashia, S. E., Gwata, E. T., Meddows-Taylor, S. & Jideani, A. I. O. (2018). Effect of fortification on thermal properties of finger millet flours fortified with vitamin B<sub>2</sub> and zinc oxide. 5<sup>th</sup> International ISEKI-Food Conference. "The Food System Approach: Challenges for Education, Research and Industry" at University of Hohenheim, Germany, 3-5 July 2018.