COMPARATIVE EVALUATION OF GROUND AND UN-GROUND GRAIN SAMPLES OF PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.) AND SORGHUM (*Sorghum bicolor* (L.) Moench) FOR TOTAL ZINC AND IRON CONTENTS

Draft Report Submitted to

ACHARYA N G RANGA AGRICULTURAL UNIVERSITY
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By

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Science with a human face

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BY

Magdalena N Hangula

B.Sc. (Ag.)

THESIS SUBMITTED TO THE
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IN PARTIAL FULFILMENT OF THE REQUIREMENTS
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COLLEGE OF AGRICULTURE
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RAJENDRANAGAR, HYDERABAD 500 030

AUGUST, 2009

CERTIFICATE

This is to certify that the project entitled "**Comparative Evaluation of Ground and Un-Ground Grain Samples of Pearl Millet (*Pennisetum glaucum* (L.) R. Br.) and Sorghum (*Sorghum Bicolor* (L.) Moench) for Total Zinc and Iron Contents**" submitted in partial fulfillment of the degree of Master of Science in Soil Science and Agricultural Chemistry to Acharya N G Ranga Agricultural University done by **Mrs. Magdalena N Hangula** is an authentic work carried out by her at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, under my supervision during the period of November 2008 to August 2009. The matter embodied in this project work has not been submitted earlier for award of any degree or diploma to the best of my knowledge and belief.

Kanwar Sahrawat

(Signature of the Guide)

Name & Designation: Dr Kanwar L Sahrawat
Visiting Scientist (Soil Chemistry)

Place : Patancheru
Date : 13 August 2009

DECLARATION

I, Magdalena N HANGULA, hereby declare that the thesis entitled "**Comparative Evaluation of Ground and Un-Ground Grain Samples of Pearl Millet (*Pennisetum glaucum* (L.) R. Br.) and Sorghum (*Sorghum Bicolor* (L.) Moench) for Total Zinc and Iron Contents**" submitted to the Acharya N.G. Ranga Agricultural University for the degree of **MASTER OF SCIENCE IN AGRICULTURE** is a result of original research work done by me. It is further declared that the thesis or part thereof has not been published earlier in any manner.

Date: 13-08-09
Place: Hyderabad

(Magdalena N Hangula)

Title	:	**COMPARATIVE EVALUATION OF GROUND AND UN-GROUND GRAIN SAMPLES OF PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.) AND SORGHUM (*Sorghum bicolor* (L.) Moench) FOR TOTAL ZINC AND IRON CONTENTS**
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Submitted	:	**August 2009**

Abstract

A study was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India to compare grain Zn and Fe determined in ground and un-ground samples of a range of sorghum and pearl millet cultivars varying in grain size. The 1000 grain weight of pearl millet samples ranged between 4.7 and 9.4 g for the small grain cultivars, whereas for the bold grain cultivars it ranged from 10.0 to 13.0 g. In sorghum, the grain size ranged between 9.6 and 19.3 g for the small grain cultivars and ranged from 26.9 to 46.4 g for the bold grain cultivars.

Grain Fe in pearl millet cultivars determined using ground samples ranged from 26.6 to 81.5 mg kg^{-1} and it ranged from 26.5 to 81.7 mg kg^{-1} when determined with un-ground samples. Grain Zn ranged from 18.7 to 73.7 mg kg^{-1} for ground and from 19.5 to 72.1 mg kg^{-1} for the un-ground samples. The analysis of variance indicated a significant difference in grain Fe due to grain size for the ground and un-ground pearl millet samples. However, there was no significant difference in grain Zn due to grain size between ground and un-ground samples.

For sorghum, grain Fe varied from 18.2 to 65.1 mg kg^{-1} in ground samples and from 19.0 to 65.0 mg kg^{-1} in un-ground samples. Grain Zn ranged from 16.9 to 61.0 mg kg^{-1} in ground and from 16.5 to 61.0 mg kg^{-1} in un-ground samples. There was no significant difference due to grain size between ground and un-ground samples for both Fe and Zn.

There was a significant correlation between grain Fe and Zn values determined using ground and un-ground pearl millet and sorghum cultivars. The results of this study with selected but diverse cultivars suggest that grain Fe and Zn in sorghum and pearl millet can be determined on un-ground samples and obviously there is a need to further confirm these results with a larger number of cultivars of these crops.

BIOGRAPHICAL SKETCH

The author was born in 10 December 1975 at Elombe, Ongwediva, Namibia. She attended primary school at Oikango Combined School and high school education at Mweshipandeka Senior Secondary School.

Magdalena joined Ogongo Agricultural College in 1996 and completed a three years Diploma course in Agriculture in 1998. Upon graduation, she was recruited as a Research Technician in the Plant Science Project at Ongwediva Agricultural Development Centre until December 1999. In January 2000, Magdalena joined University of Namibia to pursue undergraduate studies with B.Sc. Degree in Agriculture (Crop Science) until 2003. Upon graduation, she was recruited as Agricultural Researcher at Okashana Research Station in the Ministry of Agriculture, Water and Forestry in 2004. After four years of service, she joined Acharya N G Ranga Agricultural University in October 2007 to pursue postgraduate studies leading to M.Sc. Degree in the field of Soil Science and Agricultural Chemistry.

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LIST OF SYMBOLS AND ABBREVIATIONS

AAS	:	Atomic Absorption Spectroscopy
ANGRAU	:	Acharya N G Ranga Agricultural University
ANOVA	:	Analysis of Variance
BD 40	:	Block Digester 40
CIAT	:	International Centre for Tropical Agriculture
CRAL	:	Charles Renard Analytical Laboratory
CD	:	Critical difference
CV	:	Coefficient of variance
et al	:	and others
FCRD	:	Factorial Complete Randomized Design
Fe	:	Iron
g	:	Grams
H_2SO_4	:	Sulphuric acid
ICRISAT	:	International Crops Research Institute for the Semi Arid Tropics
IRRI	:	International Rice Research Institute
LSD	:	Least Significant Difference
LSU	:	Learning System Unit
mg kg^{-1}	:	Milligrams per kilogram
nm	:	Nano meter
SAT	:	Semi-Arid Tropics
ug ml^{-1}	:	Micrograms per millilitre
Zn	:	Zinc
%	:	Per cent

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(M N HANGULA)

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CHAPTER – I

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] and Pearl millet [*Pennisetum glaucum* (L.) R. Br.] are important staple food in the semi-arid tropics (SAT) of Asia and Africa. These crops are still the principal sources of energy, protein, vitamins and minerals for millions of the poorest people in these regions. These crops sustain the lives of the poorest rural people and will continue to do so in the foreseeable future. Sorghum and pearl millet grow in harsh environments where other crops do not grow well. Improvements in the production, availability and consumption of these food crops will significantly contribute to the household food security and nutrition of the inhabitants in the SAT region of Asia and Africa.

Sorghum is the world's fifth most important cereal in terms of both production and the area planted. Roughly 90% of the world's sorghum area and 95% of the world's millet area lie in the developing countries, mainly in Africa and Asia (Irén Léder 2004). In terms of global production, pearl millet is the sixth most important cereal crop after wheat, rice, maize, barley and sorghum (FAO and ICRISAT 1996). These crops are primarily grown in poor areas subject to low and erratic rainfall and drought where other grain crops do not produce without irrigation; and because of their excellent tolerance to drought, sorghum and pearl millet are able to grow and yield in the drier environment.

Pearl millet, grown in 26 million ha in some of the most marginal arid and semi-arid tropical environments of Asia (11 million ha) and Africa (15 million ha), is a major source of dietary energy and nutritional security for a vast population in these regions (Velu *et al.* 2008).

The sorghum kernel varies in colour, size and shape. The 1000-kernel weight of sorghum has a wide range and varies from 3 to 80 g, but for majority of the varieties it varies between 25 and 30 g. The pearl millet kernel too varies in colour, shape and size. The ovoid grains are about 3-4 mm long and the 1000 grain weight ranges from 2.5 to 14 g with a mean of 8 g. The size of the pearl millet kernel is about one third that of sorghum. The relative proportion of germ to endosperm is higher in pearl millet than in sorghum. (O'Kennedy 2006).

Zinc (Zn) and iron (Fe) are important micronutrients in human food. Micronutrient malnutrition alone and various vitamin deficiencies afflict over 3 billion world-wide. The consequences to human health, felicity, livelihoods and national development are staggering, resulting in increased mortality and morbidity rates, decreased worker productivity and poverty (Kumar, 2000).

Iron and Zn, are essential elements in plant growth and metabolism and they exist in soil in different forms such as primary and secondary minerals, insoluble inorganic and organic precipitates, soluble organic complexes and in exchangeable and adsorbed forms and in soil solution (Sureshkumar *at el.,* 2004). The amount and rate of transformation of these forms of zinc to available form (exchangeable plus in soil solution) determine the size of the labile zinc pool in the soil.

Zinc is one of the essential micro-nutrient elements and has attained prominence in human nutrition and health. The most widespread known nutritional deficiency in humans is that if iron, but especially in the calcareous upland soils applied Fe fertilizer is converted to ferric iron, which is insoluble and unavailable for plant uptake. Significantly, Fe deficiency in the humans can be due to causes other than Fe-deficient soils and low-Fe food crops. It can also be caused by Zn, vitamin A, beta-carotene, iodine and selenium deficiencies. Zn deficiency is the most widespread problem (Graham *et al.*, 2007). Iron deficiency is often accompanied by zinc deficiency as both of these nutrients are derived from similar sources in the diet (Welch, 2001).

Information on the grain nutrient concentration indicates the nutritional status and is used as a diagnostic tool for advisory purpose. The total uptake of Zn and Fe by pearl millet is 40 g/t and 170 g/t respectively, while for the sorghum crop it is 72 g/t of Zn and 720 g/t of Fe (Tandon, 2005). Zinc deficiency in soils not only reduces crop productivity, but also leads to low-Zn feed and food, causing animal and human malnutrition. This problem is experienced globally. However, it is more acute in the arid and semi-arid regions of the world. Livestock and humans fed on Zn-poor feed and food, particularly with high calcium levels, are liable to suffer from Zn malnutrition (Rashid and Ryan 2004).

To assess the quality of grain and other food materials for Fe and Zn nutrition, the analytical techniques to determine Fe and Zn should be simple, rapid, precise and accurate. Also, at the time of sample preparation the contamination of grains with Fe and Zn is a serious problem in their analysis. This contamination can occur during grinding of the grain samples for preparing them for analysis in the laboratory. However, it is argued that if the analysis of the grains is conducted without their grinding, this source of potential contamination and error in the analysis could be avoided. For the large-seeded size crops the grinding, however, is inevitable. For the relatively small-seeded crops such as pearl millet and sorghum, the grinding step could probably be skipped and un-ground grain samples could be used for analysis in the laboratory. With this objective in view, it was decided to compare and evaluate the results of Zn and Fe analysis performed on un-ground and ground samples of pearl millet and sorghum cultivars with varying grain sizes.

Literature available on Fe and Zn contents of ground and un-ground grains for both sorghum and pearl millet is very limited/scarce and no studies have been conducted to evaluate the same. Hence, this study was undertaken to analyse the Fe and Zn contents of both ground and un-ground grains of sorghum and pearl millet.

The specific objectives of the study are:

Objectives

- To determine and compare the results of Zn and Fe analysis in the ground and un-ground grain samples of diverse sorghum and pearl millet varieties.

- To study the effects of grain size of sorghum and pearl millet on Zn and Fe determination by the two methods of sample preparation.

- To study the variability in grain Zn and Fe in selected pearl millet and sorghum varieties.

CHAPTER – II
REVIEW OF LITERATURE

The present review is aimed to include the information which is most relevant to the problem studied.

Literature on evaluation of ground and un-ground grains of pearl millet and sorghum and with regard to analysis of Fe and Zn contents is not available. This is the first time the crops are being evaluated. Also in the past, pearl millet and sorghum being millets received less attention related to nutrient management especially with regard to micronutrients. Hence, the literature is less in its volume.

2.1 Thousand grain weight of pearl millet and sorghum

Mathur *et al.*, (1993) determined 1000 seed weight in g at 12% moisture of pearl millet and reported that the content varied from 2.54 to 19.32 with a mean of 8.6 g. Vanderlip *et al.*, (1995) reported that the average 1000 seed weight of 8.9 g for pearl millet and 25.2 g for sorghum.

Velu 2006, reported on the variability of 1000 grain weight in pearl millet to be ranging between 6.1 to 12.8 g in summer and 6.1 to 12.6 g in rainy season in an experiment carried out at ICRISAT.

In another trial carried out at ICRISAT, Velu, 2006, reported that the 1000 grain mass of pearl millet ranging from 7.0 – 14.0 g during both rainy and summer seasons. All the selected 12 varieties with high Fe and Zn content populations had larger seed size 9.6 – 13.3 g when compared to popular check WC-C75 (9.4 g).

2.2 Fe and Zn in Pearl millet grain

Velu *et al.,* (2008) conducted an experiment at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) farm in Patancheru, Andhra Pradesh, India to examine Fe and Zn variability in pearl millet grain. They found that the mean content of Fe ranged from 42.0 to 79.9 mg kg^{-1} and Zn content ranged from 27.2 to 50.2 mg kg^{-1}.

The prospects of breeding biofortified pearl millet with high grain iron and zinc content were examined and it was found that in a diverse genetic materials consisting of 40 hybrid parents, 30 each of populations and 20 germplasm accessions, the grain Fe varied from 30.1 to 75.7 mg kg^{-1} on dry weight basis and Zn varied from 24.5 to 64.8 mg kg^{-1}. The highest level of grain Fe and Zn were observed in well adapted commercial varieties and their progenies (Velu *et al.*, 2007).

In another study, the grain Fe content among hybrids of pearl millet, it ranged from 52.1to 87.5 mg kg^{-1} in the rainy season, whereas it ranged from 41.7 to 86.2 mg kg^{-1} in the summer season. The average grain Fe content was 19% higher in the rainy season (69.2 mg kg^{-1}) than that in the summer season (58.2 mg kg^{-1}), which may be due to the increased availability of Fe in the soil as indicated by higher available Fe in the soil during the rainy season than in the summer season. However, the mean grain Zn content of the hybrids was comparable in the rainy season and summer seasons (Velu *et al.*, 2007).

There was no difference in the available soil Zn in the two seasons. Based on the mean performance across the two environments, the Fe content among the pearl millet hybrids varied from 46.9 to 85.0 mg kg^{-1} and Zn content varied from 36.4 to 69.9 mg kg^{-1}. Twenty-six hybrids (half of the total hybrids in the trial) had more than 63.7 mg kg^{-1} Fe, well over the trial mean and the check hybrid 'HHB 67-improved'. Of these, 17 hybrids had Zn content well over the trial mean as well as over 'HHB 67- improved'. Eighteen hybrids had >70 mg kg^{-1} Fe, of which 11 hybrids had >50 mg kg^{-1} Zn (Velu *et al.*, 2007).

Towo *et al.*, (2006) reported on the effects of phytate and iron-binding phenolics on the content and availability of iron and Zinc in micronutrient fortified cereals (maize and pearl millet). They concluded that it improved the content of nutrients and the average total Fe was 42.26 mg kg^{-1} in the unfortified and 52.67 mg kg^{-1} in the fortified cereals. The average Zn content was 21.4 mg kg^{-1} and 25.9 mg kg^{-1} in the unfortified and fortified cereals, respectively.

Among the 21 entries selected for high Fe and Zn content, 16 had higher grain mass (9.1 to 12.5 g), compared to check WC-C75 (8.9 g). The entries with higher grain mass (11.1 – 12.5 g) had higher variability for Fe 32.4 – 75.7 mg kg^{-1} and Zn content 31.7 – 64.8 mg kg^{-1} with higher mean 57.0 mg kg^{-1} Fe and 51.3 mg kg^{-1} Zn. The entries with lower grain mass (6.5 – 9.5 g) had lesser variability for Fe 30.1 – 60.4 mg kg^{-1} and Zn content 24.5 – 59.6 mg kg^{-1} with lower mean 44.1 mg kg^{-1} Fe and 43.9 mg kg^{-1} Zn (Velu, 2006).

Velu (2006) reported on Fe and Zn contents in pearl millet grains. Among the populations identified for high grain Fe and Zn content, ICTP 8203 (13.3 g) had the highest 1000 grain mass followed by GG bulk (12.4 g). the populations with higher grain weight 11.1 – 14.0 g had more variability for grain Fe (44.1 – 79.9 mg kg^{-1}) and Zn (35.8 – 50.2 mg kg^{-1}) with higher mean 72.1 mg kg^{-1} Fe and 45.6 mg kg^{-1} Zn, whereas the populations with lower grain weight 6.5 – 9.5 g had less variability for grain Fe 43.5 – 59.7 mg kg^{-1} and Zn content 28.6 – 43.2 mg kg^{-1} with lower mean 51.3 mg kg^{-1} Fe and 36.6 mg kg^{-1} Zn.

Large and significant differences ($P < 0.01$) were observed for grain Zn content among parents (28.8-51.4 mg kg^{-1}) and hybrids (26.4-52.5 mg kg^{-1}) of pearl millet. Differences in general combining ability (GCA) among parents and in specific combining ability (SCA) among hybrids were also highly significant. The interaction of season with GCA was significant, and it was of smaller magnitude than the GCA variance. Also, there was a highly significant positive correlation ($r = 0.81$; $P < 0.01$) between mid-parental values and mid-parent heterosis, which was an additional indication of the predominant role of additive gene action for this trait (Velu *et al.*, 2007).

Hulse *et al.*, (1980) summarized the results of a few studies indicating as high as 38 mg kg^{-1} of Fe and 16 mg kg^{-1} of Zn in pearl millet grains. Another preliminary study was done with a limited number of 27 genotypes showed large variation for Fe (40 – 580 mg kg^{-1}) and Zn content (10 – 66 mg kg^{-1}) in pearl millet grains (Jambunathan and Subramanian 1988).

Irén Léder (2004) reported that the mean grain Fe in pearl millet and sorghum cultivars was 74.9 mg kg^{-1} and 50 mg kg^{-1}, respectively; and the mean Zn content was 29.5 mg kg^{-1} and 15.4 mg kg^{-1} for pearl millet and sorghum, respectively.

2.3 Fe and Zn content in Sorghum grain

Kayode *et al.*, (2006) studied the genetic and environmental effects on Fe and Zn contents in sorghum grain. The Fe concentration in grain ranged from 30 to 113 mg kg^{-1} with an average of 58 mg kg^{-1}; and the Zn concentration ranged from 11 to 44 mg kg^{-1} with an average of 25 mg kg^{-1}. The grain Fe and Zn did not show consistent linkage to genetic variation but varied significantly across various sites.

Sreeramaih *et al.*, (2007) studied Zn and Fe contents and their bio-availability in cereals and pulses consumed in India. The results showed that bio-available of Zn content of cereals ranged from 1.08 mg kg^{-1} in rice to 2.24mg100g^{-1} in sorghum. Iron content of cereals ranged from 1.32mg/100 in rice and 6.51 mg g^{-1} in sorghum.

Reddy *et al.*, (2005) evaluated different classes of breeding lines and germplasm accessions (n = 84) for grain Fe and Zn content in sorghum at ICRISAT. The grain Fe and Zn varied from 20.1 to 37.0 mg kg^{-1} with an average of 28 mg kg^{-1}, and grain Zn content varied from 13.4 to 31.0 mg kg^{-1} with a mean of 19.0 mg kg^{-1}. The grain Fe and Zn contents in germplasm accessions were significantly higher than those in other classes of breeding materials.

2.4 Uptake of Fe and Zn by Pearl millet and Sorghum

Gupta *et al.*, (1998) reported that the mean uptake of Zn and Fe by a single crop of pearl millet was higher than that of wheat. This is because crops differ significantly in their requirements for micronutrients. Post-harvest chemical analysis of soil after taking crops showed that DTPA extractable Zn was reduced from initial 0.94 mg kg^{-1} to 0.74, 0.68, 0.64 and 0.59 mg kg^{-1} in control, low, medium and high fertility treatments, respectively. There was no change in DTPA extractable Fe at initial stage and in the control, whereas the medium fertility resulted in an increase of 1.3 mg kg^{-1} soil.

Prasad (2006) reported responses to Zn application in crops in different states of India and on an average, the yield advantage with Zn application was 375 kg (19.1%) in pearl millet. Zn nutrition also improved physical quality of the produce and the crop had fewer incidences of pests. Zn nutrition hastened crop maturity. As a result of improved grain size and better produce quality, the produce from Zn-treated fields got better acceptance and market prices.

Results of analysis of soil samples for chemical fertility parameters indicated a wide spread deficiency of sulfur (S), boron (B) and Zn in farmers' fields in the semi arid region of India. These results further suggest that the S, B and Zinc reserves in the dry lands are exhausted due to continuous cropping without adequate application of the plant nutrients (Rego *et al.*, 2007).

Reddy *et al.*, (2006) indicated significant differences on the genotype variability and first-order interaction of genotype with soil type and second-order interaction of genotype with soil type and different micronutrient-fertilization on grain-Fe and Zn in the sorghum cultivars. Soil type did not significantly affect the grain-Zn content of the tested sorghum lines, but affected grain-Fe content. Interestingly, non-significant variance due to micronutrient fertilization levels suggested poor evidence of the effect of soil-micronutrient fertilization on grain-Fe and Zn contents in any particular soil type. However, significant mean squares due to interaction of micronutrient-fertilization levels with soil type indicated that grain-Zn (but not Fe) content of genotypes varied with a given combination of micronutrient level and soil type.

The relationship between soil available Zn status and the corresponding mineral contents in rice seed has been studied and there was significant increase ($p<0.05$) in the mean zinc content of rice grain sample with increasing soil zinc levels. A significant positive correlation was obtained between soil Zn levels and Zn content of the rice grain ($r=0.97^{**}$). The iron content in rice grain samples was lower when grown on high zinc status soils compared to low zinc status in soils. The iron content of rice was negatively and significantly correlated with soil zinc levels (Anonymous, 2000).

2.5 Variability for grain Fe and Zn in other crops

Large variability for grain Fe and Zn has also been reported in other crops. For instance, Monasterio (1998) found four to five fold variation for grain Fe and Zn content in the several hundred accessions of wheat. The highest concentrations were about twice than those popular modern cultivars. However, Fe and Zn content in wild relatives were 50% higher than in the modern wheat cultivars.

A diverse range of 132 wheat germplasm accessions was evaluated at International Centre for Wheat and Maize Improvement (CIMMYT), Mexico for Fe and Zn content in the grain. The variability for Fe and Zn content were 28.8 – 56.5 mg kg^{-1} for Fe and 25.2 – 53.3 mg kg^{-1} for Zn (Monasterio and Graham, 2000).

Imtiaz *et al.*, (2003) assessed the Zn content of prominent wheat varieties and the varieties collected from different countries. The grain Zn content ranged between 10 to 34 mg kg^{-1} and the highest Zn content (34 mg kg^{-1}) was observed in a variety Pirsabak and the lowest content was noticed in Turkish variety CBWF-96-151 (10 mg kg^{-1}).

Core collection of over 1000 accessioons of common bean (*Phaseolus vulgaris* L.) was screened for grain Fe and Zn content at the International Centre for Tropical Agriculture (CIAT), Columbia. The seed Fe content ranged between 34 to 89 mg kg^{-1} and Zn content ranged from 21 to 54 mg kg^{-1}. Some bean accessions from Peru were found to contain high levels of Fe averaging over 100 mg kg^{-1}. The range in seed Zn content in the core collection was narrower than seed-Fe (Beebe *et al.*, 2000). Wild types tended to have lower Zn concentrations than common cultivated types. House *et al.*, (2002) reported genetic variability of seed Zn content varying from 26.7 to 62.4 mg kg^{-1} in different classes of dry bean cultivars.

Banziger and Long (2000) screened 1814 accession of core collections, breeding lines and populations of maize at CIMMYT, Mexico for grain Fe and Zn content. The grain Fe content ranged between 9.6 to 63.2 mg kg^{-1} and grain Zn content varied between 12.9 to 57.6 mg kg^{-1}. The extent of genetic variation for grain Fe and Zn content in 109 maize inbred was evaluated by Maziya-Dixon *et al.*, (2000). The grain Fe content varied from 15 to 159 mg kg^{-1} for mid-altitude and from 14 to 134 mg kg^{-1} for lowland maize inbred lines; Zn content varied from 12 to 96 mg kg^{-1} for mid-altitude inbred and from 24 to 96 mg kg^{-1} for lowland inbred lines.

Gregorio *et al.*, (2000) evaluated 1138 brown rice genotypes for grain Fe and Zn content at the International Rice Research Institute (IRRI), Philippines. The Fe content varied from 6.3 to 24.4 mg kg^{-1} and Zn content from 13.5 to 58.4 mg kg^{-1}. The highest grain Fe content ranged from 18 to 22 mg kg^{-1} and Zn content 24 to 35 mg kg^{-1} were found in aromatic rice varieties.

CHAPTER – III
MATERIALS AND METHODS

The methodology followed for conducting the present laboratory research work is explained here under.

3.1. Location

The study was carried out at the Charles Renard Analytical Laboratory (CRAL), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, and Andhra Pradesh India. It is located at the longitude 17° 32' N and latitude 78° 16' E and altitude 545 meters above sea level.

3.2 Treatments

The experiment consisted of three factors as detailed below:

3.2.1 Factors

Factor 1: Two crops

- Crop 1 (C1) - Pearl millet
- Crop 2 (C2) – Sorghum

Factor 2 **Two treatments**

- Treatment 1 (UG) - Un-ground grain samples
- Treatment 2 (G) - Ground grain samples

Factor 3: **Two grain sizes**

- Pearl millet Size 1 (S1) - Small grains < 10g/1000 seed weight
- Pearl millet Size 2 (S2) - Bold grains > 10g/1000 seed weight
- Sorghum Size 1 (S1) - Small grains < 20g/1000 seed weight
- Sorghum Size 2 (S2) - Bold grains > 20g/1000 seed weight

No. of Replications: Three (3)

Treatments: Eight (8)

Duration of work: 6 months

Design: 2 x 2 x 2, Factorial Complete Randomized Design (FCBD)

3.2.2 Treatments Details

T1	Un-ground pearl millet < 10g/1000 seed weight
T2	Un-ground pearl millet >10g/1000 seed weight
T3	Un-ground sorghum < 20g/1000 seed weight
T4	Un-ground sorghum > 20g/1000 seed weight
T5	Ground pearl millet < 10g/1000 seed weight
T6	Ground pearl millet > 10g/1000 seed weight
T7	Ground sorghum < 20g/1000 seed weight
T8	Ground sorghum >20g/1000 seed weight

3.3 The research carried out can be divided into three parts.

3.3.1 Selection of cultivars (Pre laboratory work)

Different cultivars of pearl millet and sorghum was screened depending upon grain size (49 cultivars of sorghum and 50 cultivars of pearl millet was screened).

3.3.2 Analysis of screened cultivars (Laboratory work)

The selected cultivars of pearl millet and sorghum were analyzed in **triplicates** for their zinc and iron content using both un-ground and ground grain samples.

3.3.3 Evaluation of Analysis (Post laboratory work)

Comparison of iron and zinc contents in different grain sized cultivars of un-ground and ground samples of pearl millet and sorghum.

3.3.1: Selection of cultivars (Pre-Laboratory work):

Fifty cultivars of pearl millet were used for the study, while 49 cultivars of sorghum were used. Pearl millet and sorghum cultivars were obtained from breeders at ICRISAT. Among fifty cultivars of pearl millet, thirty five cultivars were small grains and fifteen cultivars were bold grains. For sorghum, twenty five cultivars were small grains and twenty four cultivars were bold grains. The seed samples were screened and cleaned well to remove all debris and glumes. The 1000 kernel weight of both pearl millet and sorghum samples were measured to separate the small grains and bold grains. This was done manually. Ground and un-ground grain samples were used for determining Fe and Zn for sorghum and pearl millet cultivars in each seed weight groups of sorghum and pearl millet. The grain samples were kept in an oven for 24 hrs at 60 ^{0}C before grinding them.

3.3.2. Analysis of screened cultivars (Laboratory work)

3.3 Preparation of Triacid

Triacid consists of three acids, namely perchloric acid, nitric acid and sulphuric acid in 10: 2: 0.5 (v/v).

3.4 Procedure of Sample Digestion

The triacid method was used for digesting the ground and un-ground grain samples (Official methods of analysis of the Association of Analytical Chemists, 1984.). The method used was as follows:

- One g grain or ground sample was transferred to a digestion tube in three replications.

- Ten (ml) of triacid mixture consisting of perchloric acid, nitric acid and sulfuric acid in the ratio of 10: 2: 0.5 (v/v) were added to the digestion tube and the content left overnight (for cold digestion) in the digestion chamber.

- Thereafter, the sample was heated at 120 °C for about one hour and the temperature was raised to 230 °C for two hours in a block digester (with capacity to digest samples in 40 tubes, BD 40), until the digest was clear and colorless.

- After digestion, the digestion tubes were allowed to cool down for about 30 minutes and the contents were dissolved in water and diluted to 75 ml with distilled water and the contents were shaken well.

- Then, samples were ready for total Fe and Zn analysis using Atomic Absorption Spectrometer (AAS), model SavantAA GBC 2009 (Antanasopoulos 2009). Their contents were expressed in mg kg $^{-1}$.

3.5 Preparation of Standard solution

From the stock solution of 10 mg/L of Fe or Zn 1, 2, 3, 4 and 5 ml aliquots were pipetted out into respective 25 ml volumetric flasks. For each flask the volume was made up to 25 ml with 0.5% H_2SO_4. This represented standard 1, 2, 3, 4 and 5 for instrumental calibration curve for both iron and zinc in pearl millet and sorghum.

3.6 Analysis for Fe and Zn

3.6.1 Recommended Instrument Parameter for Iron

Atomic absorption working conditions fixed are:

Lamp	Current
Fuel	Acetylene
Support	Air
Flame Stoichiometry	Oxidizing
Wavelength	248.3 nm
Spectral band pass	0.2 nm

Optimum working range	2.5 to10 *ug*/ml

3.6.2 Recommended Instrument Parameter for Zinc

Atomic absorption working conditions fixed are:

Lamp	Current
Fuel:	Acetylene
Support	Air
Flame Stoichiometry	Oxidizing
Wavelength	213.9 nm
Spectral band pass	0.1 nm
Optimum working range	0.4 to1.6 *ug*/ml

3.7 Statistical Analysis

The data obtained in the laboratory study were statistically analysed using the SAS .V 9.1 version statistical package.

Analysis of variance was computed based on Factorial Complete Randomized Design as per standard statistical procedure (Rao, 1983). The significance was tested by referring to the values of `F` table (Fischer and Yates, 1967).

CHAPTER – IV
RESULTS

As mentioned in the introduction, the objective of this study was to generate results on the comparative evaluation of ground and un-ground grain samples of pearl millet and sorghum cultivars varying in grain size for total grain Zn and Fe content. The results obtained from the study are presented under the following headings.

4.1 Pearl millet

4.1.1 Thousand Grain weight

Data are presented in Table 1 and 2. Out of fifty pearl millet cultivars studied, 35 cultivars were found to be small grain (< 10g/1000 seed) and 15 were found to have bold grain size (>10g/1000 seed). The variability in 1000 grain weight of pearl millet cultivars used in the study ranged from 4.7 to 9.4 g with a mean of 7.5 g for the small grain cultivars while for bold grain cultivars, it ranged from 10.0 to 13.0 g with a mean of 10.8 g. The lowest 1000 grain weight was recorded in FeZn -sta-T Rp 3A-125 (4.7 g) (Sl. No. 1) and the highest was recorded in ICMB 00888 (13.0 g) (Sl. No. 15) (Table 2).

4.1.2 Total Iron content of pearl millet

The result of the analysis of variance indicated that there was a significant difference in Fe content between ground and un-ground grains of pearl millet ($P< 0.05$). Similarly, there was significant difference in Fe content of the small and bold grain samples of pearl millet.

The Fe content in small grain size pearl millet ground samples ranged from 26.6 to 77.9 mg kg^{-1} with a mean value of 51.3 mg kg^{-1}, whereas for the un-ground samples, it ranged from 28.4 to 75.7 mg kg^{-1} with a mean value of 50.6 mg kg^{-1} (Table 1). For the bold grain samples, the Fe content varied from 27.7 to 81.5 mg kg^{-1} with a mean value of 49.1 mg kg^{-1} for ground samples and for the un-ground samples it ranged from 26.5 mg kg^{-1} to 81.7 mg kg^{-1} with a mean of 47.8 mg kg^{-1} (Table 2).

The highest Fe content was recorded in ICMB 04444 cultivar (Sl. No. 13) with 81.5 mg kg^{-1} and 81.7 mg kg^{-1} in ground and un-ground samples, respectively (Table 2). Whereas the lowest Fe content was noted in FeZn-sta-T Rp 3A-218 cultivar (Sl. No. 10) with 26.5 mg kg^{-1} in un-ground samples and 26.6 mg kg^{-1} in ground samples.

Regarding the Fe content in pearl millet small grains, out of total 35 samples, eight (22.9%) of samples indicated that un-ground samples contained slightly more Fe than ground sample with a range of (-0.1 to -6.3 mg kg^{-1}). While the results with other twenty six (74.3%) samples showed that ground samples contain more Fe content than un-ground samples with a range between 0.2 to 5.7 mg kg^{-1}. The highest difference was recorded in FeZn -sta-T Rp 3A-125 with 5.7 mg kg^{-1} (Sl. No. 1) and the lowest difference was noted ICMB 00777 and ICMB 04666 (Sl. No. 29 and 31) respectively. Whereas in case of one cultivar FeZn – sta T Rp 3A – 214 (Sl. No. 18). The Fe content was similar in both ground and un-ground samples with Fe content of 37 mg kg^{-1}.

In bold grain (Table 2) size pearl millet cultivars, four samples (26.7%) out of fifteen samples indicated that un-ground samples contained more Fe than ground sample with a range of -0.2 to -3.5 mg kg^{-1}. Whereas, ten samples (66.6%) showed that ground samples contain more Fe content than un-ground samples with a range between (0.4 to 8 mg kg^{-1}). Cultivar ICMB 88004 (Sl. No. 7) recorded the highest difference and ICMB 02444 (Sl. No. 3) and FeZn –sta –T Rp 3A – 330 (Sl. No. 11) recorded the lowest difference. Whereas the cultivar, ICMB

02444(Sl. No. 8) has recorded similar Fe content (59.4 mg kg^{-1}) in both ground and un-ground samples.

4.1.3 Total Zn content of pearl millet

The result of the analysis of variance showed that there was no significant difference in Zn content for ground and un-ground samples of pearl millet (P< 0.05). Likewise, there was no significant difference in Zn content between small and bold grains of pearl millet cultivars.

The Zn content in pearl millet cultivars ranged from 18.7 to 73.7 mg kg^{-1} with an average of 50.8 mg kg^{-1} for ground small grain samples, whereas for the un-ground samples it ranged from 19.5 to72.1 mg kg^{-1} with a mean value of 50.3 mg kg^{-1} (Table 3). In the case of bold and ground grain samples, the total content of Zn in pearl millet ranged from 32.3 to 62.3 mg $kg^{-1}$with a mean value of 49.9 mg kg^{-1}, whereas for the bold, un-ground grain samples, it ranged from 32.00 to 59.9 mg kg^{-1} with an average of 48.6 mg kg^{-1} (Table 4).

The highest Zn content was recorded in ICMB 91777 (Sl. No. 8) cultivar with 73.7 mg kg^{-1} in ground and 72.1 mg kg^{-1} in un-ground samples. With regard to the lowest Zn content in pearl millet cultivars, it was noted in ICMB 04555 (Sl. No. 9) cultivar with 18.7 mg kg^{-1} and 19.5 mg kg^{-1} in ground and un-ground respectively.

In the case of Zn content in pearl millet small grains, fourteen samples (40%) indicated that un-ground samples contains more Zn than ground samples with a range of (-0.4 to -7.0 mg kg^{-1}). The results with the other twenty one (60%) cultivars showed that the ground samples contained higher Zn content than the un-ground samples and the range in difference ranged between 0.2 to 7.1 mg kg^{-1}. The highest difference was recorded in FeZn -sta-T Rp 3A-125

(Sl. No. 1) with 7.1 mg kg^{-1} and the lowest difference was noted in ICMB 04666 (Sl. No. 30) with 0.2 mg kg^{-1}.

Regarding Zn content in bold grain pearl millet cultivars, the results with three (20%) cultivars indicated that the un-ground samples contained higher Zn content than ground samples with a range of -3.8 to -2.1mg kg^{-1} and the results with other twelve (80%) cultivars showed that the ground samples contained higher Zn content than the un-ground samples with a difference range of 0.1 to 9.1 mg kg^{-1}. The highest (9.1 mg kg^{-1}) and the lowest (0.1 mg kg^{-1}) differences were recorded in ICMB 04444 (Sl. No. 13) and FeZn -sta-T Rp 3A-112 (Sl. No. 5), respectively.

Table 1. Comparison of Fe content in pearl millet grains using ground (G) and un-ground (UG) samples of pearl millet cultivars with small grain size (n =35).

S.No.	Cultivar name	1000 seed weight (g)	Fe (mg kg^{-1})		Difference in Fe content (G-UG) (mg kg^{-1})
			Ground (G)	Un-ground (UG)	
1	FeZn –sta-T Rp 3A-125	4.7	68.4	62.7	5.7
2	ICMB 89111	5.2	66.5	64.7	1.8
3	ICMB 91444	5.2	71.4	70.6	0.8
4	81B	5.2	32.2	31.4	0.8
5	FeZn –sta-T Rp 3A-208	5.9	39.4	37.8	1.6
6	FeZn –sta-T Rp 3A-223	6.3	39.7	39.0	0.7
7	ICMB 92111	6.3	43.4	48.9	-5.5
8	ICMB 91777	6.6	56.8	56.1	0.7
9	ICMB 04555	6.7	39.8	40.2	-0.4
10	ICMB 00999	6.8	44.8	44.1	0.7
11	FeZn –sta-T Rp 3A-112	6.9	66.5	62.2	4.3
12	841B	7.0	45.5	48.5	-3.0
13	ICMB 02666	7.0	26.6	28.4	-1.8
14	ICMB 00666	7.2	59.2	58.3	0.9
15	FeZn –sta-T Rp 3A-110	7.2	31.1	30.7	0.4
16	ICMB 91666	7.2	56.6	59.0	-2.4
17	ICMB 04222	7.3	41.4	40.9	0.5
18	FeZn –sta-T Rp 3A-214	7.6	37.0	37.0	0.0
19	ICMB 02222	7.7	56.9	56.0	0.9
20	FeZn –sta-T Rp 3A-306	8.0	45.7	44.8	0.9
21	FeZn –sta-T Rp 3A- 122	8.1	77.9	75.7	2.2
22	ICMB 03111	8.1	60.3	58.6	1.7
23	FeZn –sta-T Rp 3A-216	8.3	31.4	31.5	-0.1
24	FeZn –sta-T Rp 3A- 324	8.3	75.7	72.1	3.6
25	ICMB 04777	8.4	58.5	57.2	1.3
26	ICMB 04999	8.5	42.7	41.3	1.4
27	FeZn –sta-T Rp 3A-305	8.5	52.3	58.6	-6.3
28	ICMB 04888	8.6	48.6	48.2	0.4
29	ICMB 00777	8.6	40.3	40.1	0.2
30	ICMB 88006	8.8	32.6	30.9	1.7
31	ICMB 04666	8.9	40.1	39.9	0.2
32	ICMB 03999	9.0	55.9	56.8	-0.9
33	843B	9.0	72.5	71.6	0.9
34	ICMB 93222	9.1	74.2	73.3	0.9
35	FeZn –sta-T Rp 3A-116	9.1	63.2	54.2	9.0
	Mean	7.5	51.3	50.6	
	SEm±		0.00025		
	CD (P = 0.05)		0.0004		
	CV (%)		0.57		

Table 2. Comparison of Fe content in pearl millet grains using ground (G) and un-ground (UG) samples in pearl millet cultivars with bold grain size (n =15).

S.No.	Cultivar Name	1000 seed weight (g)	Fe ($mg\ kg^{-1}$)		Difference in Fe Content between G-UG($mg\ kg^{-1}$)
			Ground (G)	Un-ground (UG)	
1	FeZn -sta-T Rp 3A-130	10.0	45.8	48.7	-2.9
2	FeZn -sta-T Rp 3A-303	10.0	61.1	58.7	2.4
3	842B	10.1	34.3	33.9	0.4
4	ICMB 97222	10.1	53.8	47.0	6.8
5	FeZn -sta-T Rp 3A-112	10.1	34.6	33.5	1.1
6	FeZn -sta-T Rp 3A-125	10.2	52.1	46.6	5.5
7	ICMB 88004	10.2	50.8	42.8	8.0
8	ICMB 02444	10.6	59.4	59.4	0.0
9	ICMB 02111	10.9	39.7	36.8	2.9
10	FeZn -sta-T Rp 3A-218	10.9	27.7	26.5	1.2
11	FeZn -sta-T Rp 3A-330	11.0	47.6	47.2	0.4
12	ICMB 03333	11.2	53.2	52.0	1.2
13	ICMB 04444	11.7	81.5	81.7	-0.2
14	FeZn -sta-T Rp 3A-305	12.0	39.1	42.6	-3.5
15	ICMB 00888	13.0	56.2	58.9	-2.7
	Mean	10.8	49.1	47.8	
	SEm±		0.00025		
	CD (P = 0.05)		0.0004		
	CV (%)		0.57		

Table 3. Comparison of Zn content in pearl millet grains using ground (G) and un-ground (UG) samples of pearl millet cultivars with small grain size (n =35).

S.No.	Cultivar name	1000 seed weight (g)	Zn (mg kg^{-1})		Difference in Zn content between G-UG (mg kg^{-1})
			Ground (G)	Un-ground (UG)	
1	FeZn –sta-T Rp 3A-125	4.7	67.0	59.9	7.1
2	ICMB 89111	5.2	72.1	67.7	4.4
3	ICMB 91444	5.2	69.1	71.1	-2.0
4	81B	5.2	30.0	29.8	0.2
5	FeZn -sta-T Rp 3A-208	5.9	50.4	46.3	4.1
6	FeZn -sta-T Rp 3A-223	6.3	59.5	59.9	-0.4
7	ICMB 92111	6.3	50.6	55.7	-5.1
8	ICMB 91777	6.6	73.7	72.1	1.6
9	ICMB 04555	6.7	18.7	19.5	-0.8
10	ICMB 00999	6.8	49.1	45.8	3.3
11	FeZn -sta-T Rp 3A-112	6.9	55.2	62.2	-7.0
12	841B	7.0	44.0	48.3	-4.3
13	ICMB 02666	7.0	23.8	25.0	-1.2
14	ICMB 00666	7.2	43.7	43.2	0.5
15	FeZn -sta-T Rp 3A-110	7.2	40.5	37.4	3.1
16	ICMB 91666	7.2	60.2	59.6	0.6
17	ICMB 04222	7.3	38.9	37.5	1.4
18	FeZn -sta-T Rp 3A-214	7.6	48.7	53.7	-5.0
19	ICMB 02222	7.7	48.5	48.9	-0.4
20	FeZn -sta-T Rp 3A-306	8.0	54.2	57.3	-3.1
21	FeZn -sta-T Rp 3A- 122	8.1	59.7	65.9	-6.2
22	ICMB 03111	8.1	46.9	45.3	1.6
23	FeZn -sta-T Rp 3A-216	8.3	50.7	57.3	-6.6
24	FeZn -sta-T Rp 3A- 324	8.3	60.5	55.5	5.0
25	ICMB 04777	8.4	47.2	45.4	1.8
26	ICMB 04999	8.5	43.3	40.5	2.8
27	FeZn -sta-T Rp 3A-305	8.5	69.0	65.1	3.9
28	ICMB 04888	8.6	45.8	39.1	6.7
29	ICMB 00777	8.6	33.0	26.8	6.2
30	ICMB 88006	8.8	32.5	31.1	1.4
31	ICMB 04666	8.9	51.4	50.4	1.0
32	ICMB 03999	9.0	41.9	42.8	-0.9
33	843B	9.0	62.0	59.1	2.9
34	ICMB 93222	9.1	68.5	71.7	-3.2
35	FeZn -sta-T Rp 3A-116	9.1	67.0	61.9	5.1
	Mean	7.5	50.8	50.3	
	SEm±		0.0003		
	CD (P = 0.05)		NS		
	CV (%)		0.6		

Table 4. Comparison of Zn in pearl millet grains using ground (G) and un-ground (UG) samples in pearl millet cultivars with bold grain size (n =15).

S.No.	Cultivar Name	1000 seed weight (g)	Zn ($mg\ kg^{-1}$) Ground (G)	Zn ($mg\ kg^{-1}$) Un-ground (UG)	Difference in Zn content in (G-UG) ($mg\ kg^{-1}$)
1	FeZn -sta-T Rp 3A-130	10.0	60.9	59.9	1.0
2	FeZn -sta-T Rp 3A-303	10.0	61.5	59.3	2.2
3	842B	10.1	36.1	35.5	0.6
4	ICMB 97222	10.1	56.0	53.1	2.9
5	FeZn -sta-T Rp 3A-112	10.1	45.8	45.7	0.1
6	FeZn -sta-T Rp 3A-125	10.2	56.8	53.8	3.0
7	ICMB 88004	10.2	42.8	42.0	0.8
8	ICMB 02444	10.6	52.8	55.7	-2.9
9	ICMB 02111	10.9	32.3	32.0	0.3
10	FeZn -sta-T Rp 3A-218	10.9	47.7	45.0	2.7
11	FeZn -sta-T Rp 3A-330	11.0	53.8	49.3	4.5
12	ICMB 03333	11.2	45.0	43.7	1.3
13	ICMB 04444	11.7	62.3	53.2	9.1
14	FeZn -sta-T Rp 3A-305	12.0	45.4	49.2	-3.8
15	ICMB 00888	13.0	49.3	51.4	-2.1
	Mean	10.8	49.9	48.6	
	SEm±		0.0003		
	CD (P = 0.05)		NS		
	CV (%)		0.6		

4.2 Sorghum

4.2.1 Thousand Grain weight

Data are presented in Table 5 and 6 for the small grain and bold grain cultivar of sorghum used in the study. Twenty five cultivars were small grains (< 20/1000 seed and twenty four were bold grains (>20/1000 seed). The variability in 1000 grain weight of the sorghum cultivars ranged from 9.6 to 19.3 g (<20/1000 seed) for the small grain samples and for the bold grain samples, it ranged from 26.9 to 46.4 g (>20/1000 seed). The lowest 1000 grain weight was recorded with two cultivars III MNNTT 1030 (Sl. No. 1) and II MNTT 1001 (Sl. No. 1) (Table 5) with 9.6 g and the highest was recorded in I MNTT 1062 cultivar with 46.4 g (Sl. No. 24) (Table 6).

4.2.2 Total Iron content of sorghum

The statistical analysis of the results showed that there was no significant difference in Fe content between ground and un-ground grains of sorghum ($P < 0.05$). Likewise, there was no significant difference in the Fe values between small and bold grain samples.

The Fe content in sorghum ranged from 19.0 to 65.0 mg kg^{-1} with mean value of 36.1 mg kg^{-1} for the small grain, un-ground samples, while it ranged from 18.2 – 65.1 mg kg^{-1} with an average of 34.4 mg kg^{-1} (Table 5). For bold grain ground samples, the Fe content varied from 22.5 to 62.2 mg kg^{-1} with an average of 35.8 mg kg^{-1}, while for the un-ground samples, it ranged from 23.7 to 62.4 mg kg^{-1} with an average of 34.4 mg kg^{-1} (Table 6).

In sorghum cultivars, the highest Fe content was recorded in III MNTT 1003 (Sl. No. 10) with 65.0 mg kg^{-1} in ground and 65.1 mg kg^{-1} was recorded the highest in un-ground II

MNTT 1071 (Sl. No. 22)cultivar. The lowest Fe content was recorded in II MNTT 1019 (Sl. No. 23) with 19.0 mg kg^{-1} and 18.2 mg kg^{-1} in ground and un-ground samples respectively.

Regarding the difference in the Fe content in small grains of sorghum, five (20%) out of the twenty four samples showed that un-ground samples contained higher Fe than the ground samples with the difference ranging from -0.3 to -14.2 mg kg^{-1}. The results with other twenty (80%) samples indicated that ground contained higher Fe content than un-ground, with III MNTT 1003 (Sl. No. 10) contained higher difference with 11.8mg kg^{-1}. The lowest difference was recorded in III MNNTT 1032 (Sl. No. 6) and II MNTT 1068 (Sl. No. 19) cultivars with 0.4 mg kg^{-1}.

In bold grain sorghum cultivars, the difference in Fe content between un-ground and ground ranged from -0.2 to -9.7 mg kg^{-1} in six samples (25%) which indicated that the un-ground samples contained higher Fe than the ground samples. Whereas the remaining eighteen samples (75%) ground and un-ground samples contained higher Fe with difference ranging from 0 to 11.2 mg kg^{-1}. The highest and the lowest difference was recorded for I MNTT 1025 (Sl. No. 11) and II MNTT 1067 (Sl. No. 7) cultivars, respectively.

4.2.3 Total Zinc content of sorghum

Data are presented in Table 7 and 8 for small grain and bold grain of sorghum cultivars respectively. The statistical analysis of the results showed that there was no significant difference in Zn content between ground and un-ground grains of sorghum ($P < 0.05$). Similarly, there is no significant difference between small and bold grain samples for the determination of Zn.

The Zn content in sorghum grains ranged from 16.9 to 61.0 mg kg^{-1} for small grain ground samples with an average of 34.7 mg kg^{-1}, whereas for the un-ground samples, it ranged from

16.5 to 59.8 mg kg^{-1} with an average of 31.7 mg kg^{-1} (Table 7). For the bold grain cultivars, the Zn content varied from 18.9 to 60.6 mg kg^{-1} with an average of 33.2 mg kg^{-1}, while for the un-ground samples, it ranged from 18.1 to 61.0 mg kg^{-1} with an average of 30.6 mg kg^{-1} (Table 8).

The highest Zn content in sorghum cultivars was recorded in III MNTT 1003 (Sl. No. 10) with 61.0 mg kg^{-1} in ground and 60.1 mg kg^{-1} in un-ground samples. With regard to the lowest Zn content, it was noted in II MNTT 1080 (Sl. No. 13) cultivar with 16.9 mg kg^{-1} in ground and II MNTT 1086 (Sl. No. 15) was lowest in un-ground with 16.5 mg kg^{-1}.

Zn content in small grain sorghum cultivars showed that the twenty one (84%) out of twenty five contained higher Zn content in ground samples than un-ground samples. It ranged from 0.2 to 10.7 mg kg^{-1}. The highest difference was recorded in II MNTT 1076 (Sl. No. 17) and the lowest difference was recorded in II MNTT 1095 (Sl. No. 3) cultivars. The remaining four cultivars showed lower Zn content in ground samples than un-ground samples and the difference ranged from -0.2 to -1.3 mg kg^{-1}. The highest and the lowest difference was recorded in III MNNTT 1032 (Sl. No. 6) and I MNTT 1008 (Sl. No. 25), respectively.

In the case of bold grain cultivars, twenty two (91.7%) out of the twenty four cultivars, the Zn content in ground samples was higher than in un-ground samples with a difference range of 0 to 10.2 mg kg^{-1}. The highest difference was recorded in II MNTT 1006 (Sl. No. 6) cultivar and it was same in both ground and un-ground cultivars the lowest in III MNTT 1042 (Sl. No. 14). The results with the remaining two samples (0.3%) indicated that Zn content in un-ground sample was higher than in ground samples. The lowest and highest difference was recorded in I MNTT 1027 (Sl. No. 23) and I MNTT 1112 (Sl. No. 20) respectively.

4.3 Correlation Studies

4.3.1 Correlation between ground and un-ground grains of pearl millet

There was a highly positive correlation between the values of grain Fe with ground and un-ground cultivars of pearl millet in small and bold grain for Fe content ($r^2 = 0.94$; $P < 0.05$; $n = 50$) (Fig 1). Similarly, the positive correlation was observed between ground and un-ground cultivars of pearl millet in small and bold grain for Zn content ($r^2 = 0.86$; $P < 0.05$) (Fig 2).

4.3.2 Correlation between ground and un-ground grains of pearl millet

In sorghum cultivars, the positive and significant correlation was observed between ground and un-ground grain of small and bold grains cultivars for Fe ($r^2 = 0.87$; $P < 0.05$ $n = 49$) (Fig 3). Likewise, the result showed that there is a positive correlation between ground and un-ground cultivars of sorghum in small and bold grains for Zn content ($r^2 = 0.94$; $P < 0.05$) (Fig 4).

Table 5. Comparison of Fe in sorghum grains using ground (G) and un-ground (UG) samples for sorghum cultivars with small grain size (n = 25).

S.No.	Cultivar Name	1000 seed weight (g)	Fe ($mg\ kg^{-1}$)		Difference between Fe content in G-UN($mg\ kg^{-1}$)
			Ground (G)	Un-ground (UG)	
1	III MNNTT 1030	9.6	42.2	41.5	0.7
2	II MNTT 1001	9.6	26.9	24.9	2.0
3	II MNTT 1095	10.4	35.8	39.0	-3.2
4	III MNNTT 1001	10.8	53.3	53.6	-0.3
5	III MNNTT 1044	14.5	46.5	42.7	3.8
6	III MNNTT 1032	15.0	43.3	42.9	0.4
7	III MNNTT 1019	16.8	50.8	49.0	1.8
8	III MNNTT 1026	17.5	39.9	38.2	1.7
9	II MNTT 1107	17.6	32.8	24.6	8.2
10	III MNTT 1003	17.7	65.0	53.2	11.8
11	II MNTT 1087	17.8	20.8	18.8	2.0
12	III MNNTT 1047	18.2	54.6	50.7	3.9
13	II MNTT 1080	18.4	27.0	25.2	1.8
14	II MNTT 1053	18.5	24.9	25.2	-0.3
15	II MNTT 1086	18.5	21.8	25.9	-4.1
16	II MNTT 1040	18.6	21.1	19.7	1.4
17	II MNTT 1076	18.6	47.8	42.6	5.2
18	II MNTT 1116	18.6	25.5	23.5	2.0
19	II MNTT 1068	18.7	29.0	28.6	0.4
20	II MNTT 1089	18.7	32.5	28.2	4.3
21	I MNTT 1117	18.8	38.8	31.2	7.6
22	II MNTT 1071	18.9	50.9	65.1	-14.2
23	II MNTT 1019	19.0	19.0	18.2	0.8
24	II MNTT 1066	19.0	24.8	21.8	3.0
25	I MNTT 1008	19.3	26.8	26.0	0.8
	Mean	16.8	36.1	34.4	
	SEm±		0.00019		
	CD (P = 0.05)		NS		
	CV (%)		2.08		

Table 6. Comparison of Fe in sorghum grains using ground (G) and un-ground (UG) samples of sorghum cultivars with bold grain size (n = 24).

S.No.	Cultivar Name	1000 seed weight (g)	Fe (mg kg^{-1})		Difference in Fe content between G-UN (mg kg^{-1})
			Ground (G)	Un-ground (UG)	
1	I MNTT 1065	26.9	27.9	24.4	3.5
2	I MNTT 1018	27.0	28.4	26.3	2.1
3	I MNTT 1010	27.7	28.8	27.8	1.0
4	I MNTT 1118	27.7	26.2	24.2	2.0
5	I MNTT 1061	27.8	27.9	37.6	-9.7
6	II MNTT 1006	28.9	37.1	30.5	6.6
7	II MNTT 1067	30.3	34.3	34.3	0.0
8	I MNTT 1109	31.4	41.5	35.6	5.9
9	IRAT 204 Bc23/R04	32.0	38.9	38.8	0.1
10	II MNTT 1060	32.5	33.3	27.1	6.2
11	I MNTT 1025	33.0	37.6	26.4	11.2
12	I MNTT 1032	33.3	62.2	62.4	-0.2
13	I MNTT 1111	33.4	48.7	47.9	0.8
14	III MNTT 1042	33.4	36.6	35.1	1.5
15	I MNTT 1011	34.5	36.8	33.5	3.3
16	I MNTT 1020	34.9	22.5	25.0	-2.5
17	II MNTT 1007	36.6	29.0	37.6	-8.6
18	I MNTT 1114	38.5	31.4	30.5	0.9
19	I MNTT 1033	38.7	23.0	23.7	-0.7
20	I MNTT 1112	39.2	54.8	54.4	0.4
21	I MNTT 1045	39.6	52.7	49.9	2.8
22	I MNTT 1043	41.7	31.9	27.8	4.1
23	I MNTT 1027	42.0	33.4	26.1	7.3
24	I MNTT 1062	46.4	34.2	37.4	-3.2

Mean	34.1	35.8	34.4
SEm±		0.00019	
CD (P = 0.05)		NS	
CV (%)		2.08	

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Table 8. Comparison of Zn in sorghum grains using ground (G) and un-ground (UG) samples of sorghum cultivars with bold grain size (n = 24).

S.No.	Cultivar Name	1000 seed weight (g)	Zn (mg kg^{-1})		Difference in Zn content between G-UN
			Ground (G)	Un-ground (UG)	
1	I MNTT 1065	26.9	23.0	21.3	1.7
2	I MNTT 1018	27.0	24.8	23.3	1.5
3	I MNTT 1010	27.7	26.5	25.8	0.7
4	I MNTT 1118	27.7	23.9	20.5	3.4
5	I MNTT 1061	27.8	30.3	21.8	8.5
6	II MNTT 1006	28.9	57.5	47.3	10.2
7	II MNTT 1067	30.3	24.1	22.2	1.9
8	I MNTT 1109	31.4	45.3	45.0	0.3
9	IRAT 204 Bc23/R04	32.0	32.8	29.9	2.9
10	II MNTT 1060	32.5	26.9	24.0	2.9
11	I MNTT 1025	33.0	41.0	37.5	3.5
12	I MNTT 1032	33.3	29.3	25.8	3.5
13	I MNTT 1111	33.4	44.0	42.0	2.0
14	III MNTT 1042	33.4	25.8	25.8	0.0
15	I MNTT 1011	34.5	33.0	30.0	3.0
16	I MNTT 1020	34.9	26.4	25.3	1.1
17	II MNTT 1007	36.6	39.2	33.5	5.7
18	I MNTT 1114	38.5	25.5	22.9	2.6
19	I MNTT 1033	38.7	18.9	18.1	0.8
20	I MNTT 1112	39.2	60.6	61.0	-0.4
21	I MNTT 1045	39.6	31.0	27.5	3.5
22	I MNTT 1043	41.7	38.4	35.2	3.2
23	I MNTT 1027	42.0	36.8	37.3	-0.5
24	I MNTT 1062	46.4	32.3	31.3	1.0
	Mean	34.1	33.2	30.6	
	SEm±		0.00015		
	CD (P = 0.05)		NS		
	CV (%)		1.58		

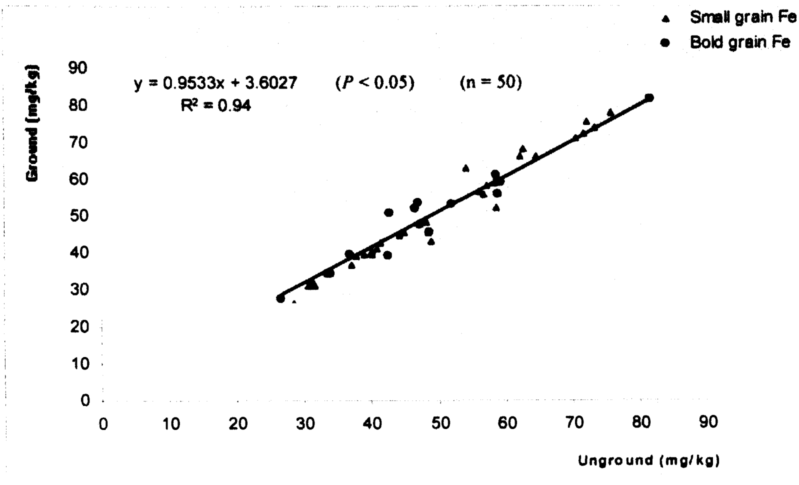

Figure 1. Relationship between grain Fe content determined in ground and un-ground samples of pearl millet cultivars.

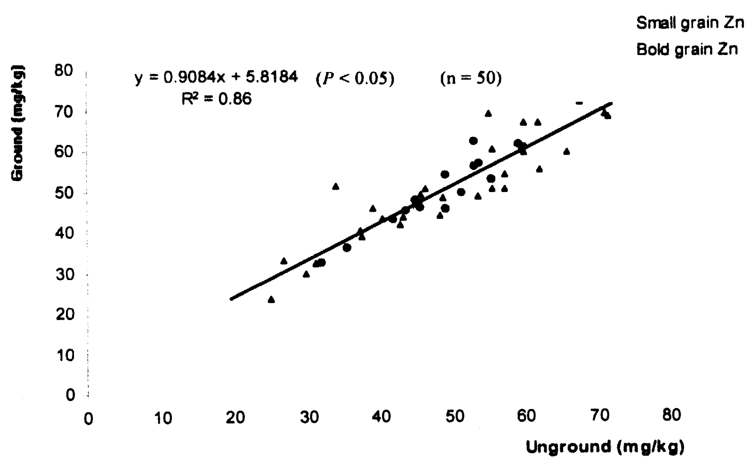

Figure 2. Relationship between grain Zn determined in ground and un-ground samples of pearl millet cultivars:

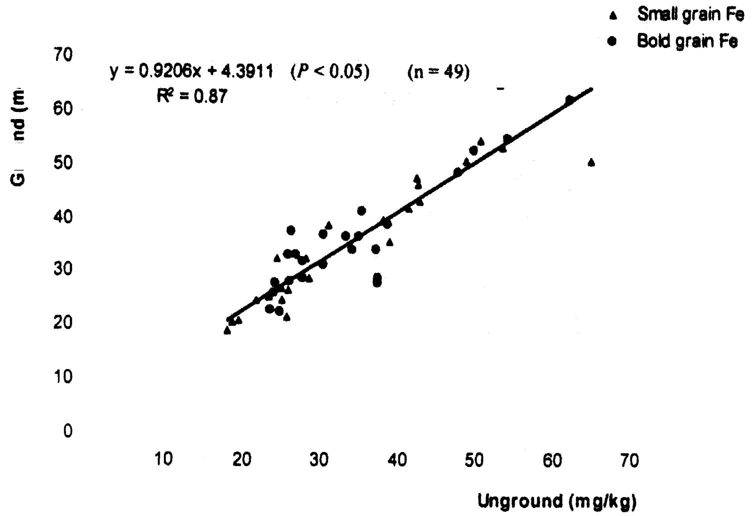

Figure 3. Relationship between grain Fe determined in ground and un-ground samples of sorghum cultivars

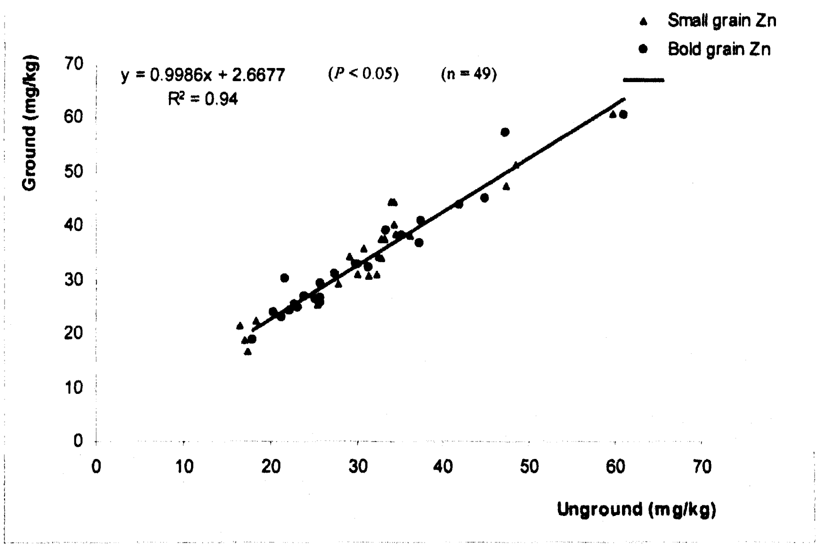

Figure 4. Relationship between grain Zn contents determined in ground and un-ground samples of sorghum cultivars

CHAPTER – V
DISCUSSION

Sorghum and Pearl millet are important staple food in the Semi-Arid Tropics (SAT) of Asia and Africa. These crops are still the principal sources of energy, protein, vitamins and minerals for millions of the poorest people in these regions. Sorghum and pearl millet grow in harsh environments where other crops do not grow well. To assess the quality of grain of these crops for Fe and Zn, comparative evaluation was made by analyzing these nutrients in both ground and un-grounded grain samples of both small and bold grain cultivars. The results obtained are discussed here under.

Studies that specifically deal with Fe and Zn content in ground and un-ground grains of pearl millet and sorghum are not available. This is the first time that this study is being carried out to evaluate the same. Limited literature on grain size and Fe and Zn contents on these two crops are available for discussion.

5.1 Thousand Grain weight

Studies indicated that, the 1000 grain weight of pearl millet ranges from 2.5 to 14 g with a mean of 8 g. The size of the pearl millet kernel is about one third that of sorghum (O'Kennedy 2006). The present study showed that, the grain size of pearl millet varied from 4.7 to 9.1 g and 10.0 to 13.0 g for small and bold grain respectively. Thousand seed weight of 2.54 to 19.32 g with a mean of 8.6 g was reported by Mathur *et al.*, (1993) and 8.9 g by Vanderlip *et al.*, (1995).

The range of 1000 kernel weight of sorghum has a wide range and varies from 3 to 80 g, but for majority of the varieties it varies between 25 and 30 g. This study indicated the wide range of sorghum grains from 9.6 to 19.30 g for small grains and 26.90 to 46.40 g for bold grains.

5.2 Fe content of pearl millet grains

The range of grain Fe content varied among the different grain sized cultivars. It ranged from 26.6 to 77.9 mg kg^{-1} in small grain cultivars and from 26.5 to 81.7 mg kg^{-1} in bold grain cultivars. The grain Fe content is almost similar to those obtained by Velu *et al.* (2006), (2007) and Towo (2006).

For both sample preparation methods used (ground and un-ground) to determine Fe content in grain samples of pearl millet, there was significant difference. Likewise, there was significant difference between grain sizes. Both in small and bold grain samples, majority of the samples (66.6 to 74.3%) it was observed that grounded samples contained relatively higher Fe content than un-grounded samples. This indicates the probability of contamination of Fe in grounded samples at the time of sample preparation. Nearly up to 5.7 mg kg^{-1} higher Fe content of grain samples was noticed due to grinding of samples in small grain cultivars and it was up to 8.0 mg kg^{-1} in case of bold grain cultivars of pearl millet. However, in some varieties, un-grounded samples recorded higher Fe content than ground samples.

Among different cultivars it appears that Fe content in grains is more in bold grain varieties than small grained cultivars. Literature in relation to such studies is not available.

5.3 Zn content of pearl millet grains

The mean Zn content in pearl millet in ground and un-ground samples is almost similar (50.8 and 50.3 mg kg^{-1}) respectively. It ranged from 18.7 to 73.7 mg kg^{-1}, whereas it ranged from 27.2 to 50.2 mg kg^{-1} (Velu *et al.*, 2008) and 24 to 64.8 mg kg^{-1} (Velu 2007) and 16.0 mg kg^{-1} (Hulse *et al.*, 1980 and 29.5 mg kg^{-1} (Irén Léder, 2004).

Like Fe, in majority of ground samples (60%), the mean Zn content was higher in ground samples when compared to un-ground samples. The mean Zn content was relatively higher in small grain of pearl millet than bold grain cultivars. However, the results were non significant indicating that grinding has not resulted in much contamination with regard to Zn content of Pearl millet grains. No literature on effect of grinding on Fe content of pearl millet is available for comparison.

5.4 Fe content of sorghum grains

The Fe content in different cultivars of sorghum (n = 49) ranged from 18.20 to 65.1 mg kg^{-1}. Kayode *et al.*, 2006 reported 11.0 to 44 mg kg^{-1} with an average of 25 mg kg^{-1} of Zn. The Fe content did not show consistent linkage to genetic variation but varied significantly across sites.

Sreeramaiah *et al.*, (2007) reported 6.51 mg kg^{-1} of Fe per 100 g sorghum. Reddy *et al.*, (2005*)* reported 20.1 to 37.0 mg kg^{-1} of Fe with average of 28 mg kg^{-1} in sorghum.

In sorghum, compared to un-ground samples, ground samples recorded higher mean Fe content (36.1 mg kg^{-1}) when compared to 34.4 mg kg^{-1} in un-ground small grain sorghum samples. However, the results were statistically not-significant. The trend indicating that there is a possibility of contamination during grinding for sample preparation. Similar results were noticed in bold grain too. The mean Fe contents are more or less uniform in small grain. Literature related to evaluation of ground sorghum cultivars is not available.

5.5. Zn content of sorghum grains

Similar to Fe content in sorghum, the results obtained by Kayode *et al.* (2006) confirm the results obtained in the present study with regard to Zn content in grains. Likewise, lower results of Zn content in sorghum grains was reported by Reddy *et al.* (2005). So far, no literature is available to evaluate the content of Zn in ground and un-ground samples. There is a significant between grain Fe (r^2 = 0.87 and Zn (r^2 = 0.94 contents determined by using ground and un-ground pearl millet and sorghum cultivars.

The total Zn content in grain ranged from 16.5 to 61.0 mg kg^{-1}. Here also in majority of samples (84%). The Zn content in ground samples was found to be relatively higher than un-ground samples indicate the probability of contamination while sample preparation. In both ground and un-ground samples, the grain Zn content was relatively higher in small grain sorghum cultivar than bold grain sorghum cultivars. However, the results were found to be non significant. No literature is available to compare with these results.

The results of this study with selected diverse cultivars suggest that grain Fe and Zn in sorghum and pearl millet can be determined on un-ground samples and obviously there is a need to further confirm these results with a larger number of cultivars of these crops.

CHAPTER – VI
SUMMARY

A study was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, to compare grain Zn and Fe determined in ground and un-ground samples of a range of pearl millet and sorghum cultivars varying in grain size. A 2 x 2 x 2 factorial complete randomized design was used with three replications. The three factors were two crops (pearl millet and sorghum), two treatments (ground and un-ground grain samples) and two grain sizes (small and bold) with a total of eight treatments.

In case of pearl millet, cultivars with 1000 seed weight of < 10 g were considered as small grain and >10 g were considered as bold grain. In case of sorghum, cultivars with 1000 seed weight of < 20 g were considered as small grain and >20 g were considered as bold grain.

Fifty pearl millet cultivars were used for the study. Thirty five cultivars were small grains and fifteen cultivars were bold grains. Forty nine cultivars of sorghum were used, twenty five cultivars were small grains and the other twenty four cultivars were bold grains. All the samples were analysed in triplicates.

The data was recorded on the 1000 grain weight, total Fe and Zn contents in ground and un-ground samples of pearl millet (50 cultivars) and sorghum (49 cultivars) crops in small and bold grains. The summary of results and conclusions drawn are presented here under.

1. The variability in 1000 grain weight of pearl millet cultivars used ranged from 4.7 to 9.1 g with a mean of 7.5 g (Table 1) for the small grain cultivars, while for the bold grain cultivars, it ranged from 10.0 to 13.0 g with a mean of 10.8 g (Table 2). The lowest 1000 grain weight was recorded in FeZn -sta-T Rp 3A-125 (4.7 g) (Sl.

No. 1 of Table 1) and the highest was recorded in ICMB 00888 (Sl. No. 15 of Table 2) (13.0 g).

2. In sorghum cultivars, the 1000 grain weight of sorghum samples ranged from 9.6 to 19.3 g with a mean of 16.8 g (Table 5) for the small grain samples and for the bold grain samples, it ranged from 26.9 to 46.4 g with a mean of 34.1 g (Table 6). The lowest 1000 grain weight was recorded with two cultivars III MNNTT 1030 and II MNTT 1001 (Sl. No. 1 and No. 2 of Table 5 respectively) with 9.6 g and the highest was recorded in I MNTT 1062 cultivar with 46.4 g (Sl No. 2 of Table 6).

3. A wide range of variability of grain iron content was found for both small and bold grain cultivars of pearl millet with ground and un-ground sample preparation. The Fe content in small grain and ground samples ranged from 26.6 to 77.9 mg kg^{-1} with a mean of 51.3 mg kg^{-1} whereas for the small and un-ground samples, it ranged from 28.4 to 75.7 mg kg^{-1} with a mean of 50.6 mg kg^{-1}.

4. For the bold grains and ground samples of pearl millet cultivars, the Fe content varied from 27.7 to 81.5 mg kg^{-1} with a mean of 49.1 mg kg^{-1} whereas for bold and un-ground samples it ranged from 26.5 mg kg^{-1} to 81.7 mg kg^{-1} with a mean of 47.8 mg kg^{-1}.

5. The highest Fe content was recorded in ICMB 04444 cultivar with 81.7 mg kg^{-1} (Sl. No. 13 of Table 1) in un-ground samples. The lowest Fe content was noted in FeZn -sta-T Rp 3A-218 cultivar (Sl. No. 10 of Table 2) with 26.5 mg kg^{-1} in un-ground samples. There exists a significant difference in Fe content between ground and un-ground and also between grain sizes of pearl millet.

6. Both in small and bold grain of pearl millet cultivars, nearly 66.6 to 74.3 percent of ground samples had relatively higher Fe content when compared to un-ground samples (0.2 to 8.0 mg kg^{-1}) indicating the probability of contamination at the time of grinding for the sample preparation.

7. Small grained cultivars of pearl millet had relatively more total iron content (50.6 to 51.3 mg kg^{-1}) when compared to bold grain cultivars (47.8 to 49.1 mg kg^{-1})

8. The variation in Zn content in pearl millet cultivars ranged from 18.7 - 73.7 mg kg^{-1} with a mean of 50.8 mg kg^{-1} for ground small grain samples. Whereas, for the un-ground samples, it ranged from 19.5 to 72.1 mg kg^{-1} with a mean of 50.3 mg kg^{-1}. The highest (73.7 mg kg^{-1}) and the lowest (18.7 mg kg^{-1}) Zn content were observed in ground ICMB 91777 (Sl. No. 8 of Table 8) and ICBM 04555 (Sl. No. 9) cultivars respectively.

9. For bold and ground grain of pearl millet cultivars, Zn content ranged from 32.3 – 62.3 mg kg^{-1} with a mean of 49.9 mg $kg^{-1.}$ The highest recorded in ICMB 04444 (Sl. No. 8) for the bold, un-ground grain samples from 32.0 – 59.9 mg kg^{-1} with a mean of 48.6 mg kg^{-1}.

10. Both in small and bold grain cultivars of pearl millet, majority of the cultivars (60 to 80%) showed relatively higher Zn content in ground grain samples (0.2 to 7.1 mg kg^{-1}) than un-ground.

11. Small grained pearl millet cultivars in general recorded higher mean Zn content (50.3 to 50.8 mg kg^{-1}) when compared to bold grain cultivars (48.6 to 49.9 mg kg^{-}

12. The range of Fe content in sorghum was 19.0 to 65.0 mg kg^{-1} with a mean of 34.1 mg kg^{-1} for the small and un-ground samples and 18.2 to 65.1 mg kg^{-1} with a mean of 36.1 mg kg^{-1} for the small and ground samples The highest (65.1 mg kg^{-1}) was recorded in un-ground II MNTT 1071 cultivar (Sl. No. 22). The lowest (18.2 mg kg^{-1}) was recorded in II MNTT 1019 for un-ground samples (Sl. No. 23) (Table 5).

13. For bold grain and ground samples of sorghum, the Fe content varied from 22.5 to 62.2 mg kg^{-1} with a mean of 35.8 mg kg^{-1} whereas for the un-ground samples, it ranged from 23.7 to 62.4 mg kg^{-1} with a mean of 34.4 mg kg^{-1}. No significant difference in Fe content between ground and un-ground grains of sorghum and between grain sizes was noticed.

14. Relatively higher Fe content was noticed (0.3 to 14.2 mg kg^{-1}) in majority (80%) ground sorghum samples when compared to un-ground samples.

15. Relatively higher Fe content was noticed in small grain sorghum cultivars (34.4 to 36.1 mg kg^{-1}) when compared to bold grain (34.4 to 35.8 mg kg^{-1}) cultivars.

16. Variation in Zn content was also recorded in small and bold grain of sorghum cultivars. In small grains and ground samples, it ranged from 16.9 - 61.0 mg kg^{-1} with a mean of 34.7 mg kg^{-1} while for the un-ground samples, it ranged from 16.5 to 59.8 mg kg^{-1} with a mean of 31.7 mg kg^{-1}. In the bold grains, Zn content ranged from 18.9 - 60.6 mg kg^{-1} with a mean of 33.2 mg kg^{-1} and 18.1 – 61.0 mg kg^{-1} with a mean of 30.6 mg kg^{-1} for ground and un-ground samples respectively. There is no significant difference in Zn content between ground and un-ground and also between grain sizes of sorghum cultivars.

17. The highest Zn content was noticed in the sorghum cultivar III MNTT 1003 (Sl. No. 10 of Table 7) which has 61.0 mg kg^{-1} in un-ground samples. It is interesting to note that the same cultivar had the higher Fe content (65.0 mg kg^{-1}).

18. Relatively higher Zn content was noticed in majority (84%) of ground samples of both small and bold grain (0.2 to 10.7 mg kg^{-1}) cultivars of sorghum when compared to un-ground samples.

19. Relatively higher Zn contents were also noticed in small grain cultivars of sorghum (31.7 to 34.7 mg kg^{-1}) when compared to bold grain (30.6 to 33.2 mg kg^{-1}) cultivars of sorghum.

20. Significant positive correlation between ground and un-ground cultivars of pearl millet in both small and bold grains for both Fe (r^2 = 0.94 and Zn (r^2 = 0.86) was observed (Fig 1 and 2).

21. Similarly, there is highly and significant positive correlation between ground and un-ground cultivars of sorghum in both small and bold grains for both Fe (r^2 = 0.87) and Zn (r^2 = 0.94) content was observed (Fig 3 and 4).

22. The results of this study with selected cultivars of small and bold grains of pearl millet and sorghum suggest that grain Fe and Zn in sorghum and pearl millet can be determined in un-ground samples; and obviously there is a need to further confirm these results with a larger number of cultivars of these crops.

23. The cultivars of pearl millet with the highest Fe content was identified as ICMB 04444 (81.7 mg kg^{-1}) (Sl. No. 13 of Table 2). Similarly the cultivar with the highest Zn content was identified as ICMB 91777 (73.7 mg kg^{-1}) (Sl. No. 8 of Table 3).

Sorghum with highest Fe content are identified as II MNTT 1071 (65.1 mg kg^{-1}) (Sl. No. 23 of Table 5) closely followed by III MNTT 1003 (65.0 mg kg^{-1}) (Sl. No. 10 of Table 5.) The same III MNTT 003 cultivar recorded the highest Zn content (61.0 mg kg^{-1}).

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