Genet Resour Crop Evol
DOI 10.1007/s10722-009-9469-4

RESEARCH ARTICLE

Cassava, *Manihot esculenta* Crantz genetic resources: a case of high iron and zinc

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Received: 11 June 2009 / Accepted: 30 July 2009

Abstract Cassava hybrids from interspecific crosses with *Manihot cearulescens* Pohl, *M. pseudoglaziovii* Pax and Hoffmann and *M. dichotoma* Ule showed a very high iron and zinc content in both roots and leaves, e.g. 98.15 mg kg^{-1} in roots of the interspecific hybrid cassava-*M. cearulescens* versus 12.17 mg kg^{-1} in a cassava cultivar. This promising results show the potential of wild *Manihot* species for micronutrient enhancement of cassava.

Keywords Interspecific hybrids · Iron · Leaf · Root · Zinc

Introduction

Cassava provides about 70% of daily calories to 200 million people (Nassar and Ortiz 2007). Its ability to adapt to poor soils and long periods of dry spell, as well its host-plant resistance to some pests and pathogens makes cassava an important famine reserve to poor people in the developing world. Furthermore, it tuberous roots can remain in the soil until harvest, thus storage facilities are not needed (Nassar 2007).

The roots of cassava are extremely rich in carbohydrates; likely to be second to sugarcane among crop plants. Cassava can produce 250×10^3 cal ha^{-1} daily, which is higher than that of rice (176×10^3) or wheat (110×10^3) (Charles et al. 2005). Despite cassava being a valuable source of energy, most of the current cultivars are deficient in proteins, fat, some minerals, vitamins and essential amino acids (Nassar and Sousa 2007).

Mineral deficiency has been considered a kind of malnutrition and named as "hidden hunger" by the World Health Organization (WHO). Iron (Fe) and zinc (Zn) are two micronutrients that have capture the attention of nutritionists. About 2 billion of the world population, mainly women and children, suffer from Fe and Zn malnutrition (WHO 2002). Iron is important for formation of hemoglobin, a large number of enzymes, metabolic reactions, the regulation of cell growth and immunity, and for the proper function of the liver. Zinc is vital for physical and mental development, immune system, vision and fertility. This element also appears to be necessary for the functioning of more than 300 enzymes in the human body. Its deficiency has been linked to vitamin A underutilization (Khush 2001).

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Journal : Medium 10722	Dispatch : 7-8-2009	Pages : 5
Article No. : 9469	☐ LE	☐ TYPESET
MS Code : GRES1527	☑ CP	☑ DISK

Cassava can play an important role in food security by providing micronutrients in the same way it does with energy poor populations that have limited access to foods derived from animals. Various reports have emphasized variability in the rich genetic resources of cassava and its wild *Manihot* relatives from Brazil, the country of origin of this crop (Nassar 2006a, b; 2007, Nassar and Ortiz 2008). The aim of this research was therefore to survey Fe and Zn content in accessions, cultivars, and a wild

Table 1 Cassava accessions, cultivars, *Manihot* species, and interspecific hybrids

Indigenous cultivars Amarela 1, Amarela 2, Amarela 4, Amarela 5, Branca Santa Catarina Vermelha 1, *Manihot zehntneri* Ule, hybrids from *M. anomala* Poh × Cassava, *M. cerulecens* × Cassava, *M. glaziovii* Muell. Arg × Cassava—Polyploid type, *M. grahamai* Hooker × Cassava, *M. grahamai* × Cassava 2, *M. pilosa* Pohl × Cassava accession 1076, *M. pohlii* × Cassava, *M. pseudoglaziovii* Muell. Arg. × Cassava—Diploid type and *M. pseudoglaziovii* × Cassava—Polyploid type, Hybrid Manihot esculenta Pax × cassava (namely ICB 300)—Polyploid type, ICB 300 Progeny 9, Cassava cultivar UnB 60 Diploid type, Cassava cultivar UnB 60 Polyploid type, Cassava cultivar UnB 530 Diploid type, Cassava cultivar UnB 530 Polyploid type, Cultivar UnB 031 Diploid type, Cultivar UnB 031 Polyploid type, Cassava cultivar UnB S1, Cassava cultivar UnB 307, Cassava cultivar UnB 567

Table 2 Iron contents in cassava and *Manihot* materials (mg kg^{-1} dry weight)

Material	Root		Leaf	
	Minimum	Maximum	Minimum	Maximum
Amarela 1	16.75	28.25	63.25	97.75
Amarela 2	–	13.25	–	55.75
Amarela 4	10.75	12.25	82.00	88.50
Amarela 5	11.00	12.25	61.00	73.25
Branca Santa Catarina	12.75	22.00	61.25	75.50
Vermelha 1	20.50	32.50	45.25	58.00
Manihot zenhtneri	–	51.25	–	105.50
M. anomala × Cassava	16.50	19.25	70.50	84.25
M. cerulecens × Cassava	69.75	91.25	64.50	86.75
M. glaziovii × Cassava Polyploid type	–	25.50	–	60.75
M. grahamaii × Cassava	28.00	85.50	66.75	70.75
M. pilosa × Cassava accession 1076	–	33.00	–	50.00
M. pohlii × Cassava	54.25	61.25	78.50	92.25
Hybrid Restituição (*M. pseudoglaziovii* × Cassava)	–	18.00	–	100.00
Hybrid M. pseudoglaziovii × Cassava Diploid	24.25	26.75	60.00	79.75
Hybrid M. pseudoglaziovii × Cassava Polyploid	–	32.00	–	136.00
Hybrid M. oligantha × Cassava (ICB 300) Polyploid type	26.75	29.50	64.25	244.25
ICB 300 Progeny 9	16.00	38.00	59.25	76.50
Cassava cultivar UnB60 Diploid	–	16.25	–	65.75
Cassava cultivar UnB60 Polyploid	23.50	32.00	68.75	74.00
Cassava cultivar UnB530 Diploid	18.25	18.25	62.75	83.75
Cassava cultivar unB 530 Polyploid	15.25	23.50	63.00	78.25
Cassava cultivar UnB 031 Diploid	–	21.25	–	95.00
Cassava cultivar UnB 031 Polyploid	–	11.50	–	236.75
Cassava cultivar UnB S1	15.75	24.75	72.75	74.75
Cassava cultivar UnB 307	13.00	15.50	65.00	134.75
Cassava cultivar UnB 567	14.50	32.00	64.25	87.75

Journal : Medium 10722 Dispatch : 7-8-2009 Pages : 5
Article No. : 9469 ☐ LE ☐ TYPESET
MS Code : GRES1527 ☑ CP ☑ DISK

from Brazil as well as some interspecific *Manihot*-cassava hybrids available from the University of Brasilia.

Materials and methods

Cassava and interspecific hybrids materials

Table 1 lists the materials used for determining Fe and Zn contents. Seven of them are indigenous cultivars (Amarela 1, 2, 4 and 5, Branca Santa Catarina and Vermelha 1) and a wild species (*M. zehntneri* Ule) The 27 accessions, cultivars, species and interspecific hybrids analyzed in this work are part of the living Collection of Cassava, placed in the Biological Experimental Station of the University of Brasília. They were collected from Amazon, Para, Minas Gerais, Mato Grosso do Sul, and Goias States.

Method for analyzing micro-nutrient concentrations

The samples of these cassava materials were analyzed twice. The results of the preliminary analysis provided means for selecting those materials for the second phase of analysis. The roots were cleaned with distilled water and dried in an air oven at 70°C after skin removal. The leaves were also cleaned and

Table 3 Zinc content ranges in cassava and *Manihot* materials (mg kg^{-1} dry weight)

Material	Roots		Leaves	
	Minimum	Maximum	Minimum	Maximum
Amarela 1	7.25	8.00	12.50	15.00
Amarela 2	–	5.25	–	17.00
Amarela 4	8.75	9.50	15.75	26.50
Amarela 5	9.75	11.75	32.50	38.75
Branca Santa Catarina	7.00	8.75	12.00	12.00
Vermelha 1	6.25	10.00	18.25	21.75
Manihot zehntneri	–	16.00	–	15.00
M. anomala × Cassava	11.75	15.00	17.50	20.25
M. cearulecens × Cassava	7.50	11.50	16.25	17.75
M. glaziovii × Cassava—Polyploid type	–	11.00	–	48.25
M. grahamai × Cassava	11.00	11.50	12.75	20.00
M. pilosa × Cassava accession no. 1076	–	9.75	–	18.75
M. pohlii × Cassava	13.00	17.75	73.75	280.00
Hybrid Restituição (*M. pseudoglaziovii* × Cassava)	–	13.50	–	26.00
M. pseudoglaziovii × Cassava Diploid type	12.25	13.75	24.75	29.75
M. pseudoglaziovii × Cassava Polyploid type	–	7.25	–	25.25
M.oligantha Pax × Cassava (ICB 300) Polyploid type	12.75	14.25	11.25	13.00
ICB 300 Progeny no. 9	6.00	8.50	11.50	15.75
Cassava cultivar UnB 60 Diploid type	–	5.00	–	33.50
Cassava cultivar UnB 60 Polyploid type	9.50	12.00	19.00	21.50
Cassava cultivar UnB 530—Diploid type	10.25	10.75	18.25	20.25
Cassava cultivar UnB 530 Polyploid type	8.25	10.50	14.00	15.00
Cassava cultivar UnB 031 Diploid type	–	9.50	–	19.25
Cassava cultivar UnB 031 Polyploid type	–	9.75	–	22.50
Cassava cultivar UnB S1	9.00	12.50	20.00	56.25
Cassava cultivar UnB 307	8.00	11.00	24.50	25.75
Cassava cultivar UnB 567	8.50	12.25	21.75	22.00

Journal : Medium 10722 Dispatch : 7-8-2009 Pages : 5
Article No. : 9469 ☐ LE ☐ TYPESET
MS Code : GRES1527 ✔ CP ✔ DISK

Table 4 Iron (Fe) and zinc (Zn) content ranges of six selected cassava cultivars, interspecific hybrids and a wild species (mg kg^{-1} dry weight)

Material	Root Fe		Leaf Fe		Root Zn		Leaf Zn	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
S1	7.50	19.50	72.00	77.25	5.50	9.00	27.00	71.00
Cassava cultivar UnB31, Polyploid type	10.50	13.75	193.25	199.50	6.75	7.00	27.75	29.50
Cassava cultivar Amarela 2	10.25	14.50	57.25	62.75	4.50	7.00	21.75	23.50
Hybrid M. pseudoglaziovii × Cassava Diploid type	11.50	24.75	57.25	64.25	10.25	13.75	38.25	48.75
M. cerulecens × Cassava	62.94	124.88	58.75	89.75	7.66	18.98	18.75	21.50
Manihot zehntneri	39.75	47.75	93.75	97.50	18.75	18.75	16.75	18.00

dried as per the roots. The dried rhizome and leaves were ground using a laboratory Wiley mill. Wet digestion using a mixture of sulphuric, nitric and perchloric acids (1:10:2) was employed for chemical analysis, and Fe and Zn were determined by atomic absorption spectrophotometry (Allen 1989).

Results and discussion

Table 2 provides the results of the preliminary Fe content analysis in cassava and *Manihot* materials. Roots showed a great variability in Fe content: from 10.75 mg kg^{-1} in Amarela 4–91.25 mg kg^{-1} in *M. cerulecens* × *Manihot* hybrid. There was also a great variation of Fe leaf content: from 45.25 to 244.25 mg kg^{-1}.

The wild species *Manihot zenhtneri* showed the highest Zn content (16 mg kg^{-1}) in the roots. The Zn leaf content ranged from 11.25 mg kg^{-1} in Hybrid ICB 300 Polyploid to 280 mg kg^{-1} in *M. pohlii* × *Manihot* (Table 3). Above results led to select six cassava and *Manihot* materials with the aim to assess them statistically. The materials included cultivars (Amarela 2 and Amarela 5), interspecific hybrids (S1, Clone 031 Polyploid and *M. cearulecens* × *Manihot*), and the wild species *M. zenhtneri* (Table 4), which showed the highest Fe or Zn root and leaf levels in the preliminary analyses.

There were significant differences ($P < 0.05$) for both Fe and Zn content among the selected materials (Table 5). The interspecific hybrid *M. cearulescens* × *Manihot* showed on average the highest content of root Fe (98.15 mg kg^{-1}), which was significantly above that of cassava cultivars (12.17 mg kg^{-1}). The same interspecific hybrid had higher Zn root content (12.15 mg kg^{-1}) than cassava cultivars (7 mg kg^{-1}). The Clone 031 Polyploid (offspring of the interspecific hybrid of *M. dichotoma* with cassava) showed significantly higher Fe leaf content (196.83 mg kg^{-1}) than cultivar Amarela 2 (60 mg kg^{-1}). S1—a selection derived from the offspring of an interspecific hybrid of cassava with *M. pseudoglaziovii*—had 67.58 mg kg^{-1} of Zn leaf

Table 5 Iron (Fe) and zinc (Zn) average contents in leaf and root samples of cassava and *Manihot* materials

Material	Leaf		Root	
	Fe	Zn	Fe	Zn
Cassava cultivar UnB S1	74.96 c	47.63 a	15.29 c	7.79 bc
Cassava cultivar UnB 031 Polyploid type	196.83 a	28.67 ab	12.83 c	6.92 bc
Cassava cultivar Amarela 2	60.00 c	22.42 ab	12.17 c	5.58 c
Hybrid *M. pseudoglaziovii* × *Cassava*. Diploid type	61.67 c	43.33 ab	16.71 c	11.88 b
Hybrid *M. cerulescens* × *Cassava*	73.05 c	21.25 ab	98.15 a	12.15 b
Manihot zehntneri	95.63 b	17.38 b	42.75 b	18.75 a

Means follow by same letters are not significantly different at $P \leq 0.05$ as per Tukey's Multiple Comparison Test

Journal : Medium 10722
Article No. : 9469
MS Code : GRES1527
Dispatch : 7-8-2009
Pages : 5
☐ LE
☑ CP
☐ TYPESET
☑ DISK

content vis-à-vis 22.42 mg kg^{-1} of cassava cultivar Amarela 2.

The wild species *M. cearulescens*, *M. dichotoma* and *M. pseudoglaziovii* appear to be rich for Fe and Zn sources, which can be transferred to interspecific hybrids and inherited by their derived offspring. These results show therefore the potential of wild *Manihot* species to improve both Fe and Zn contents in the cassava gene pool, which can provide better food to fight malnutrition, especially in resource-poor populations.

Acknowledgments The National Council for Scientific Development (CNPq, Brasilia, Brazil) provided funding for this research. The forementioned living collection was established at the Universidade de Brasilia through a grant from the International Development Center (IDRC, Canada) to whom the authors are grateful.

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Journal : Medium 10722 | Dispatch : 7-8-2009 | Pages : 5
Article No. : 9469 | ☐ LE | ☐ TYPESET
MS Code : GRES1527 | ☑ CP | ☑ DISK