AFRIMETS - INTRA-AFRICA METROLOGY SYSTEM

Final Report of AFRIMETS.M.M-S6 Supplementary Comparison of 100 mg, 100 g, 500 g, 1 kg and 5 kg Stainless Steel Mass Standards

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ABSTRACT

This report summarizes the results of AFRIMETS.M.M-S6 mass standards comparison conducted between eleven participating laboratories/countries. Two sets of five weights with nominal values 100 mg, 100 g, 500 g, 1 kg and 5 kg were used as the traveling standards. These nominal values were decided from the needs of participating laboratories submitted to the pilot laboratory through a questionnaire and agreed upon by all participants. The traveling standards were hand carried between laboratories starting from February 2014 and were received from the last participants in October 2014. The programme was coordinated by National Metrology Institute of South Africa (NMISA), who provided the travelling standards and reference values for the comparison. NMISA has participated in inter-laboratory comparisons of higher accuracy level at CCM and RMO (APMP) with satisfactory results. The corrections to the BIPM as-maintained mass unit [5] have insignificant influence on the results of this comparison.

Introduction

During the AFRIMETS working group for mass and related quantities meeting held in Benin in September 2012, it was agreed to start a comparison concerning mass calibration. The main purpose of comparing the results was to test and prove metrology equivalence in the AFRIMETS region to ensure mutual confidence in measurements to promote recognition of calibration and measurements certificates. The comparison used two loops with two sets of class E2 level weights according to OIML R111-1:2004 [1], of denominations 100 mg, 100 g, 500 g, 1 kg and 5 kg, which were chosen as per the needs of participants submitted to the pilot laboratory through a questionnaire. The comparison was aimed at laboratories operating at OIML class F1 level. The weights were hand carried between the laboratories. National Metrology Institute of South Africa (NMISA) acted as the pilot laboratory and provided the reference values.

Objectives

The comparison was meant to test and prove metrology equivalence in the region and to ensure mutual confidence in mass measurements. It is also meant to promote recognition of calibration and measurements certificates in the region and the world as a whole. Moreover, it was intended to extend metrological equivalence to the whole of the AFRIMETS region by including countries who do not have capabilities to participate at high level comparisons.

Participants

The following table contains participants of this comparison.

Table 1: List of participants

Country	Name of The Laboratory
South Africa	National Metrology Institute of South Africa (NMISA) - Pilot
Zimbabwe	Scientific and Industrial Research and Development Centre (SIRDC-NMI)
Namibia	Namibian Standards Institution (NSI)
Tanzania	Tanzania Bureau of Standards (TBS)
Seychelles	Seychelles Bureau of Standards (SBS)
Democratic Republic of Congo	Office Congolaise de Controle (OCC)
Uganda	Uganda National Bureau of Standards (UNBS)
Botswana	Botswana Bureau of Standards (BOBS)
Mozambique	Instituto Nacional de NormalizaÇãoc e Qualidade (INNOQ)
Zambia	Zambia Bureau of Standards (ZABS)
Mauritius	Mauritius Standards Bureau (MSB)
Ghana	Ghana Standards Authority (GSA)

The weights (Artifacts)

The chosen mass standards were two sets of OIML shape stainless steel (non-magnetic) mass pieces, without cavities, with nominal values 100 mg, 100 g, 500 g, 1 kg and 5 kg. The weights are of accuracy OIML class E2. The densities for the weights were known and were given to the participants with protocol. The weights were acquired by NMISA through sponsorship from PTB- International Technical Cooperation and were calibrated by NMISA prior to being put into circulation and at the end of circulation. The weights were circulated as per time schedule below.

Time schedule

Each participating laboratory had 4 weeks to receive the weights, carry out measurements and send to the next laboratory. The weights were expected to be at the next laboratory by the 1st working day of the month. The comparison was divided into two loops (petals) and measurements started concurrently. The time schedule was as follows:

Table 2: Participants divided into two loops

Number	NMI	Country	Participation Date
Petal/Loop 1			
1	NMISA	South Africa	December 2013
2	NSI	Namibia	February 2014
3	BOBS	Botswana	March 2014
4	INNOQ	Mozambique	April 2014
5	SIRDC-NMI	Zimbabwe	May 2014
6	MSB	Mauritius	June 2014
1	NMISA	South Africa	July 2014
Petal/Loop 2			
1	NMISA	South Africa	December 2013
2	ZABS	Zambia	February 2014
3	OCC	Democratic Republic of Congo	March 2014
4	GSA	Ghana	April 2014
5	UNBS	Uganda	May 2014
6	TBS	Tanzania	June 2014
7	SBS	Seychelles	July 2014
1	NMISA	South Africa	August 2014

There were some problems experienced with some participants (financial, political, etc.), which affected the transportation of the weights, as a result the time schedule was not followed exactly as in the above table, which therefore delayed the completion date by two months.

Results and Analysis

The participating laboratories were requested to determine the conventional mass values of the weights in air. The uncertainties claimed by each participant were supported by uncertainty budgets which had to be expressed in accordance with “A Guide to the Expression of Uncertainty in Measurements” (GUM) [2]. All participants submitted a full calibration report with relevant data and uncertainty estimates to the coordinating laboratory (NMISA). The results are presented in table 4 and table 5 for loop 1 and loop 2 respectively, indicated as the deviation from nominal, where deviation is defined to be nominal value minus the measured value.

The stability of each of the travelling artifacts was assessed by NMISA measuring the values of the artifacts before and after each loop circulation. The change in mass of the

traveling standards from December 2013 to October 2014 in both loops were found to be smaller than their associated uncertainties except for 5 kg's in both loops with a decrease of about 3.3 mg for both weights. Moreover, graphs in appendix 2 (figure 1 to figure 10.1) do not show any clear trend in the mass value of any of the traveling standards. Because of this, the mass of each traveling standard was taken to be stable during the comparison process. Variation in the mass of the traveling standards was included in the standard deviation of the mass values measured by NMISA as part of the uncertainty component [3]. Table 3 shows the change in mass and the associated uncertainties for the travelling standards as measured at NMISA. The changes in mass measurements during the course of the comparison except for the 5 kg's give a reasonable indication that the artifacts were stable during the comparison.

Table 3: Change in mass for the traveling standards

	Change in Mass from December 2013 to October 2014		
Loop 1	NMISA	**Change in mass (g)**	Unc (± g)
	5 kg	-0.0032	0.0025
	1 kg	-0.0001	0.0005
	500 g	-0.00016	0.00025
	100 g	0.00003	0.00005
	100 mg	0.000004	0.000005
Loop 2			
	5 kg	-0.0033	0.0025
	1 kg	-0.00005	0.0005
	500 g	-0.00009	0.00025
	100 g	0.00005	0.00005
	100 mg	0.000004	0.000005

Reference values and degree of equivalence

NMISA's measurements and associated measurement uncertainties carried out before and after the circulation where averaged and used to calculate the reference values for the two loops, as agreed by participants in 2013 at Addis Ababa. The reported expanded measurement uncertainties of the reference values were obtained according to GUM 1995 [2], where combined standard uncertainties were multiplied by a coverage factor of *k*=2, which for a normal distribution which approximates a level of confidence of 95.45%. The uncertainty of measurement was calculated from contributions such as the reference standard used, the weighing process, buoyancy correction, balance used and weights instability which was negligible. The correction to the BIPM as-maintained mass unit was considered to be negligible for these measurements.

Degree of equivalence for each participant with respect to the reference value was determined. It was calculated as the difference between the reference value (X_r) and the values reported by the participants (X_i). From the differences and their corresponding uncertainties, the normalized errors were calculated for each nominal value as follows [4]:

$$En = \frac{|\mathrm{X}_i - \mathrm{X}_r|}{\sqrt{{U_i}^2 + {U_r}^2}}$$

Where:
E_n - normalized error
X_i - the mass value reported by the participant
X_r - the reference value for the comparison
U_i - the expanded measurement uncertainty reported by the participant
U_r - the reference expanded measurement uncertainty

The value of En has the following meaning:

- The results of a laboratory are consistent (passed) if $En \leq 1$
- The results are inconsistent (failed) if $En > 1.1$
- Where results are $1 < En \leq 1.1$ a "warning level" is defined. For this particular situation the particular lab is recommended to check their procedures and methodology.

Conclusion

As per table 6 and table 7 majority of the results of the participating laboratories are consistent with the reference value. However, in most cases the uncertainties presented by laboratories were bigger than calibration and measurement capabilities recommended for OIML class F1 weights. Specifically, four different laboratories (for each nominal value) reported uncertainties for 5 kg, 500 g, 100 g and 100 mg which are higher than recommended values for OIML class F1. Moreover, one laboratory reported uncertainty associated with 1 kg higher than the recommended value for OIML class F1.

In loop one (table 6): the result reported for 500 g by MSB laboratory differs significantly from the reference value.

In loop two (table 7): the results reported for 1 kg and 100 mg by ZABS differ significantly from the reference values.

Four laboratories (SIRDC-NMI, ZABS, TBS, MSB) where requested to recheck their results while preparing Draft A report. One laboratory (MSB) did not make any changes while the other three (ZABS, TBS & SIRDC-NMI) made corrections and resubmitted their revised results. The changes have already been incorporated in this report. NMISA found errors in TBS results in converting true mass to conventional mass, and TBS was requested to rectify and resubmit their results.

The correction to the BIPM as-maintained mass unit was considered to be negligible for these measurements [5].

There was one-time slot which was exchanged between two participating laboratories.

References

1. OIML R 111-1 Edition 2004 (E): International Recommendation – Weights of classes E_1, E_2, F_1, F_2, M_1, M_{1-2}, M_2, M_{2-3} and M_3.
   Part 1: Metrological and technical requirements

2. BIPM et al, Guide to the Expression of Uncertainty in Measurement (GUM), Corrected and Reprinted 1995, International Organization for Standardization, Switzerland

3. S Krishnan et al. Final report of APMP Comparison of Mass Standards, APMP.M.M-K2 (Sub) Multiples mass key comparison. 2009, New Delhi, India

4. NIST (National Institute of Standards and Technology-US), (2011): PT/ILC Report Terminology Guidance

5. M Stock, P Barat, R Davis, A Picard & M Milton, (2015). Calibration Campaign against the international prototype of the kilogram in anticipation of the redefinition of the kilogram part I: Comparison of the international prototype with its official copies. Metrologia, **52**, (2015): 310-316

APPENDIX 1

The mass as presented in the tables below from participants is given as conventional mass with expanded uncertainty (coverage factor of K=2)

Table 4: Results presented by participants of loop 1 as the difference from nominal value

LOOP 1											
Country	**NMI**	**5 000 g**	**Uc (± g)**	**1 000 g**	**Uc (± g)**	**500 g**	**Uc (± g)**	**100 g**	**Uc (± g)**	**0.1 g**	**Uc (± g)**
SA	NMISA	-0.0062	0.0025	-0.0006	0.0005	-0.00053	0.00025	-0.00001	0.00005	-0.000003	0.000005
Namibia	NSI	-0.0060	0.0070	-0.0010	0.0020	0.00000	0.00200	0.00010	0.00020	0.000010	0.000020
Botswana	BOBS	-0.0006	0.2000	0.0000	0.0030	0.00080	0.00200	0.00055	0.00100	-0.000203	0.001000
Zimbabwe	SIRDC-NMI	0.0000	0.1000	0.0000	0.0007	0.00000	0.00040	0.00000	0.00010	0.000000	0.000010
Mozambique	INNOQ	0.0000	0.0080	-0.0005	0.0016	-0.00050	0.00080	-0.00010	0.00024	0.000000	0.000240
Mauritius	MSB	-0.0050	0.0040	-0.0001	0.0008	0.00020	0.00040	0.00010	0.00020	-0.000004	0.000008
SA	NMISA	-0.0030	0.0025	-0.0005	0.0005	-0.00037	0.00025	-0.00005	0.00005	-0.000007	0.000005

Table 5: Results presented by participants of loop 2 as the difference from nominal value

Loop 2											
Country	**NMI**	**5 000 g**	**Uc (± g)**	**1 000 g**	**Uc (± g)**	**500 g**	**Uc (± g)**	**100 g**	**Uc (± g)**	**0.1 g**	**Uc (± g)**
SA	NMISA	-0.0063	0.0025	-0.0005	0.0005	-0.00040	0.00025	0.00003	0.00005	-0.000002	0.000005
Zambia	ZABS	-0.0024	0.0060	0.0008	0.0010	-0.00010	0.00180	0.00010	0.00100	0.000078	0.000002
DRC	OCC	-0.0038	0.0080	0.0001	0.0016	0.00020	0.00080	0.00000	0.00030		
Ghana	GSA	-0.0015	0.0080	-0.0013	0.0016	-0.00010	0.00080	0.00002	0.00016	-0.000004	0.000016
Uganda	UNBS	-0.0050	0.0240	-0.0006	0.0007	-0.00050	0.00040	-0.00008	0.00007	0.000001	0.000028
Tanzania	TBS	-0.0060	0.0030	-0.0011	0.0003	-0.00031	0.00026	-0.00009	0.00008	-0.000002	0.000010
Seychelles	SBS	-0.0030	0.0301	-0.0001	0.0130	-0.00030	0.01201	-0.00008	0.00051	0.000008	0.000115
SA	NMISA	-0.0031	0.0025	-0.0004	0.0005	-0.00031	0.00025	-0.00001	0.00005	-0.000006	0.000005

Note: DRC did not submit results for 100mg as they do not have capabilities in this range

Tables below only indicate the degree of equivalence between the reference and the signatory NMIs for the measurements done in this comparison.

Table 6: Degree of equivalence for laboratories in loop 1

Calculation for E_n Values															
	5 kg			1 kg			500 g			100 g			0.1 g		
Loop 1	m-m_0	U_c	$\mathbf{E_n}$	m-m_0	U_c	$\mathbf{E_n}$	m-m_0	U_c	$\mathbf{E_n}$	m-m_0	U_c	$\mathbf{E_n}$	m-m_0	U_c	$\mathbf{E_n}$
NMISA	-0.0046	0.0025	**-**	-0.0006	0.0005	**-**	-0.00045	0.00025	**-**	-0.00003	0.00005	**-**	-0.000005	0.000005	**-**
NSI	-0.0060	0.0070	0.19	-0.0010	0.0020	0.22	0	0.00200	0.22	0.00010	0.00020	0.63	0.000010	0.000020	0.73
BOBS	-0.0006	0.2000	0.02	0	0.0030	0.18	0.00080	0.00200	0.62	0.00055	0.00100	0.58	-0.000200	0.001000	0.20
SIRDC-NMI	0	0.1000	0.05	0	0.0007	0.64	0	0.00040	0.96	0	0.00010	0.27	0	0.000010	0.45
MSB	-0.0050	0.0040	0.09	-0.0001	0.0008	0.48	0.00020	0.00040	1.38	0.00010	0.00020	0.63	-0.000004	0.000008	0.11

Table 7: Degree of equivalence for laboratories in loop 2

Calculation for E_n values															
	5 kg			1 kg			500 g			100 g			0.1 g		
Loop 2	m-m_0	U_c	$\mathbf{E_n}$	m-m_0	U_c	$\mathbf{E_n}$	m-m_0	U_c	$\mathbf{E_n}$	m-m_0	U_c	$\mathbf{E_n}$	m-m_0	U_c	$\mathbf{E_n}$
NMISA	-0.0047	0.0025	**-**	-0.00046	0.0005	**-**	-0.00035	0.00025	**-**	0.00001	0.00005	**-**	-0.0000041	0.000005	**-**
ZABS	-0.0024	0.0060	0.35	0.00080	0.0010	1.13	-0.00010	0.00180	0.14	0.00010	0.00100	0.09	0.000078	0.000002	15.61
GSA	-0.0020	0.0080	0.38	-0.00130	0.0016	0.50	-0.0001	0.00080	0.30	-0.00002	0.00016	0.18	-0.000004	0.000016	0.00
SBS	-0.0030	0.0300	0.06	-0.00010	0.0130	0.03	-0.0003	0.01200	0.01	-0.00008	0.00051	0.17	0.000008	0.000115	0.11

LOOP 1

Table 8: Differences in assigned values between two laboratories (g) for 5 kg (conventional mass)

5 kg	NMISA	NSI	BOBS	SIRDC-NMI	MSB
NMISA		0.001415	-0.003985	-0.004585	0.000415
NSI	-0.001415		-0.005400	-0.006000	-0.001000
BOBS	0.003985	0.005400		-0.000600	0.004400
SIRDC-NMI	0.004585	0.006000	0.000600		0.005000
MSB	-0.000415	0.001000	-0.004400	-0.005000	

Table 9: Differences in assigned values between two laboratories (g) for 1 kg (conventional mass)

1 kg	NMISA	NSI	BOBS	SIRDC-NMI	MSB
NMISA		0.000447	-0.000553	-0.000553	-0.000453
NSI	-0.000447		-0.001000	-0.001000	-0.000900
BOBS	0.000553	0.001000		0.000000	0.000100
SIRDC-NMI	0.000553	0.001000	0.000000		0.000100
MSB	0.000493	0.000900	-0.000100	-0.000100	

Table 10: Differences in assigned values between two laboratories (g) for 500 g (conventional mass)

500 g	NMISA	NSI	BOBS	SIRDC-NMI	MSB
NMISA		-0.000452	-0.001252	-0.000452	-0.000652
NSI	0.000452		-0.000800	0.000000	-0.000200
BOBS	0.001252	0.000800		0.000800	0.000600
SIRDC-NMI	0.000452	0.000000	-0.000800		-0.000200
MSB	0.000652	0.000200	-0.000600	0.000200	

Table 11: Differences in assigned values between two laboratories (g) for 100 g (conventional mass)

100 g	NMISA	NSI	BOBS	SIRDC-NMI	MSB
NMISA		-0.00013	-0.00058	-0.00003	-0.00013
NSI	0.00013		-0.00045	0.00010	0.00000
BOBS	0.00058	0.00045		0.00055	0.00045
SIRDC-NMI	0.00003	-0.00010	-0.00055		-0.00010
MSB	0.00013	0.00000	-0.00045	0.00010	

Table 12: Differences in assigned values between two laboratories (g) for 100 mg (conventional mass)

100 mg	NMISA	NSI	BOBS	SIRDC-NMI	MSB
NMISA		-0.000015	0.000198	-0.000005	-0.000001
NSI	0.000015		0.000213	0.000010	0.000014
BOBS	-0.000198	-0.000213		-0.000203	-0.000199
SIRDC-NMI	0.000005	-0.000010	0.000203		0.000004
MSB	0.000001	-0.000014	0.000199	-0.000004	

Loop 2

Table 13: Differences in assigned values between two laboratories (g) for 5 kg (conventional mass)

5 kg	NMISA	ZABS	GSA	SBS
NMISA		-0.003925	-0.003187	-0.001690
ZABS	0.002287		-0.000900	0.000598
GSA	0.003187	0.000900		0.001498
SBS	0.001690	-0.000598	-0.001498	

Table 14: Differences in assigned values between two laboratories (g) for 1 kg (conventional mass)

1 kg	NMISA	ZABS	GSA	SBS
NMISA		-0.001286	0.000837	-0.000365
ZABS	0.001263		0.002100	0.000898
GSA	-0.000837	-0.002100		-0.001202
SBS	0.000365	-0.000898	0.001202	

Table 15: Differences in assigned values between two laboratories (g) for 500 g (conventional mass)

500 g	NMISA	ZABS	GSA	SBS
NMISA		-0.000296	-0.000253	-0.000055
ZABS	0.000253		0.000000	0.000198
GSA	0.000253	0.000000		0.000198
SBS	0.000055	-0.000198	-0.000198	

Table 16: Differences in assigned values between two laboratories (g) for 100 g (conventional mass)

100 g	NMISA	ZABS	GSA	SBS
NMISA		-0.000067	0.00003	0.00009
ZABS	0.00009		0.00012	0.00018
GSA	-0.00003	-0.000120		0.00006
SBS	-0.00009	-0.000180	-0.00006	

Table 17: Differences in assigned values between two laboratories (g) for 100 mg (conventional mass)

100 mg	NMISA	ZABS	GSA	SBS
NMISA		-0.000082	0.000000	-0.000012
ZABS	0.000082		0.000082	0.000070
GSA	0.000000	-0.000082		-0.000012
SBS	0.000012	-0.000070	0.000012	

APPENDIX 2

Graphs indicates the reported value measured by the participants with the error bars showing standard uncertainties (k =2) for various nominal

Loop 1

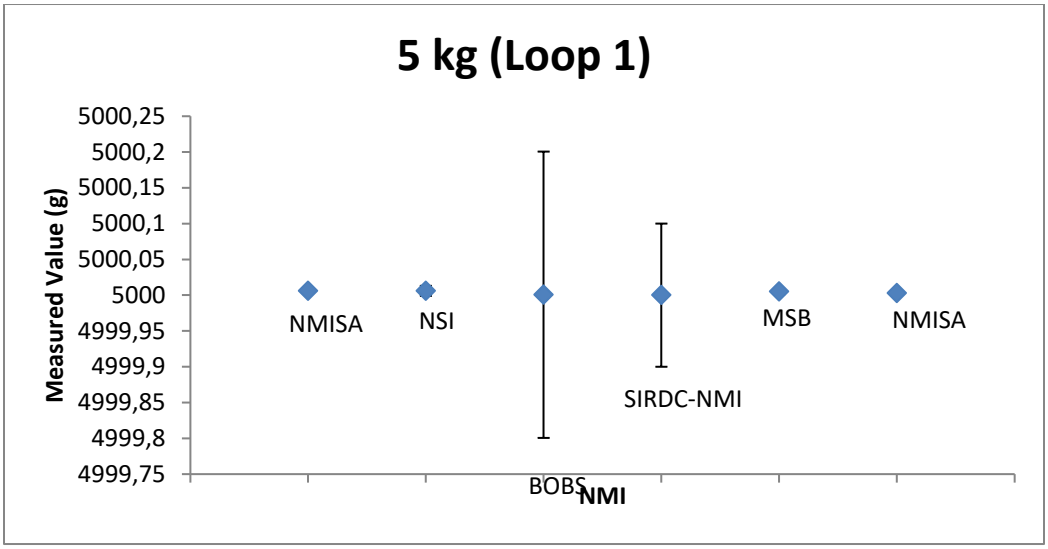

Figure 1: Measured values reported by participants of loop 1 for 5 kg

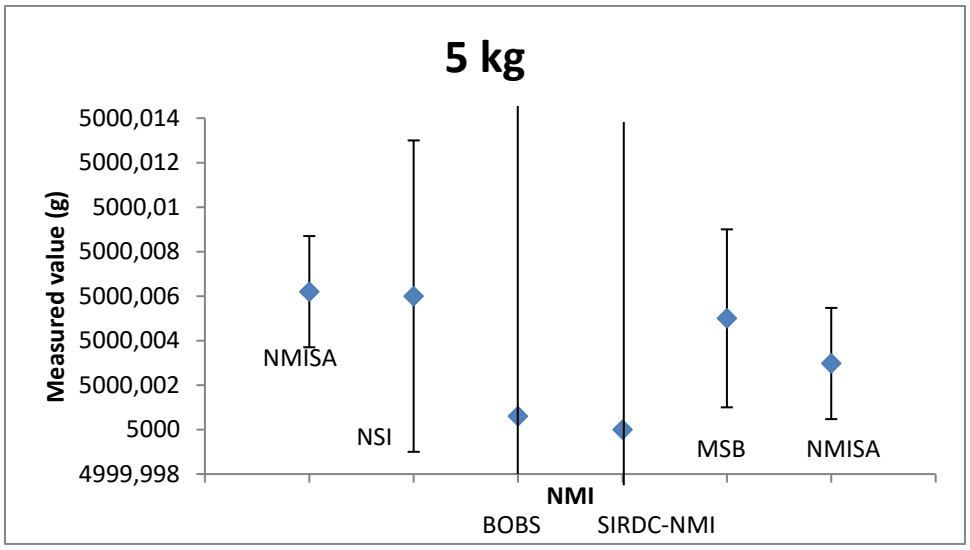

Figure 1.1: Reduced Scale-Measured values reported by participants of loop 1 for 5 kg

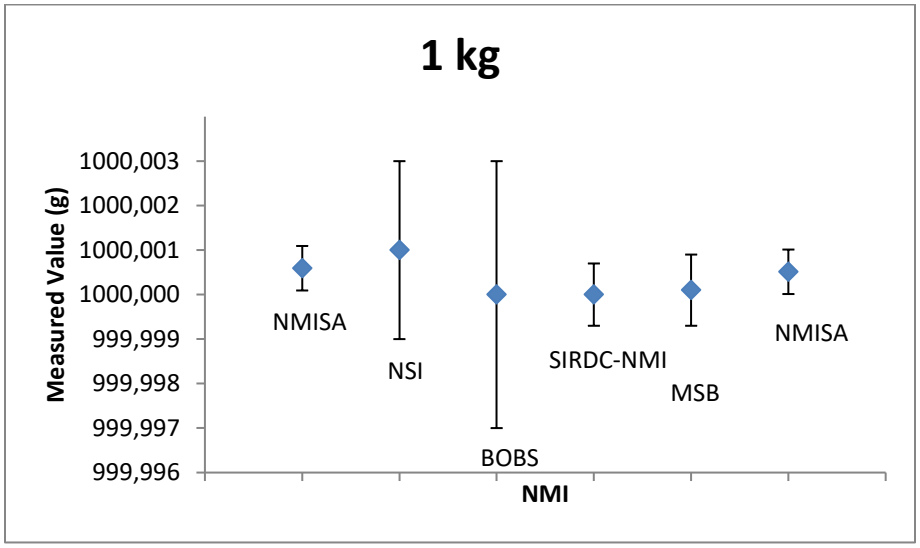

Figure 2: Measured values reported by participants of loop 1 for 1 kg

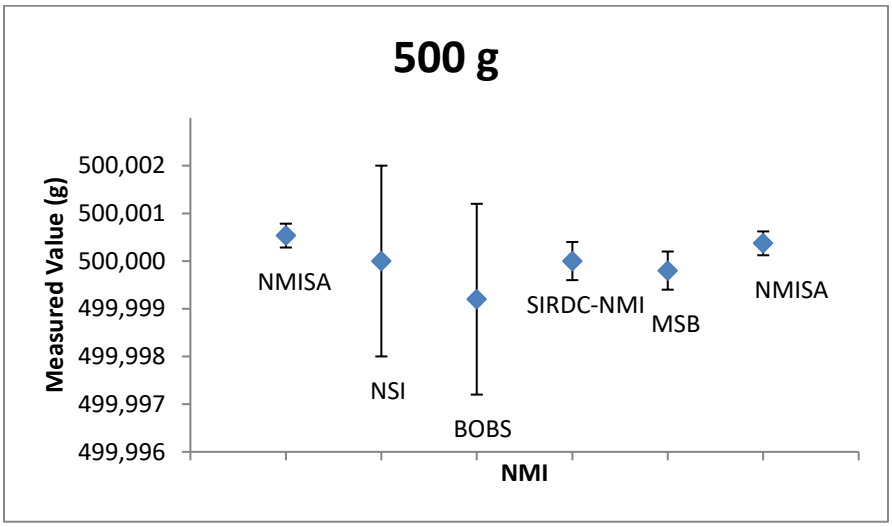

Figure 3: Measured values reported by participants of loop 1 for 500 g

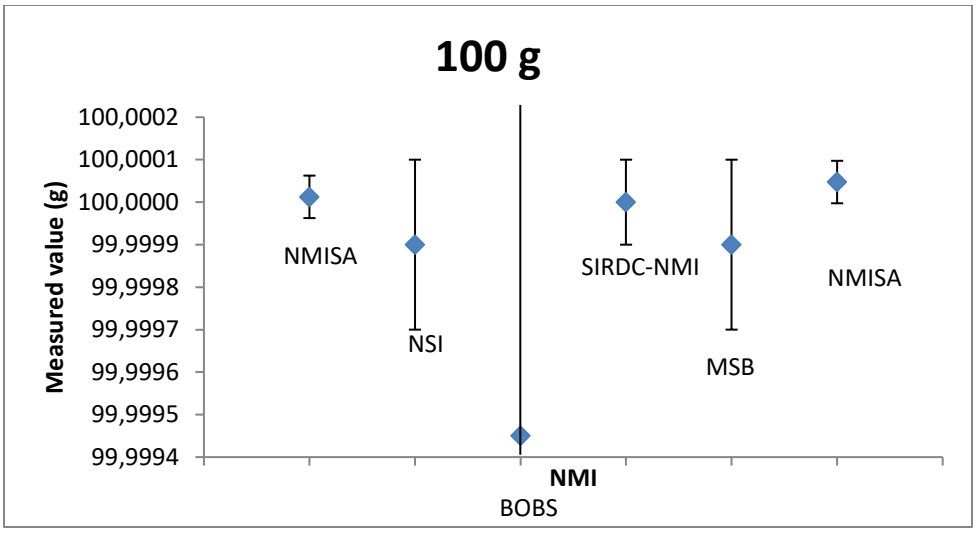

Figure 4: Measured values reported by participants of loop 1 for 100 g

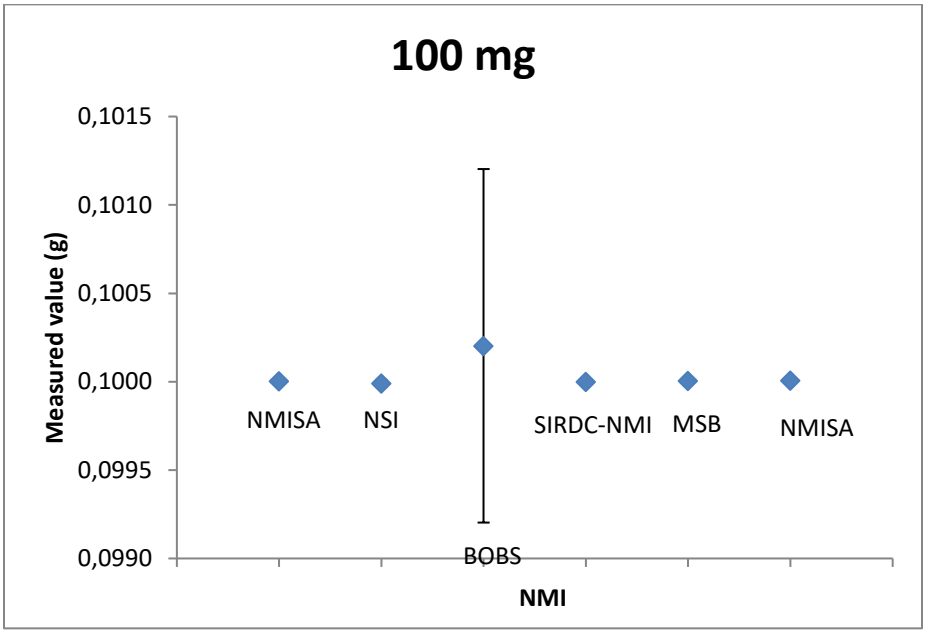

Figure 5: Measured values reported by participants of loop 1 for 100 mg

Reduced scale for 100 mg omitting results for BOBS

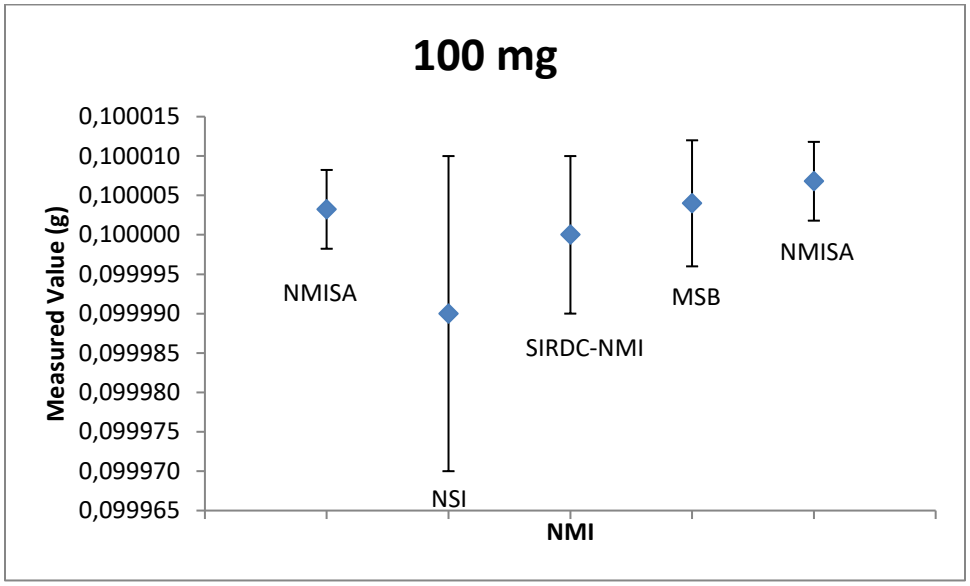

Figure 5.1: Measured values reported by participants of loop 1 for 100 mg

Loop 2

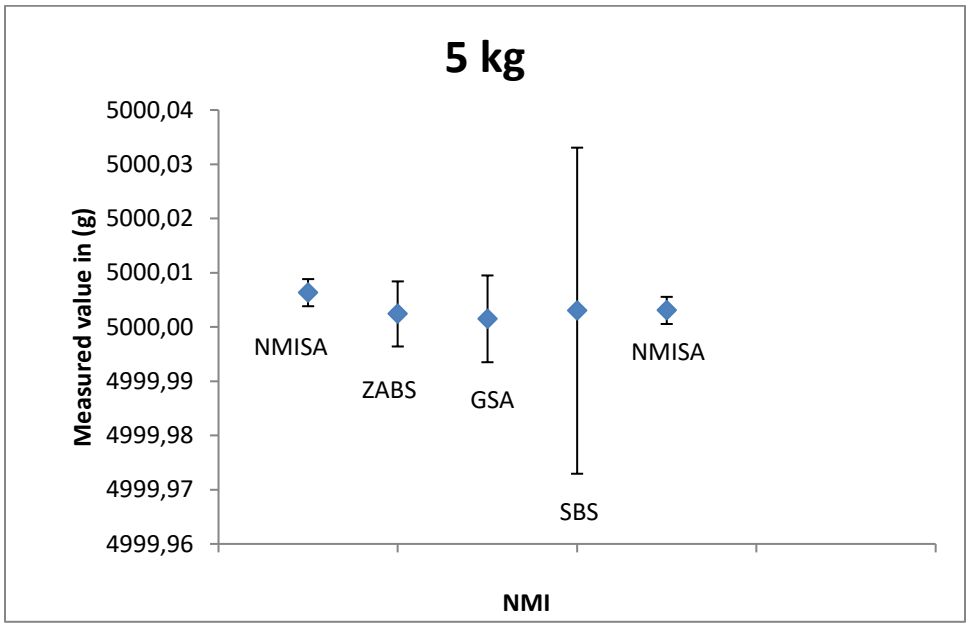

Figure 6: Measured values reported by participants of loop 2 for 5 kg

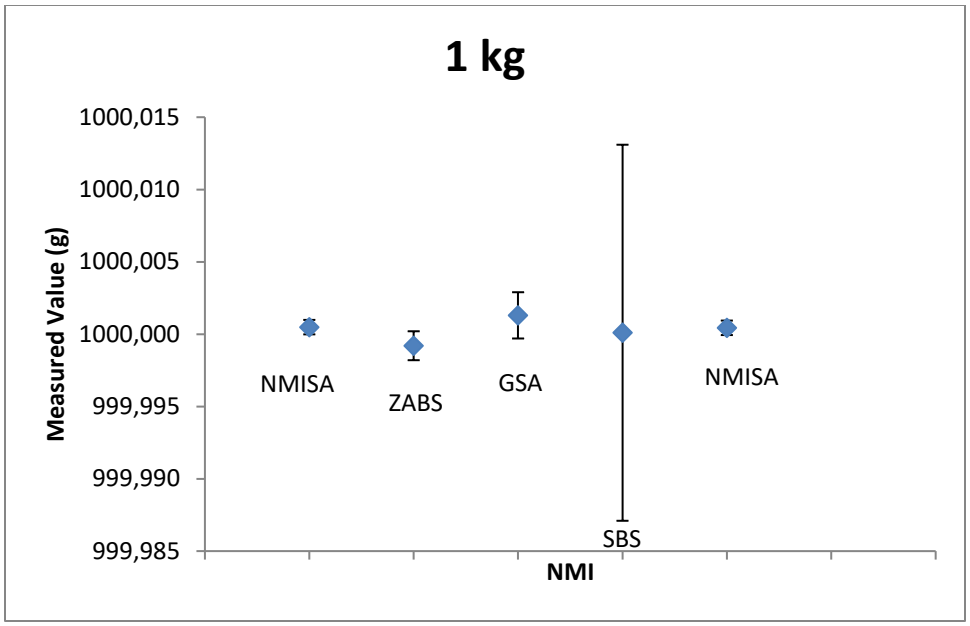

Figure 7: Measured values reported by participants of loop 2 for 1 kg

Reduced scale for 1 kg

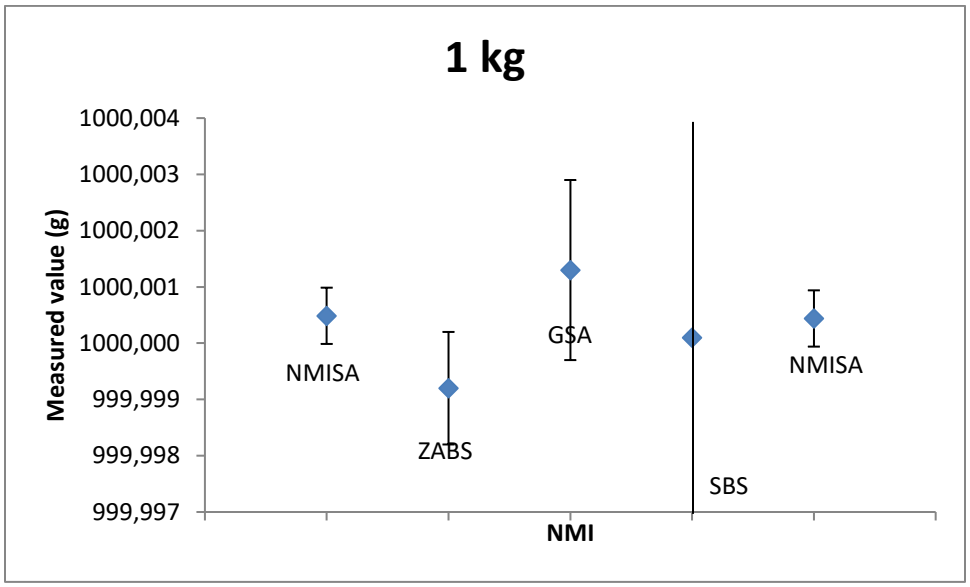

Figure 7.1: Reduced scale for figure 7

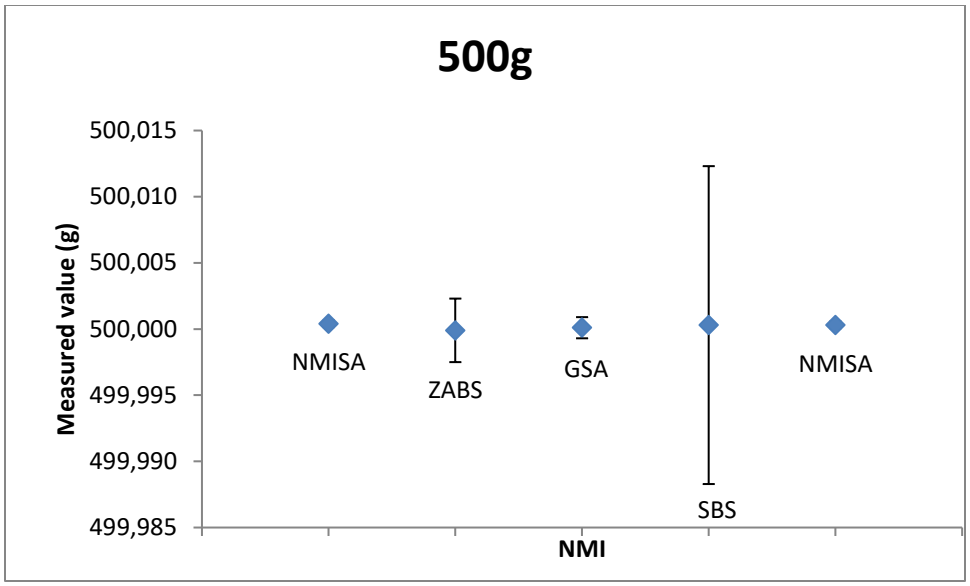

Figure 8**:** Measured values reported by participants of loop 2 for 500 g

Reduced scale for 500 g

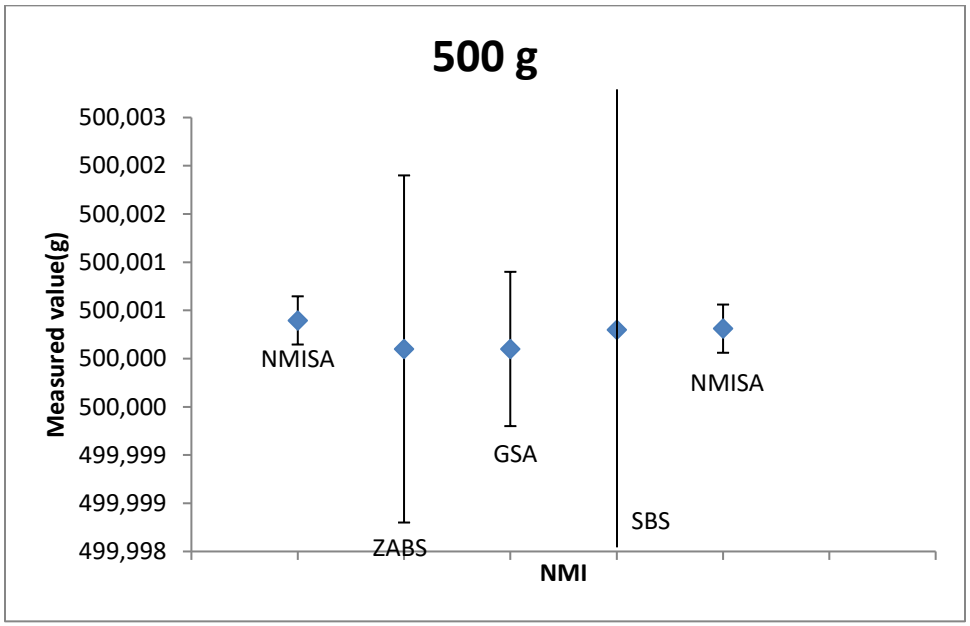

Figure 8.1: Measured values reported by participants of loop 2 for 500 g

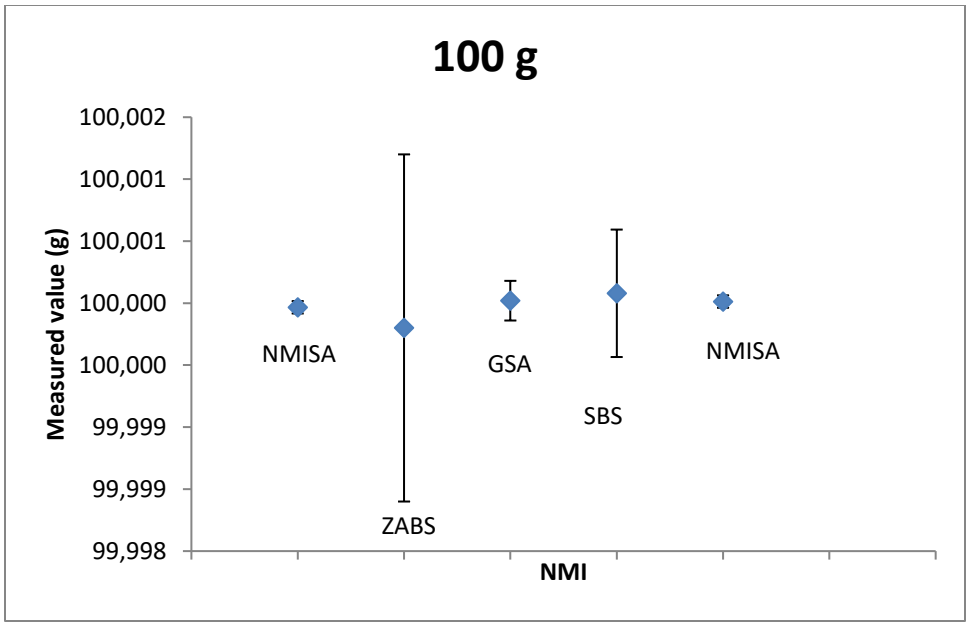

Figure 9: Measured values reported by participants of loop 2 for 100 g

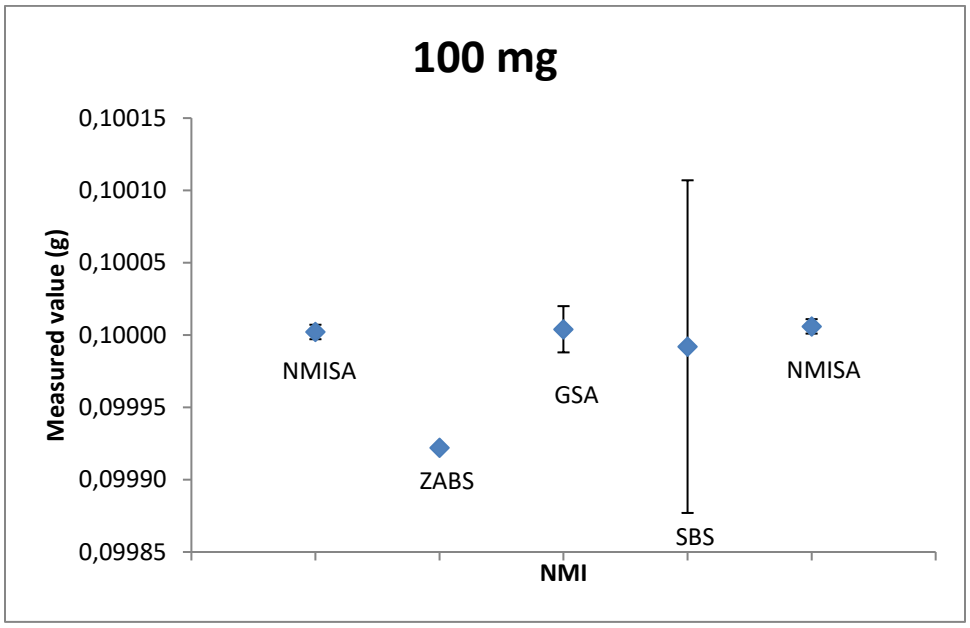

Figure 10: Measured values reported by participants of loop 2 for 100 mg

Reduced scale for 100 mg

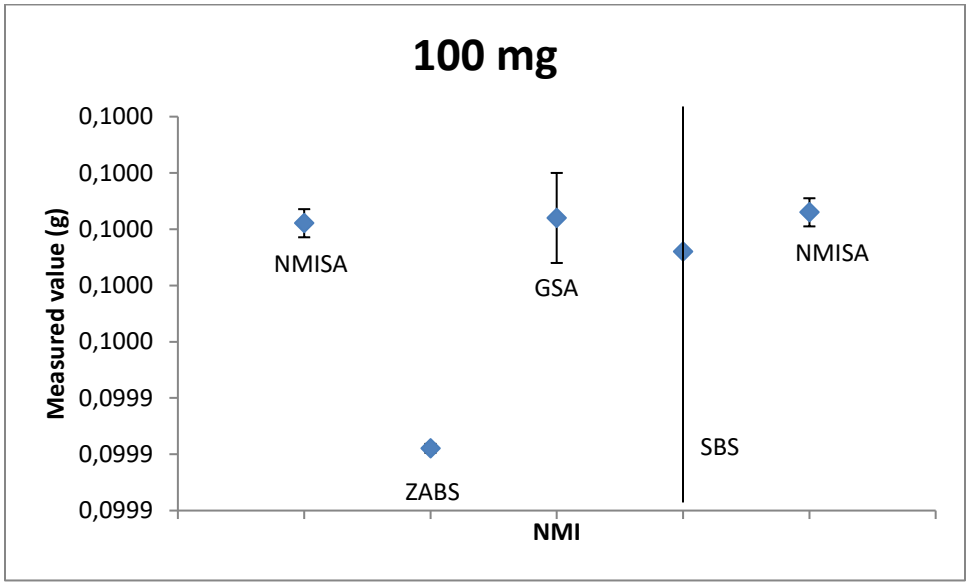

Figure 10.1: Measured value reported by participants of loop 2 for 100 mg