Selenium biofortification in rice

Maria Chiara Fontanella[a], R. D'Amato[b], D. Businelli[b] and G.M. Beone[a]

[a]*Department for Sustainable Process, Università Cattolica del Sacro Cuore, Piacenza, Italy.*
[b]*Department of Agricultural, Environmental and Food Science, University of Perugia, Perugia, Italy*

Trace elements in food: applications with ICP-MS and ICP-MS/MS

Università Cattolica del Sacro Cuore, Piacenza
Venerdì 21 Giugno 2019, Residenza Gasparini – Fienile

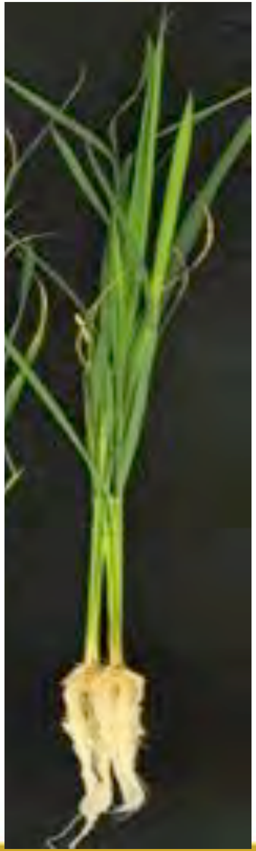
SUMMARY

- ✧ Selenium Introduction
- ✧ Selenium biofortification in rice (article)
- ✧ Antimony introduction
- ✧ Effects of Selenium on Antimony uptake in rice
- ✧ Conclusions
- ✧ Future perspectives

Selenium (Se)

- an ambivalent element: essential for human nutrition but toxic at high concentration
- Se content of most of foods is very low, the Se requirement of the body can be satisfied with dietary supplements or with Se-enriched foods
- Se agronomic biofortification crop by selenate (Se(VI) or selenite (Se(IV))
- Se(VI) ➔ washed out by irrigation/rainfall
- Se(IV) ➔ adsorbed by soil minerals
- Different Se incorporation in agriculture field (aqueous solution in soils o spraying on leaves)

Selenium in rice



- High Se concentration in roots than in shoots
- C-Se-C compounds being the dominant species of Se in all roots (Wang et al. 2015)

SELENITE (Se(IV))

- Se(IV) is transformed into organic Se in roots, limit translocation in shoots
- Selenite uptake into the plant may occur via phosphate transporters (Li et al. 2008) or passive diffusion (Shrift and Ulrich, 1969; Arvy, 1993) and/or a silicon (Si) influx transporter Lsi1 (OsNIP2;1) (Zhao et al., 2010).

UNIVERSITÀ CATTOLICA del Sacro Cuore

1st PART: Se biofortification in rice

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Article

Cite This: J. Agric. Food Chem. 2018, 66, 4082–4090

pubs.acs.org/JAFC

Selenium Biofortification in Rice (*Oryza sativa* L.) Sprouting: Effects on Se Yield and Nutritional Traits with Focus on Phenolic Acid Profile

Roberto D'Amato,[†] Maria Chiara Fontanella,[‡] Beatrice Falcinelli,[†] Gian Maria Beone,[‡] Elisabetta Bravi,[†] Ombretta Marconi,[†] Paolo Benincasa,[*,†] and Daniela Businelli[†]

[†]Department of Agricultural, Food and Environmental Sciences, University of Perugia, 06121 Perugia, Italy

[‡]Department for Sustainable Food Process, Università Cattolica del Sacro Cuore of Piacenza, 29100 Piacenza, Italy

OBJECTIVE:

Evaluate Se accumulation in sprouts as organic and inorganic forms, and Se optimal concentrations and biofortification efficiency

Se experimental design

Rice (Oryza sativa L., cv. Selenio)

water

Se(IV) mg L^{-1}

Se(IV)_15 | Se(IV)_45

Se(IV)_135 | Se(IV)_405

Se(VI) mg L^{-1}

Se(VI)_15 | Se(VI)_45

Se(VI)_135 | Se(VI)_405

Roots Shoots

Total Se content

Se speciation

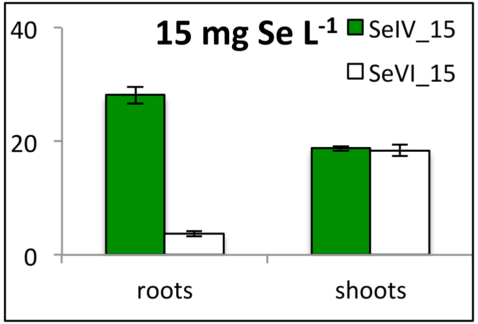
Total selenium (tSe) content in rice roots and shoots

Shoot length was not affected by Se(IV), while it was always decreased by Se(VI).

tSe content increased in all Se treatments (except for Se(VI)_135 and Se(VI)_405)

Se(VI) application causes Se accumulation mainly in shoots

Se(IV) application causes Se accumulation mainly in roots



tSe content increased in all Se treatments.

Root length increased at low level of Se(IV) and Se(VI), while it decreased at higher Se concentrations especially in Se(VI).

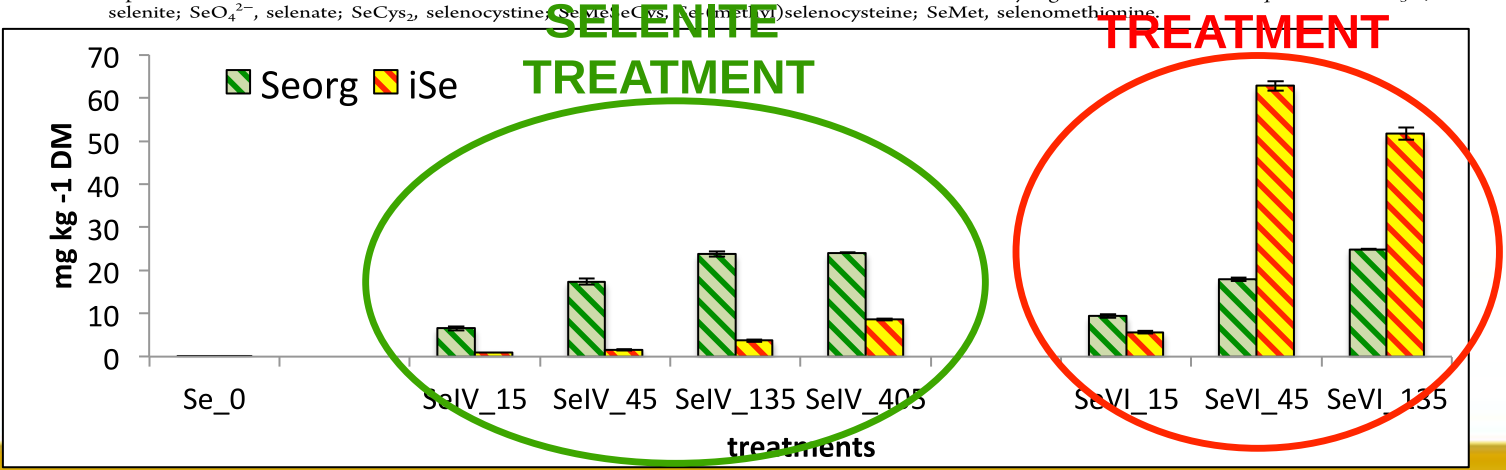
Organic (orgSe) and inorganic (iSe) selenium distribution in shoots (1/2)

Journal of Agricultural and Food Chemistry Article

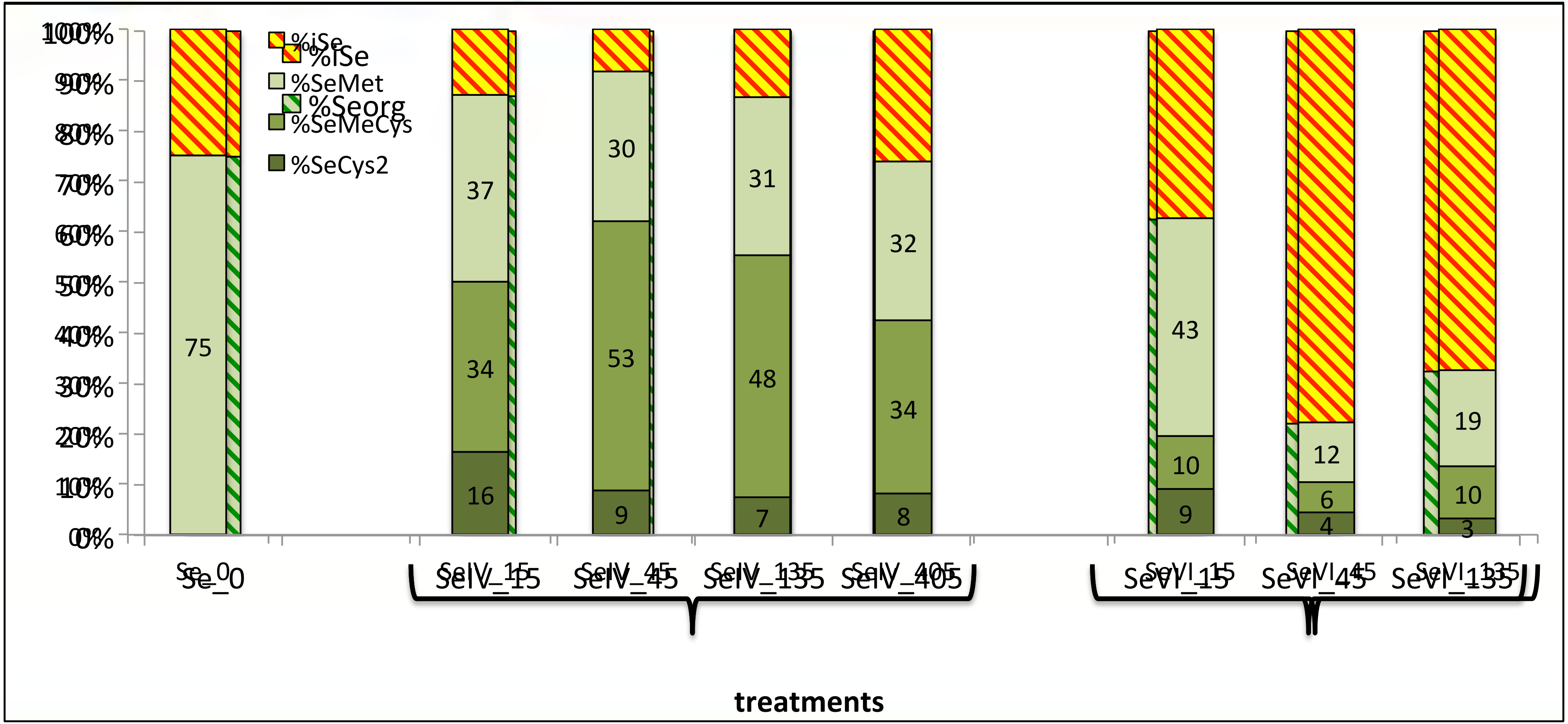
Table 3. Inorganic and Organic Se Species and Protein Content in Shoots of 10-Day Old Rice Sprouts[a]

	Se species (μg g^{-1} DM)							
	inorganic species			organic species				
treatments	SeO_3^{2-}	SeO_4^{2-}	total	$SeCys_2$	SeMeSeCys	SeMet	total	proteins (mg BSA g^{-1} DM)
Se_0	0.02 (0.01) g	<LOD	0.02 (0.01) h	<LOD	<LOD	0.06 (0.01) h	0.06 (0.01) f	110 (1.75) b
SeIV_15	0.98 (0.03) f	<LOD	0.98 (0.03) g	1.24 (0.20) e	2.55 (0.13) f	2.80 (0.23) g	6.58 (0.50) e	107 (1.65) bc
SeIV_45	1.58 (0.16) e	<LOD	1.58 (0.16) f	1.65 (0.08) d	10.1 (0.28) c	5.62 (0.42) f	17.4 (0.75) c	130 (2.82) a
SeIV_135	3.62 (0.28) d	0.08 (0.01) d	3.70 (0.27) e	2.03 (0.08) c	13.2 (0.9) a	8.62 (0.44) d	23.8 (0.59) b	108 (0.49) bc
SeIV_405	8.49 (0.17) a	0.06 (0.02) de	8.55 (0.18) c	2.63 (0.19) b	11.2 (0.59) b	10.3 (0.45) b	24.1 (0.05) ab	103 (2.16) c
SeVI_15	1.66 (0.20) e	3.95 (0.11) c	5.61 (0.31) d	1.34 (0.09) e	1.57 (0.07) g	6.46 (0.37) e	9.37 (0.45) d	92.3 (1.37) d
SeVI_45	5.64 (0.24) c	57.2 (1.34) a	62.8 (1.10) a	3.55 (0.10) a	4.86 (0.09) e	9.51 (0.24) c	17.9 (0.35) c	78.5 (1.85) e
SeVI_135	7.59 (0.29) b	44.1 (1.54) b	51.7 (1.39) b	2.48 (0.12) b	7.81 (0.13) d	14.6 (0.12) a	24.9 (0.18) a	51.9 (3.32) f

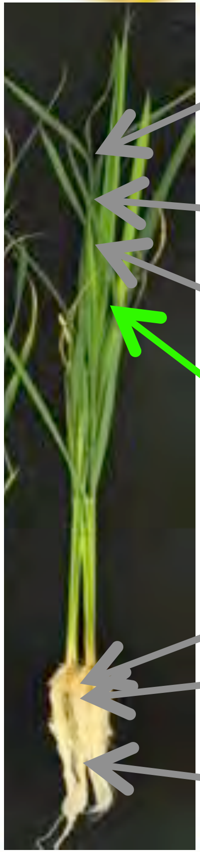
[a]Obtained with distilled water (Se_0) or at 15, 45, 135, and 405 mg L^{-1} of sodium selenite (SeIV_15, SeIV_45, SeIV_135, and SeIV_405) and 15, 45, 135 mg L^{-1} of sodium selenate (SeVI_15, SeVI_45, SeVI_135). Average values for $n = 3$ independent replicates, each analyzed in triplicate, are reported. Standard deviations in brackets. Different letters within each column indicate statistically significant differences at $p < 0.05$. SeO_3^{2-}, selenite; SeO_4^{2-}, selenate; $SeCys_2$, selenocystine; SeMeSeCys, Se-(methyl)selenocysteine; SeMet, selenomethionine.



Organic (orgSe) and inorganic (iSe) selenium distribution in shoots (2/2)



Total Se content and speciation in rice roots and shoots



Shoot length was not affected by Se(IV), while it was always decreased by Se(VI).

tSe content increased in all Se treatments (except for Se(VI)_135 and Se(VI)_405)

Se(VI) application causes Se accumulation mainly in shoots

Higher values of OrgSe in Se(IV) treatment (SeMet and SeMeCys).
Higher values of iSe in Se (VI) treatment.

Se(IV) application causes Se accumulation mainly in roots

tSe content increased in all Se treatments.

Root length increased at low level of SeIV and SeVI, while it decreased at higher Se concentrations especially in SeVI.

2nd PART:

Effects of Selenium on Antimony uptake in rice (Oryza sativa L.): speciation analysis

OBJECTIVES:

Investigate uptake and translocation of Sb in rice plants Se-biofortified or not, exposed to Sb(III) and Sb(V) at increased concentrations under hydroponic condition.

Study how Se influences/is influenced by the different Sb concentrations in the distribution of organic ($SeCys_2$, SeMeSeCys and SeMet) and inorganic forms [Se(IV), Se(VI)] of selenium from roots to shoots.

Sb

- priority pollutants
- Sb(III) and Sb(V)
- Sb(III) more toxic than Sb(V) species
- Sb(V) has octahedral structure, larger radius (Å=3.68)
- Sb(V) is the predominant species in soil solution like $Sb(OH)^{-}_{6}$.
- Sb(V) transport requires mediation by transporters
- Sb(III) cross cell membranes passively with water (aquaporins)

Se and Sb experimental design

Rice (Oryza sativa L., cv. Selenio)

water
- water
- Sb(III)1 | Sb(III)27
- Sb(V)1 | Sb(V)27

Se(IV) 1 mg L^{-1}
- water
- Sb(III)1 | Sb(III)27
- Sb(V)1 | Sb(V)27

Se(IV) 10 mg L-1
- water
- Sb(III)1 | Sb(III)27
- Sb(V)1 | Sb(V)27

7 days of Se biofortification

7 days of hydroponic contact of Sb species

Materials and method

Roots Shoots

Total Se, Sb content

0.25 g DM
+8 mL of ultrapure HNO_3 (65%w/w)
+2 mL H_2O_2 (30%w/w)

Microwave digestion

Dilution with water up to 20 mL

Filtration

ICP-MS
Octapole Reaction System

Se and Sb speciation

0.1 g FM
+4 mL of water
+1,5 mL protease

stirred in water bath at 37 °C for 4 h

Centrifugation

Supernatant filtration

HPLC - ICP-MS

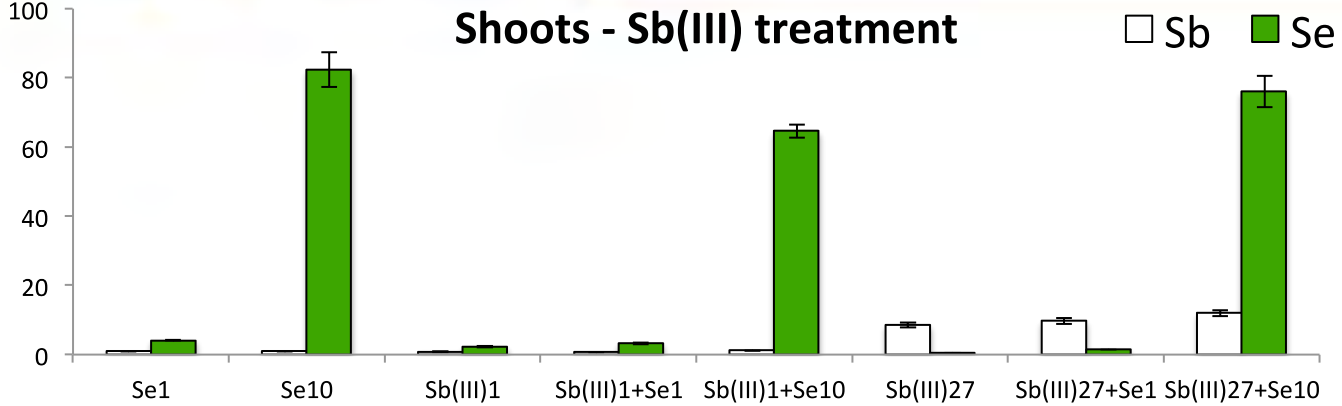
Ammonium acetate (gradient analysis)

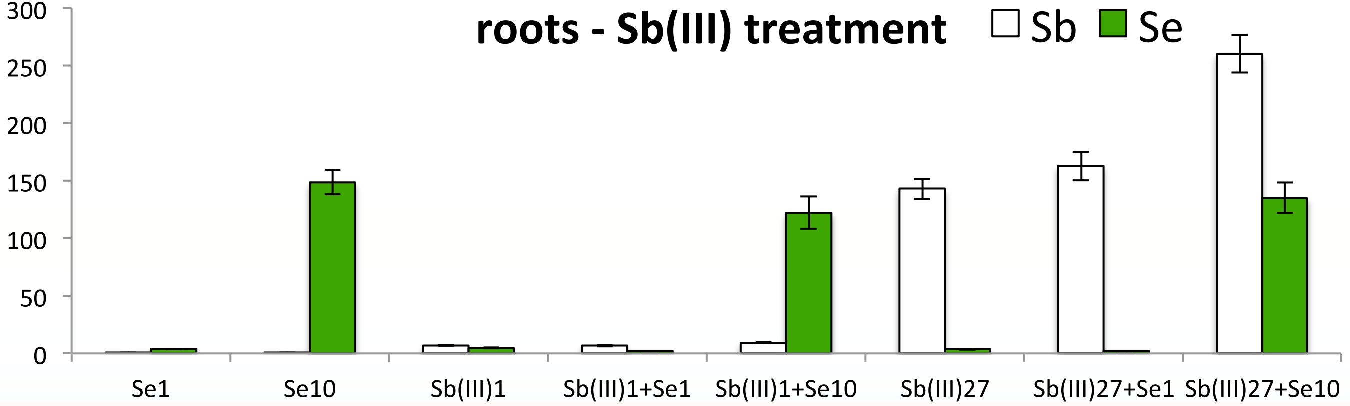
Na2EDTA + KHP (isocratic analysis)

RESULTS

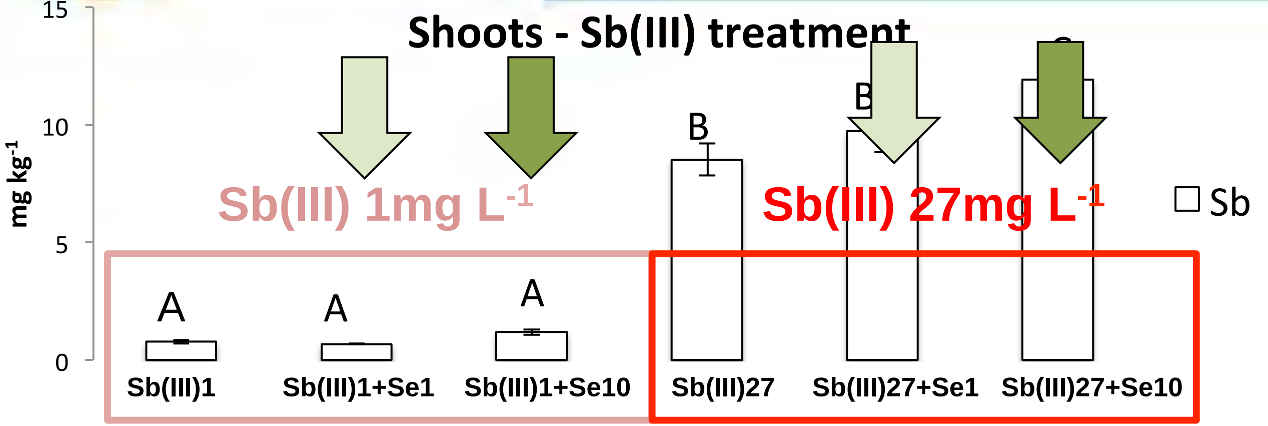
Sb and Se distribution in roots and shoots

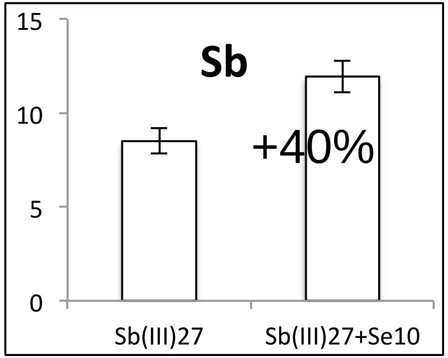
tSb and tSe distribution in roots and shoots
(Sb(III)+Se in hydroponic solution)

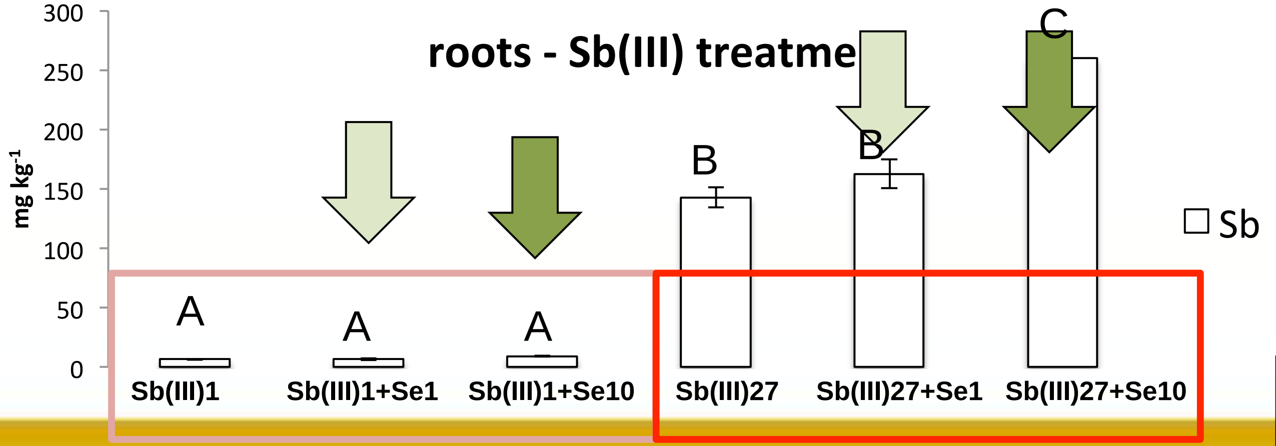


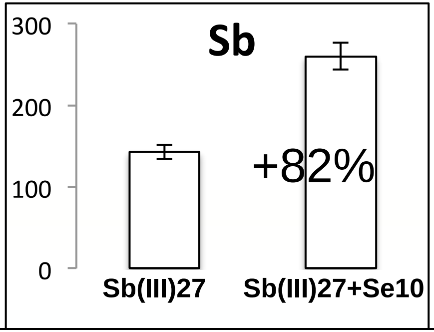


tSb distribution in roots and shoots
(Sb(III)+Se in hydroponic solution)





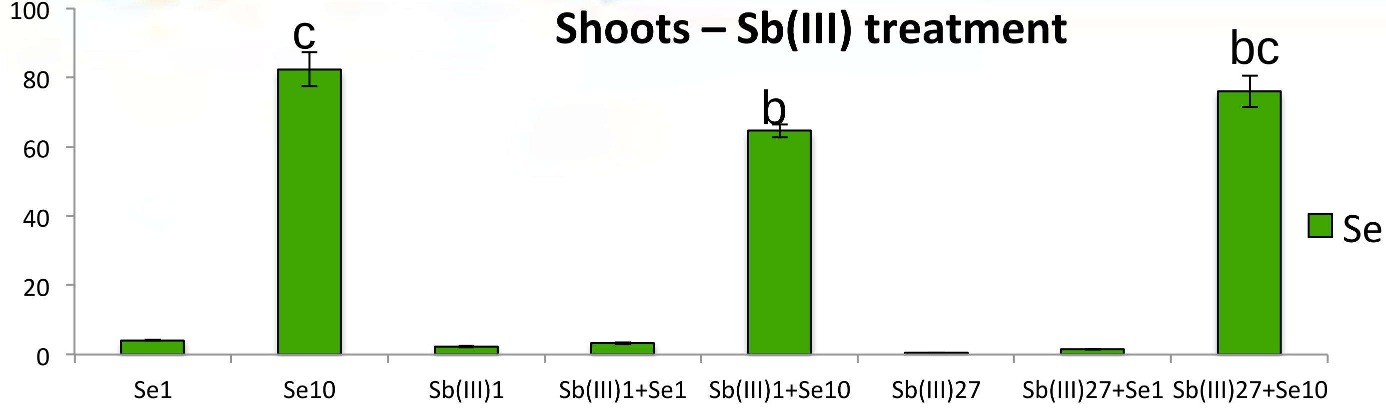


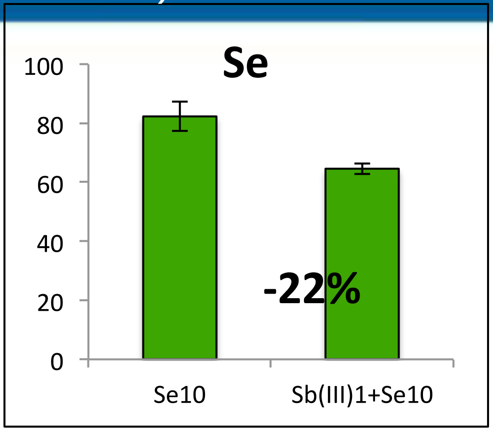


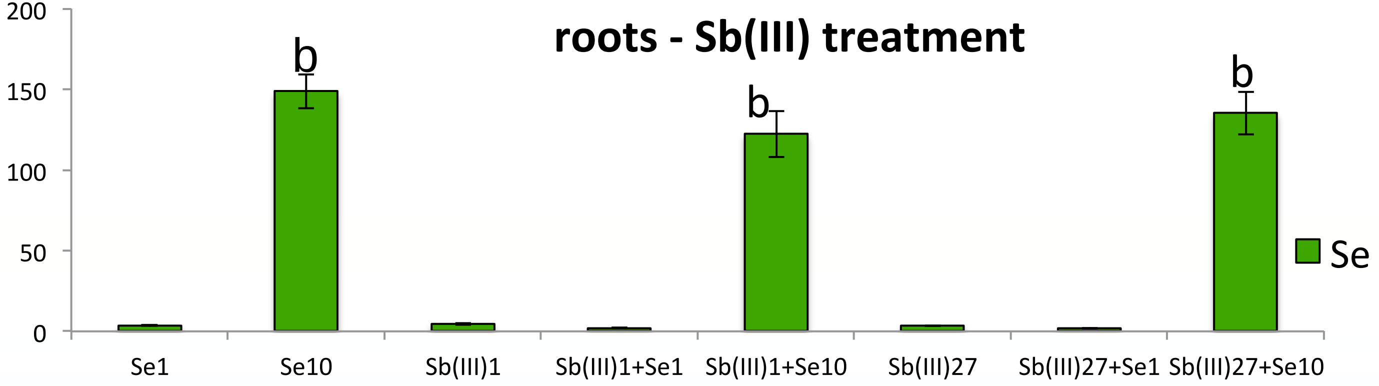
SYNERGIC EFFECT

tSe distribution in roots and shoots

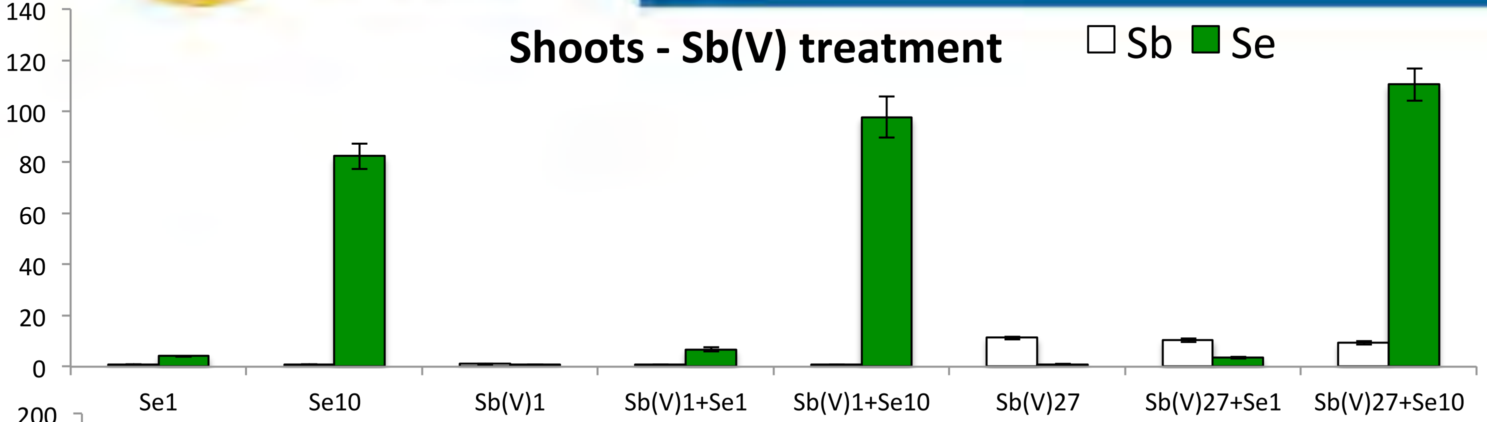
(Sb(III)+Se in hydroponic solution)

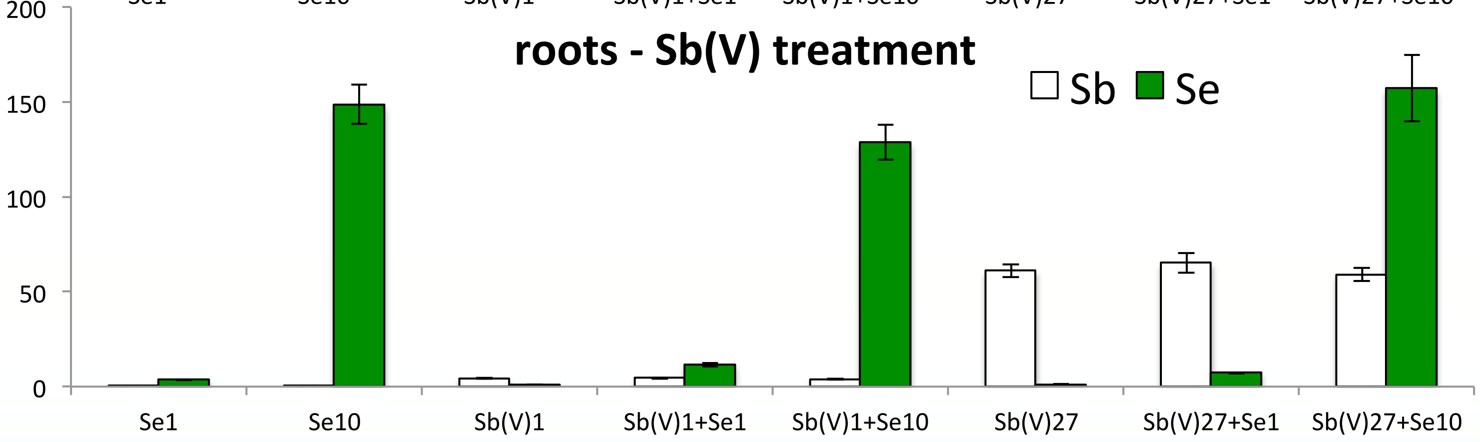






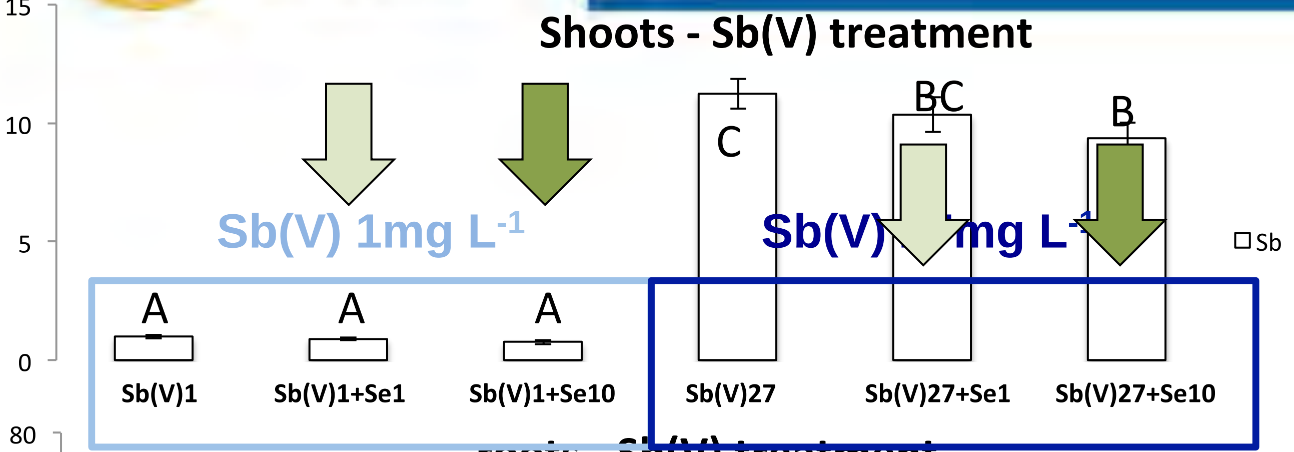
tSb and tSe distribution in roots and shoots
(Sb(V)+Se in hydroponic solution)

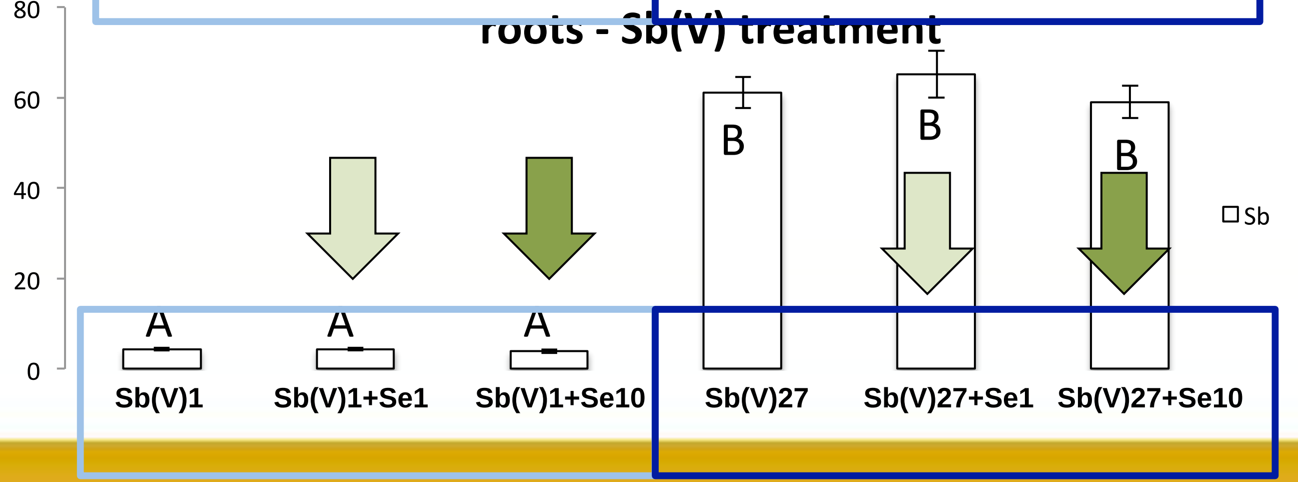


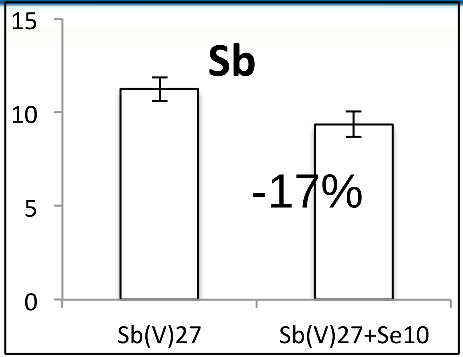


tSb distribution in roots and shoots

(Sb(V)+Se in hydroponic solution)



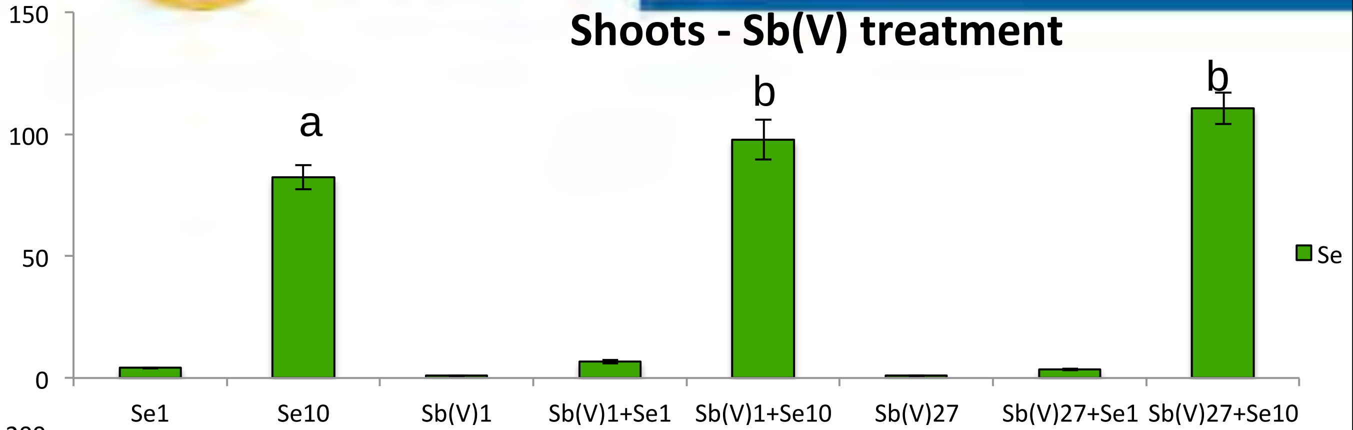


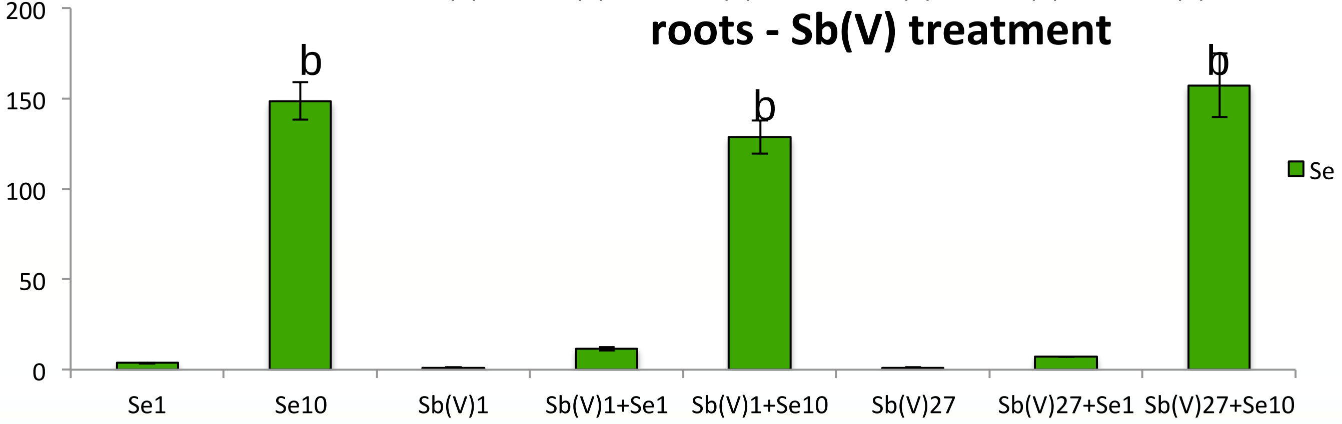


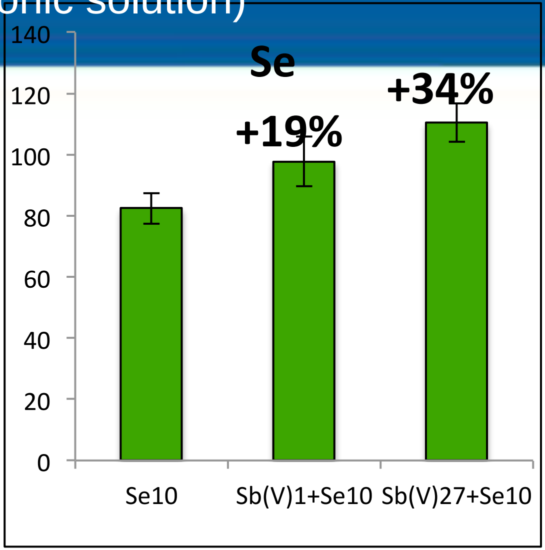
Antagonistic effect

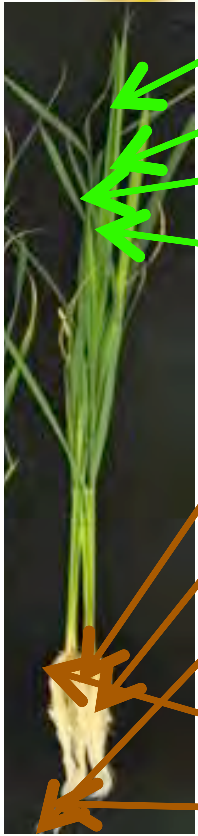
tSe distribution in roots and shoots

(Sb(V)+Se in hydroponic solution)









tSb decreased with high level of Se (Sb(V)27+Se10) (antagonistic effect)

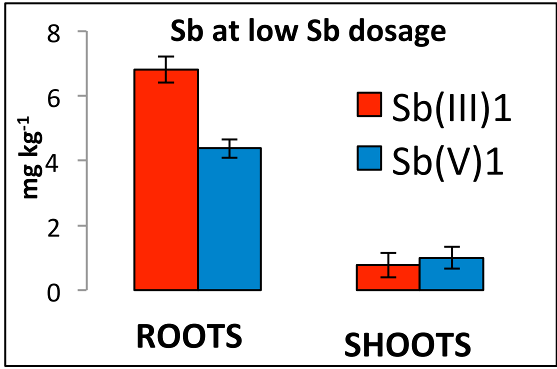
tSb increased with high level of Se (Sb(III)27+Se10) (synergic effect).

tSe increased with low and high Sb(V) levels

tSe decreased at low level of Sb(III)

tSb content is higher in roots than shoots under Sb(III) and Sb(V) treatments.

Sb(III) is accumulated more easily than Sb(V)



tSe is higher in roots than shoots under Sb(III) and Sb(V) treatments.

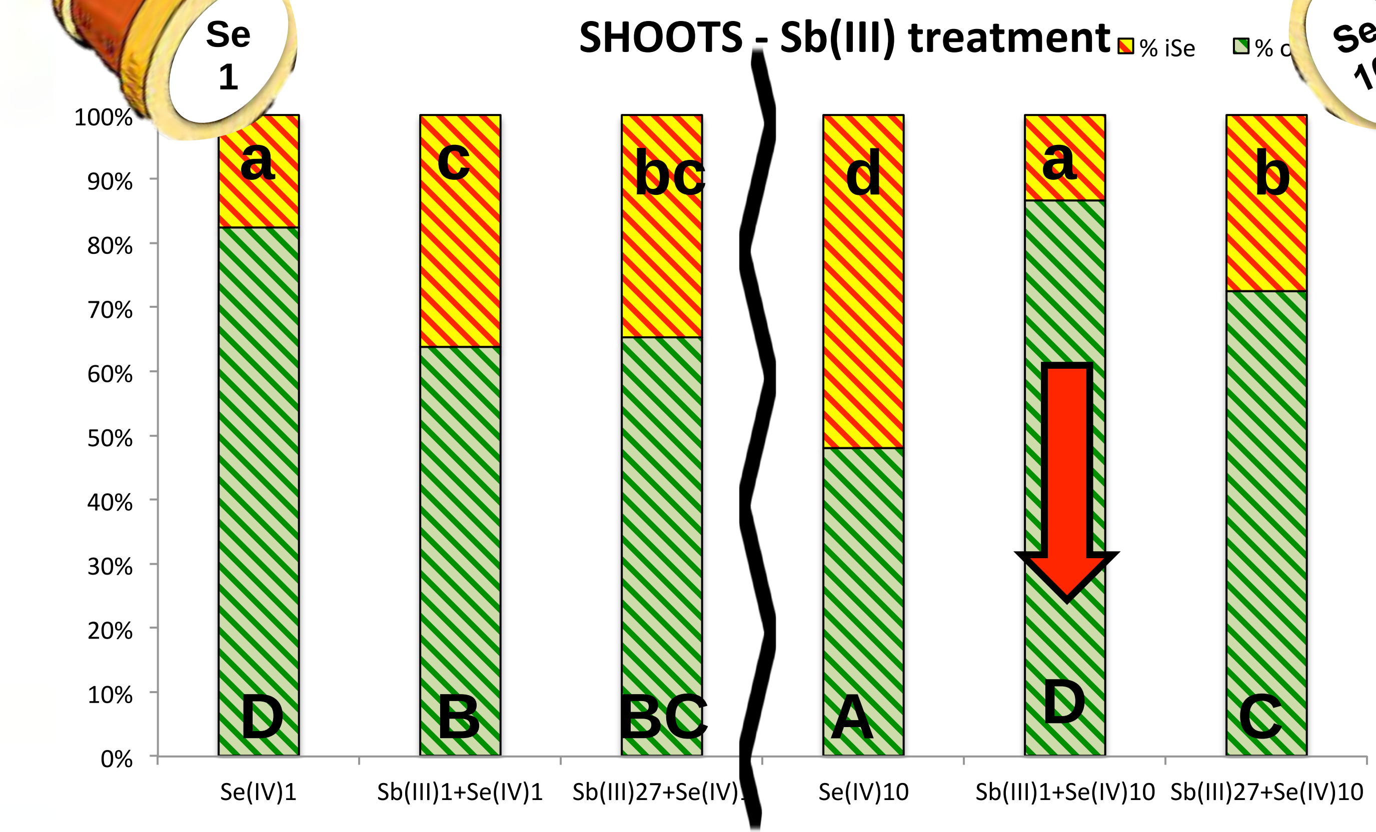
tSb increased with high level of Se (Sb(III)27+Se10) (synergic effect).

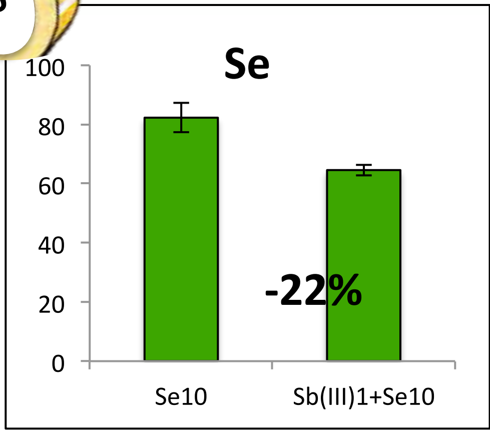
Sb(III) and Sb(V) treatments don’t influence tSe content

RESULTS

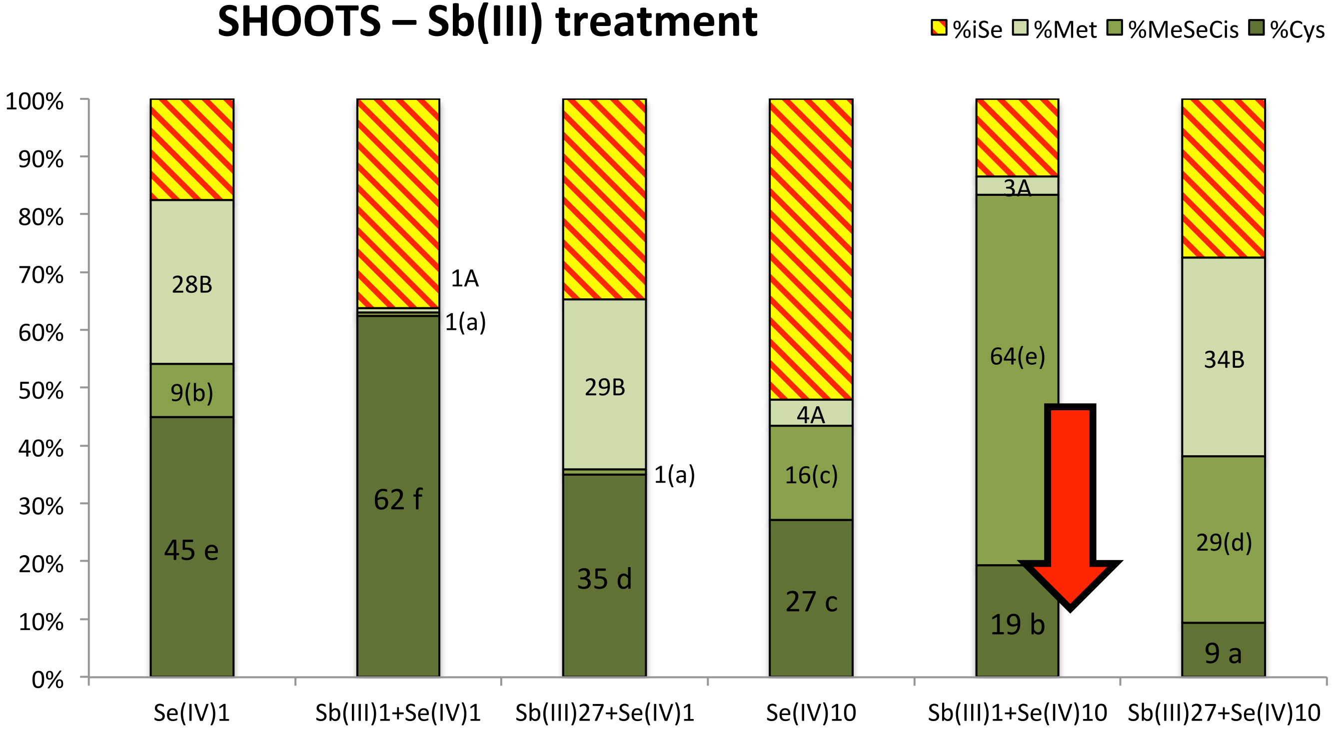
Organic (orgSe) and inorganic (iSe) selenium distribution

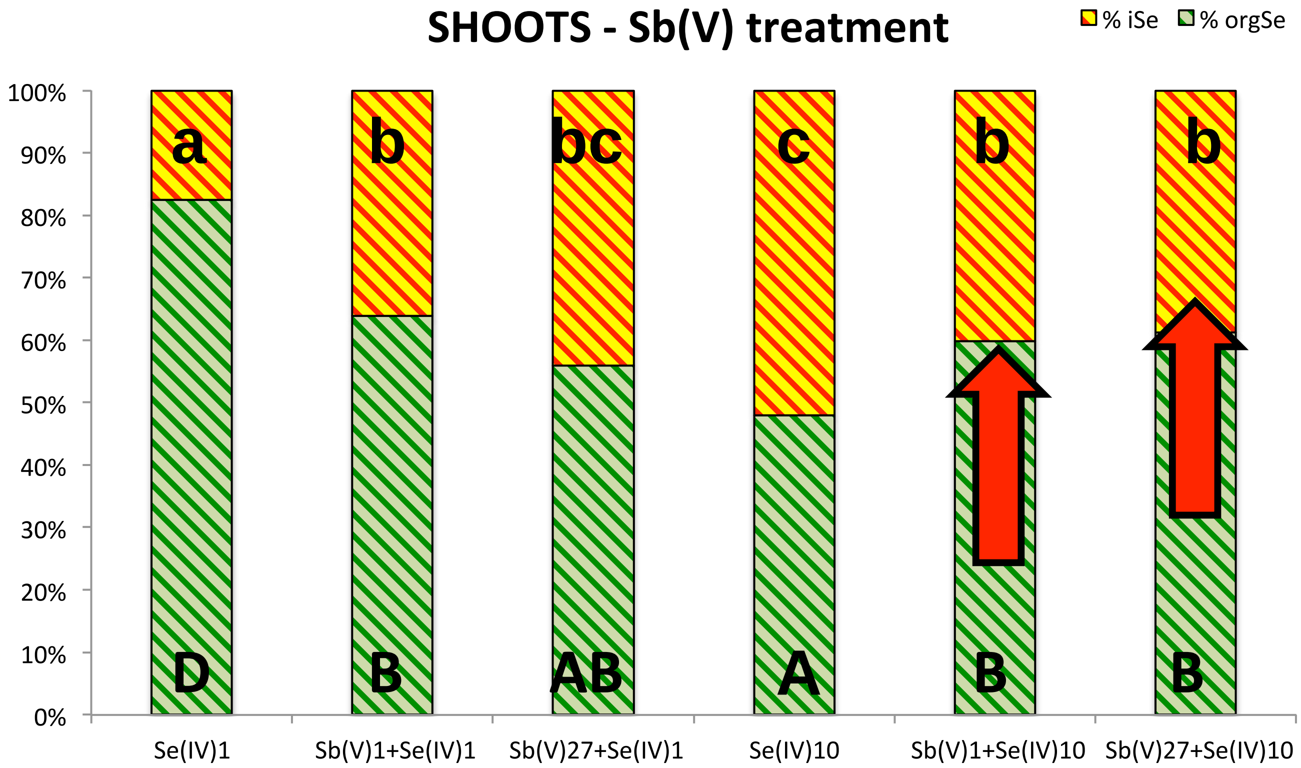
Organic (orgSe) and inorganic (iSe) selenium distribution

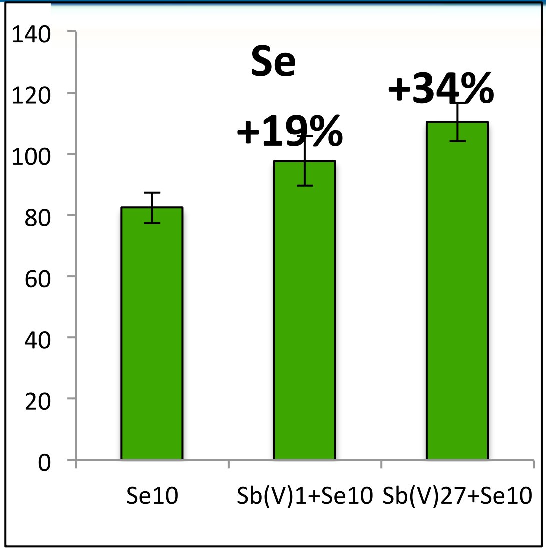


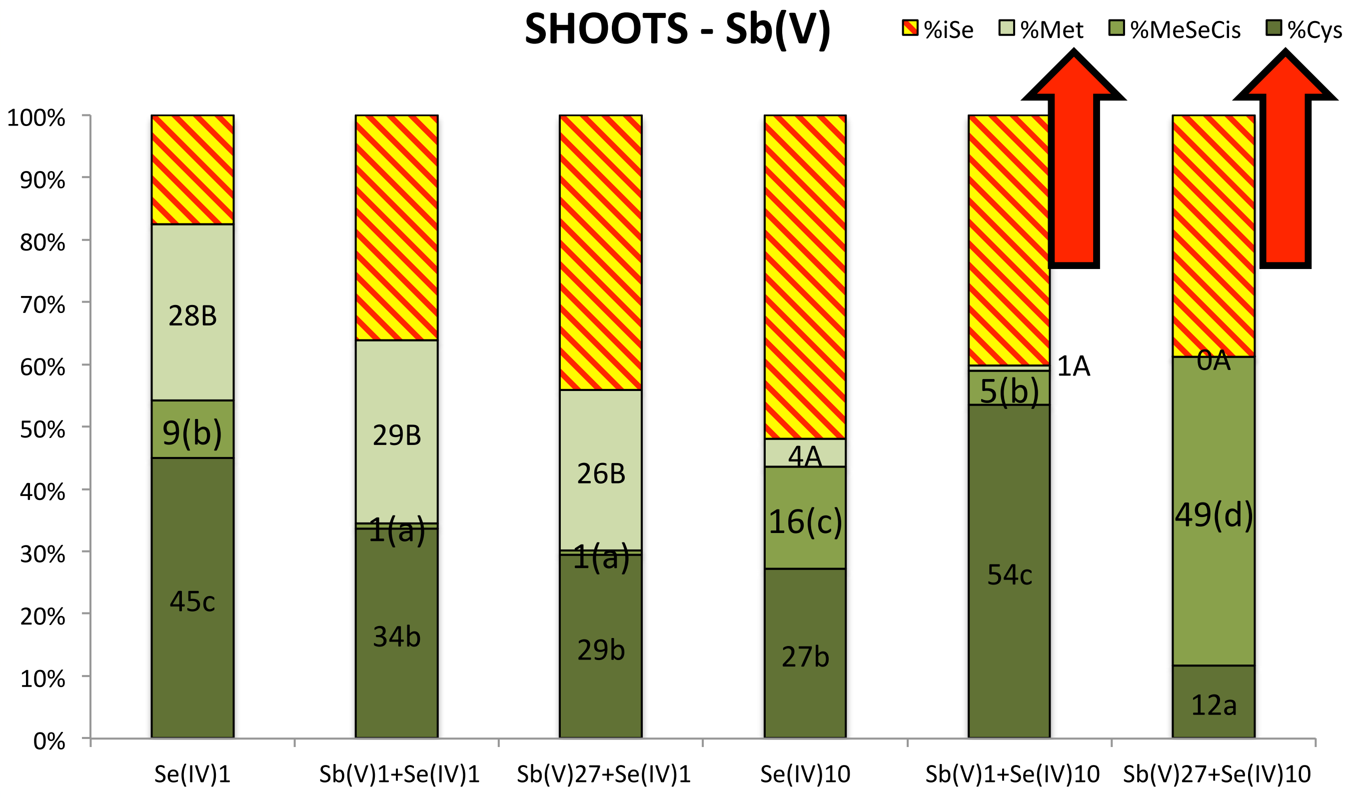


SHOOTS – Sb(III) treatment




SHOOTS - Sb(V) treatment
% iSe
% orgSe
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
a
b
bc
c
b
b
D
B
AB
A
B
B
Se(IV)1
Sb(V)1+Se(IV)1
Sb(V)27+Se(IV)1
Se(IV)10
Sb(V)1+Se(IV)10
Sb(V)27+Se(IV)10


Se
140
120
100
80
60
40
20
0
+19%
+34%
Se10
Sb(V)1+Se10
Sb(V)27+Se10


SHOOTS - Sb(V)
%iSe
%Met
%MeSeCis
%Cys
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
28B
9(b)
45c
29B
1(a)
34b
26B
1(a)
29b
4A
16(c)
27b
1A
5(b)
54c
0A
49(d)
12a
Se(IV)1
Sb(V)1+Se(IV)1
Sb(V)27+Se(IV)1
Se(IV)10
Sb(V)1+Se(IV)10
Sb(V)27+Se(IV)10

CONCLUSIONS

- Sb and Se are more stored in roots than in shoots
- Synergic effect of Se on Sb(III) in roots and shoots
- Antagonistic effect of Se on Sb(V) in shoots
- Sb treatments exhibit consequences on Se contents in shoots (negative with Sb(III) and positive with Sb(V))

Future perspectives

Improving knowledge about plant behaviour of other rice varieties

Deepening Sb influences on rice seedling in soil plots, until grains production.

Instrumental upgrade (different nebulizer for sensitivity improves, UHPLC-triple quad-ICP MS)

Thank You!