Limite de détection et incertitude en spectroscopie proche infrarouge

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1

LOD

detection limit : the smallest concentration difference that can be detected
above the background noise level of a NIR instrument.

!., *J. Near Infrared Spectrosc.* **17,** 59–67 (2009)
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JNIRS
JOURNAL
OF
NEAR
INFRARED
SPECTROSCOPY

Rapid detection of melamine in milk powder by near infrared spectroscopy

than 1 ppm.[21] In order to overcome the limitation of the methods which had already been evaluated, this study tried to establish a fast detection method for pure melamine in milk powder by near infrared (NIR) spectrometry together with LS-SVM and has shown some promise. The detection limit of this method was lower than 1 ppm. It conforms to the national standard for melamine in infant milk products. The

3974 J. Agric. Food Chem. 2009, 57, 3974–3980
DOI:10.1021/jf900587m

JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY
ARTICLE

Melamine Detection in Infant Formula Powder Using Near- and Mid-Infrared Spectroscopy

models are not matrix independent. New calibration models are required for application to different brands or formulations of infant formula powders or other food products. It is expected that the analytical approach for quantifying or detecting melamine using NIR or FTIR spectroscopy would be applicable to other products. The NIR and FTIR methods meet the need for a rapid, simple, and available technique for detecting 1 ppm melamine in infant formula powder.

the noise sources. Those responsible for developing calibrations for constituents at ppm levels must demonstrate the impact of the possible noise sources on their results before suggesting possible limits of detection. Of course, before putting the results into practice the technology must be tested with real food process samples.

All of this discussion has used only the detection of melamine, but the same noise sources are present with other possible contaminants.

K. Norris, *J. Near In*
Received: 10 Septem

Letter to the Editor

Hazards with near infrared spectroscopy in detecting contamination

Karl Norris

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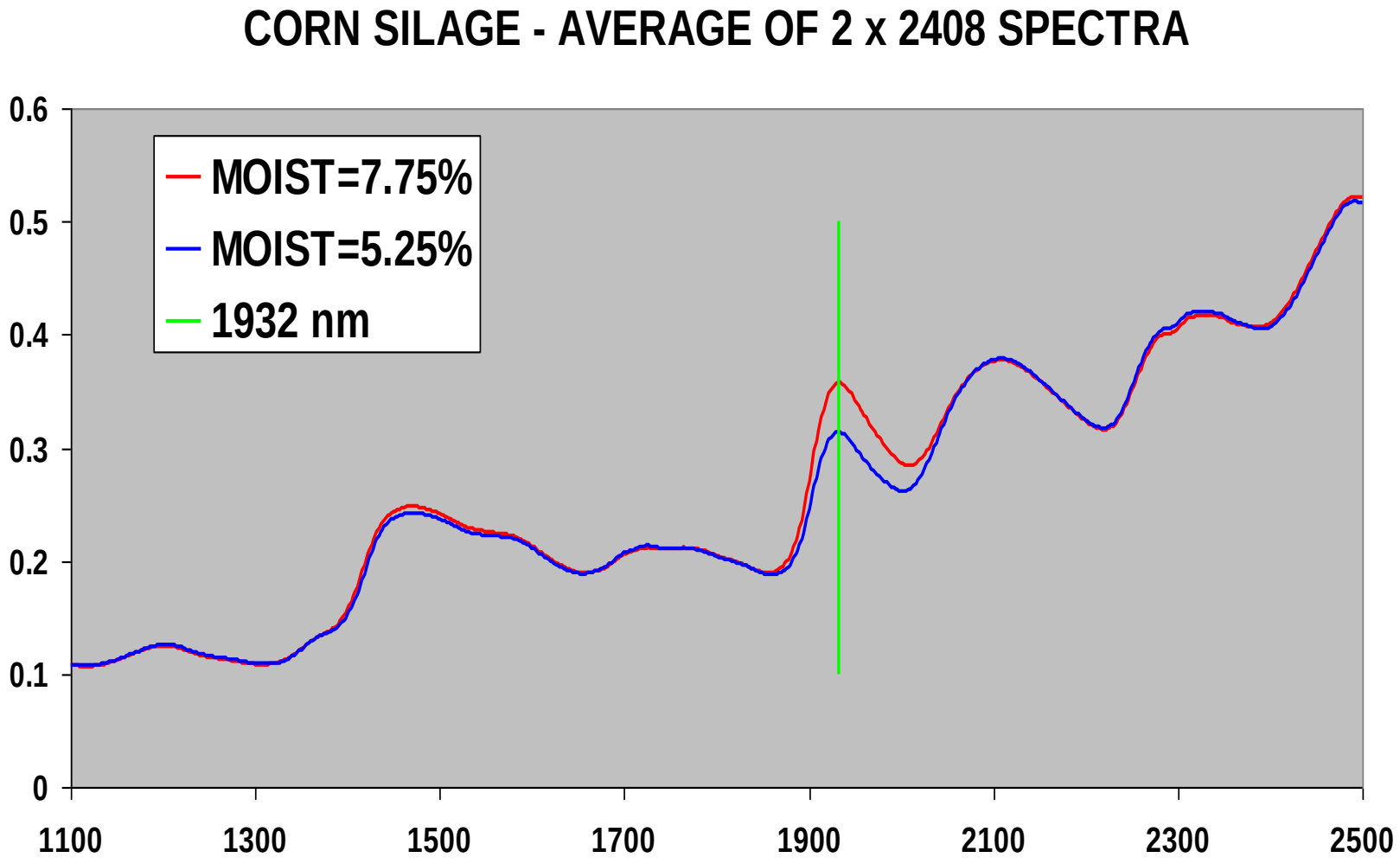
$$Abs. = A = -\log_{10}\left(\frac{I}{I_0}\right) = -\log_{10} R = \varepsilon.c.l$$

A : absorbance (OD)
I : energy of reflected light
I_0 : energy of initial light
R : reflectance
ε : absorptivity
c : concentration
l : pathlength

$$A = \frac{L}{moles\_.\_cm} . \frac{moles}{L} .cm$$

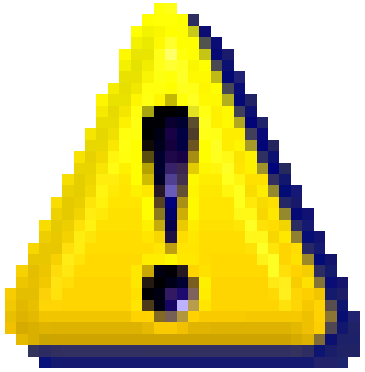
LOD of NIRS

CORN SILAGE DATA SET 4816 spectra sorted/H2O %



LOD of NIRS

	1932
MOIST=7.75%	0.357243
MOIST=5.25%	0.313645
2.5	0.043598
1	0.017439



If <0.1%

A units	Water %	ppm	ppb
0.020 000	1	10 000	10 000 000
0.002 000	0.1	1 000	1 000 000
0.000 200	0.01	100	100 000
0.000 020	0.001	10	10 000

Villeneuve d'ascq, 5-6 Décembre 2012

Polytech'Lille, Université Lille1, FRANCE

Connexion

NAVIGATION

- Accueil
- Lieu de la conférence
- Conférenciers invités
- Liste de communications acceptées
- Programme CHIMIOMETRIE 2012
- Comités
- Résumé et inscription
- Publication dans CHEMOLAB
- Challenge 2012
- Prix et récompenses
- Hébergement
- Exposants / Partenaires / Sponsors
- Devenir partenaire / Sponsoriser cette conférence

CHALLENGE 2012

Le Challenge est ouvert !

Le challenge organisé par le Groupe Français de Chimiométrie se présente sous la forme d'une énigme. Il s'agit de trouver les réponses d'un fichier "test" à partir d'un fichier dit d'étalonnage. Les données de ce dernier fichier peuvent être polluées (données manquantes, données aberrantes, etc.).

Le fichier d'étalonnage et le fichier "test" sont mis à votre disposition ci-dessous. L'analyse des solutions se fait au cours du congrès. Les congressistes ayant proposé les meilleurs solutions seront invités à présenter brièvement leur méthodologie lors d'une session spéciale CHALLENGE. Les meilleures solutions seront primées.

NOUVEAUTÉ : Afin de favoriser la participation des jeunes chimiométriciens (moins de 30 ans), le comité scientifique a décidé cette année de créer une catégorie spécifique dite "Junior". Ces contributions au Challenge seront ainsi étudiées séparément de celles des séniors.

Téléchargez le fichier de données : ICI

Description du CHALLENGE CHIMIOMETRIE 2012 :

270 spectra in a CAL set with known concentration of a contaminant.

276 spectra in a TEST set to be predicted.

CA SET (only soya meal (SM))

240 with 4 concentrations (0.10, 0.25, 0.50, 1.00%)

+30 randomly selected from the clean set

270 spectra

TEST SET

T1 = 40 SM randomly selected with high contamination (2, 3, 4, 5%)

T2 = 50 randomly selected from the clean set

T3 = 43 soyameal spl from another origin + another instrument

T4 = 78 wheat gluten (39 in duplicates)

T5 = 65 maize gluten .

Total : 276

Foss XDS

Foss 6500
Clean & Conta.
Melamine
Cyanuric Acid

MLR : Multi Linear Regression – manual step up

WinISI Global

File Options Tables Graphs Help

Click on an option to continue

Percent C

Step-up Regression Statistics

Input File	CALSET1S.CAL	REP File	None
Validation File	None	Equation File	None
Math Treatment	0, 0, 1, 1	Number of variables	550
Scatter Corrected	None	Downweight outliers	Yes
Constituent	mela	Number of samples	300

Cross validation By groups, no pre-sort, form groups by blocks, group duplicates together

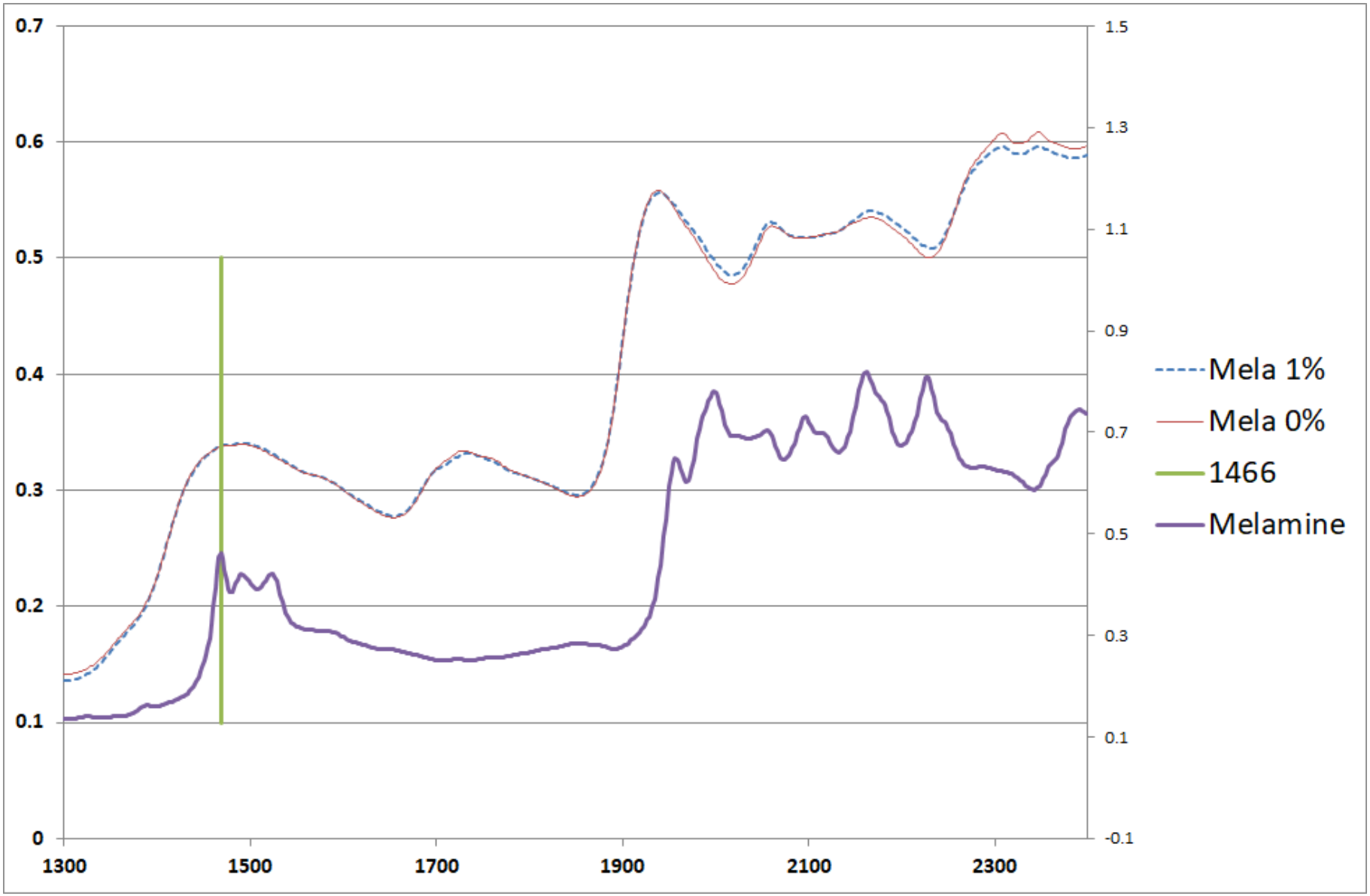
Mean 0.370 Range 0.00 - 1.00 Standard deviation 0.358

Number of terms 3 SEC 0.081 AdjRSQ 0.949

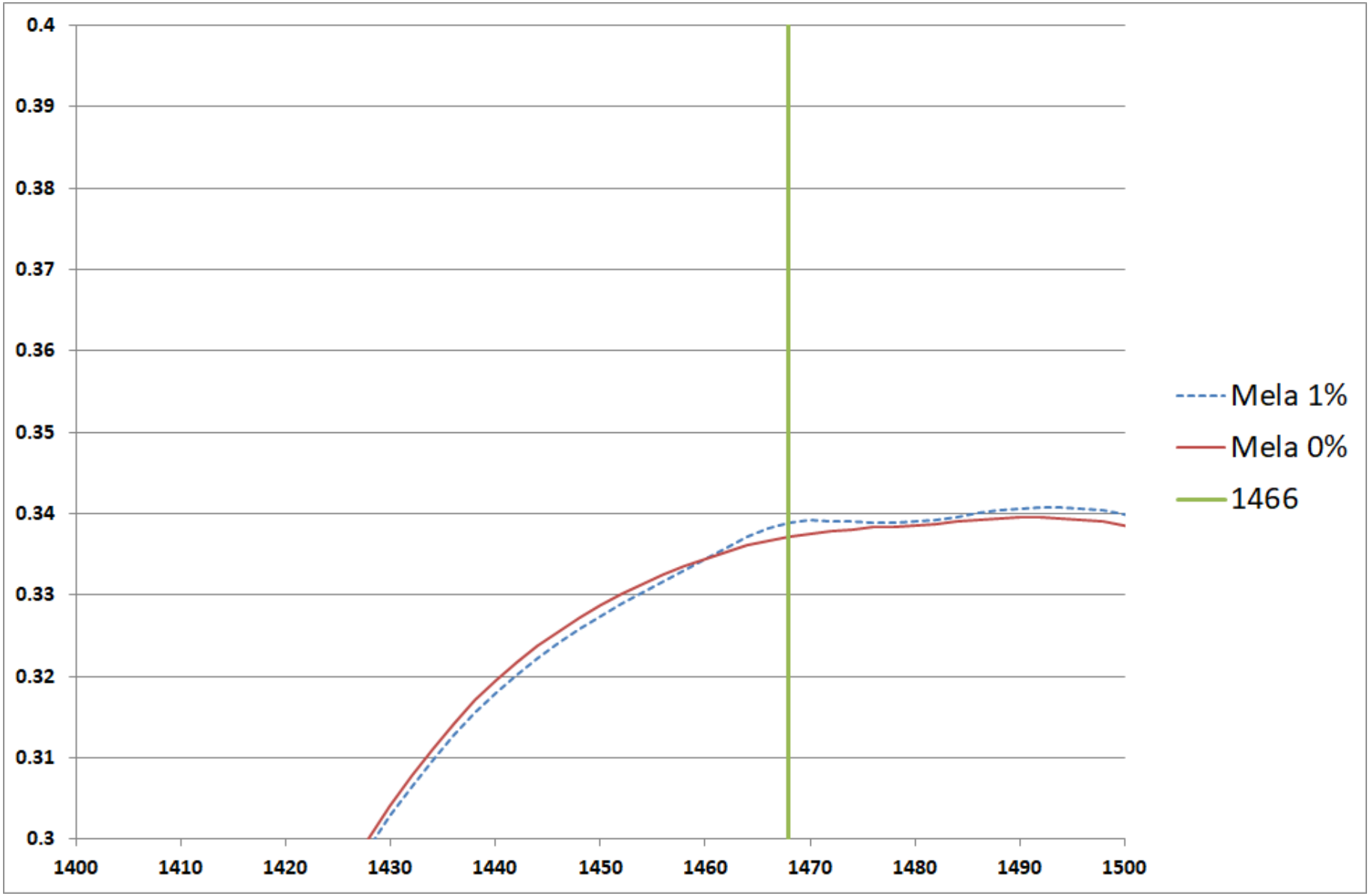
	Coefficient	Data Point	Wavelength	F
B[0] =	-0.143			
B[1] =	-792.693	86	1470.0	1634.24
B[2] =	1714.127	84	1466.0	3500.19
B[3] =	-922.584	82	1462.0	5463.41

SEC= 0.08 → SECV = 0.1 (1 000 ppm)

Average 0 and 1 % (60 spectra)


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
-0.1
1300
1500
1700
1900
2100
2300
Mela 1%
Mela 0%
1466
Melamine

Average 0 and 1 % (60 spectra)

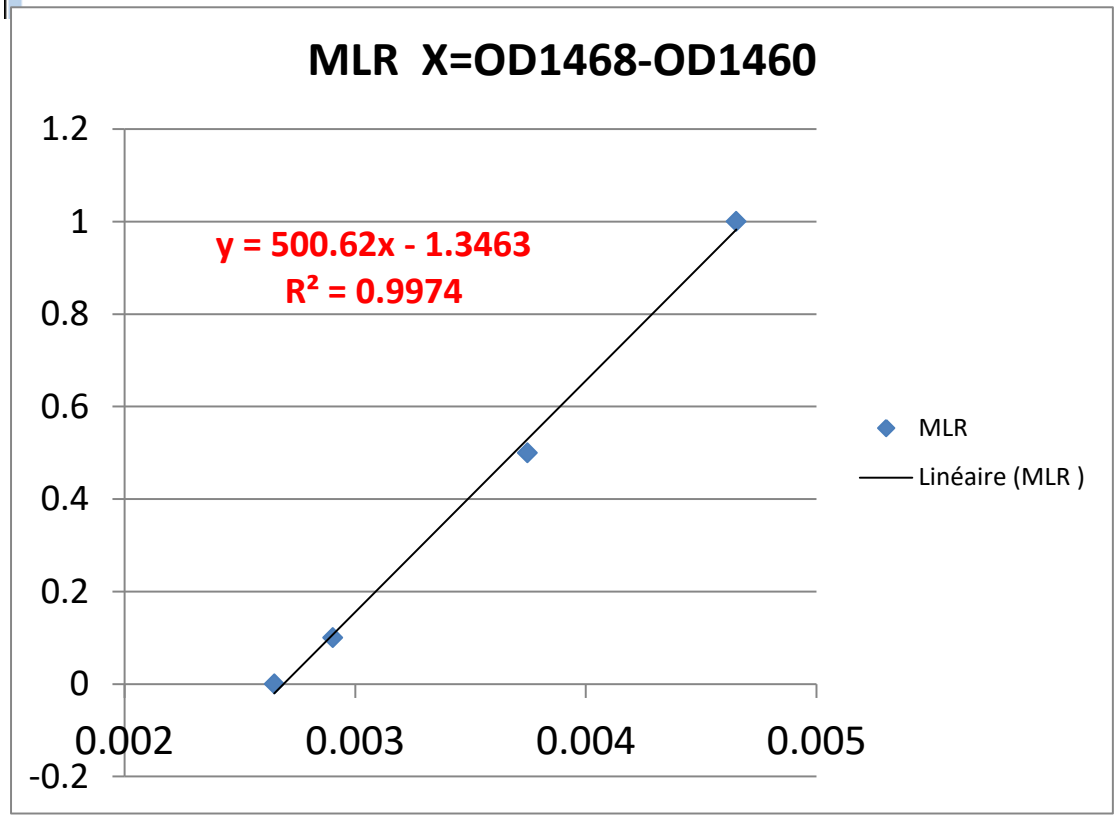


300 sp. → Average by group of 60 samples : 0.0, 0.10, 0.25, 0.50, 1%

Step-up Regression Statistics

Input File	totmeans6.cal	REP File	None
Validation File	None	Equation File	None
Math Treatment	0, 0, 1, 1	Number of variables	550
Scatter Corrected	None	Downweight outliers	Yes
Constituent	mela	Number of samples	5
Cross validation	By groups, no pre-sort, form groups by blocks, group duplicates together		
Mean 0.370	Range 0.00 - 1.00	Standard deviation 0.399	
Number of terms 2	SEC 0.032	AdjRSQ 0.994	

	Coefficient	Data Point	Wavelength	F
B[0] =	-0.209			
B[1] =	518.336	85	1468.0	613.22
B[2] =	-521.870	81	1460.0	614.07



1/500 = 0.002

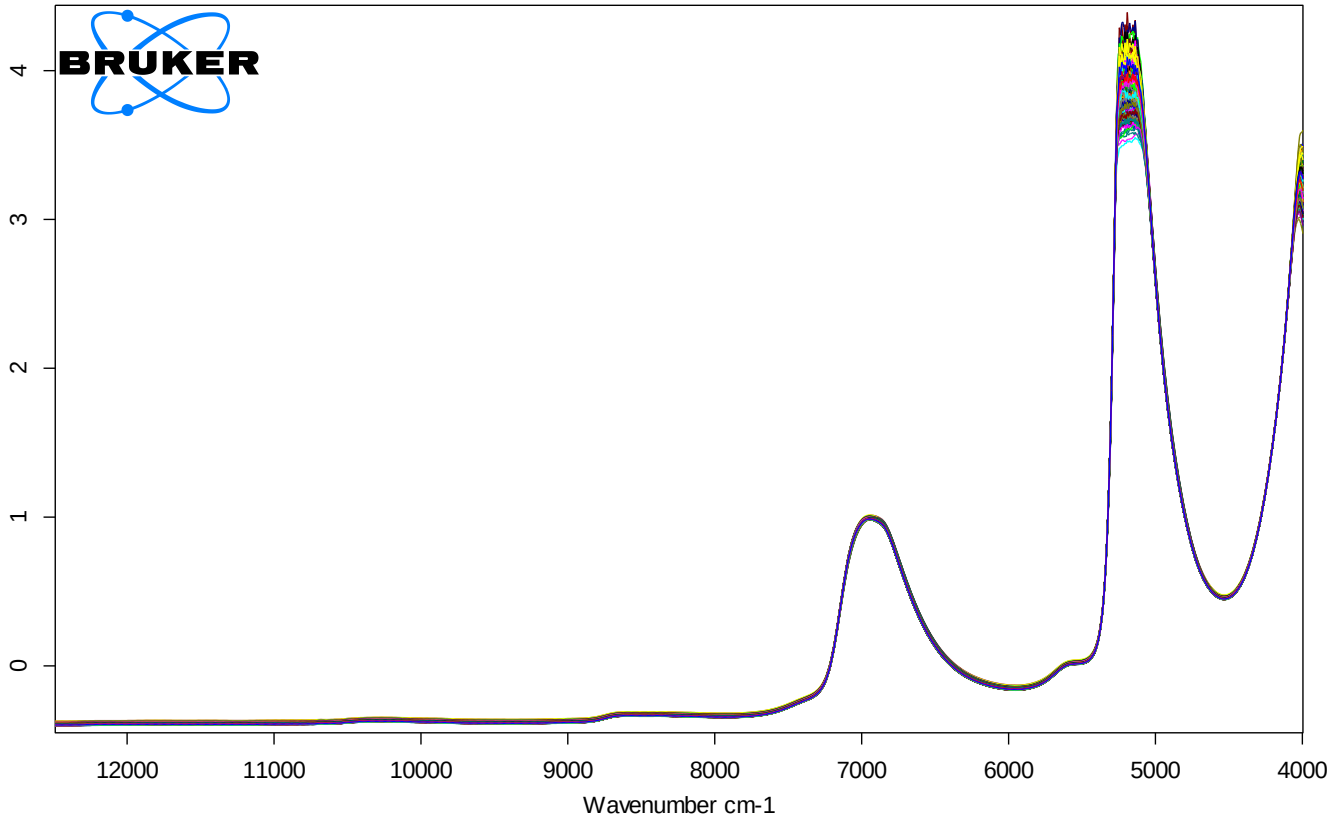
A OD difference of
0.002 = 1% melamine

A Units	µLog	Melamine %	ppm	ppb
0.002	2000	1	10 000	10 000 000
0.000 2	200	0.1	1 000	1 000 000
0.000 02	20	0.01	100	100 000
0.000 002	2	0.001	10	10 000

MELAMINE ABSORBS 10 x LESS THEN WATER !!

Water analysis by NIRS

702 spectra of water
(13 brands x 6 bottles/brand x 9 scans)



DRY EXTRACT in mineral waters
: (values on the stickers : mg/L) (averages 54 spectra)

Step-up Regression Statistics

Input File	liste3m13.cal	REP File	None
Validation File	None	Equation File	None
Math Treatment	0, 0, 1, 1	Number of variables	1102
Scatter Corrected	None	Downweight outliers	No
Constituent	LAB1	Number of samples	11
Cross validation	By groups, no pre-sort, form groups by cycling, group duplicates together		

Mean 744.818 Range 33.00 - 2513.00 Standard deviation 838.062

Number of terms 2 SEC 115.274 AdjRSQ 0.981

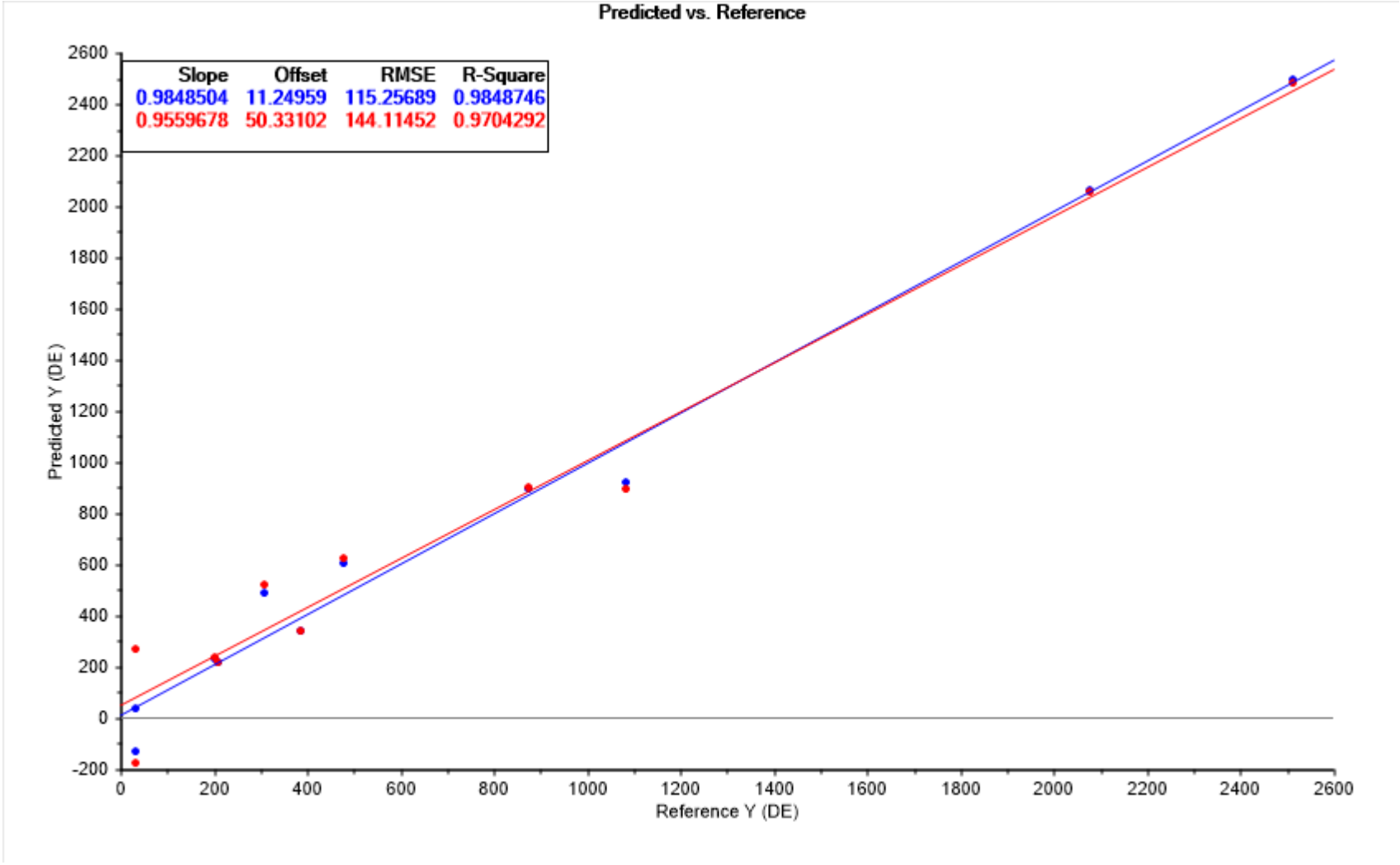
	Coefficient	Data Point	Wavelength	F
B(0) =	1240184.220			
B(1) =	-1182091.610	727	727.0	517.50
B(2) =	1231799.860	806	806.0	458.93

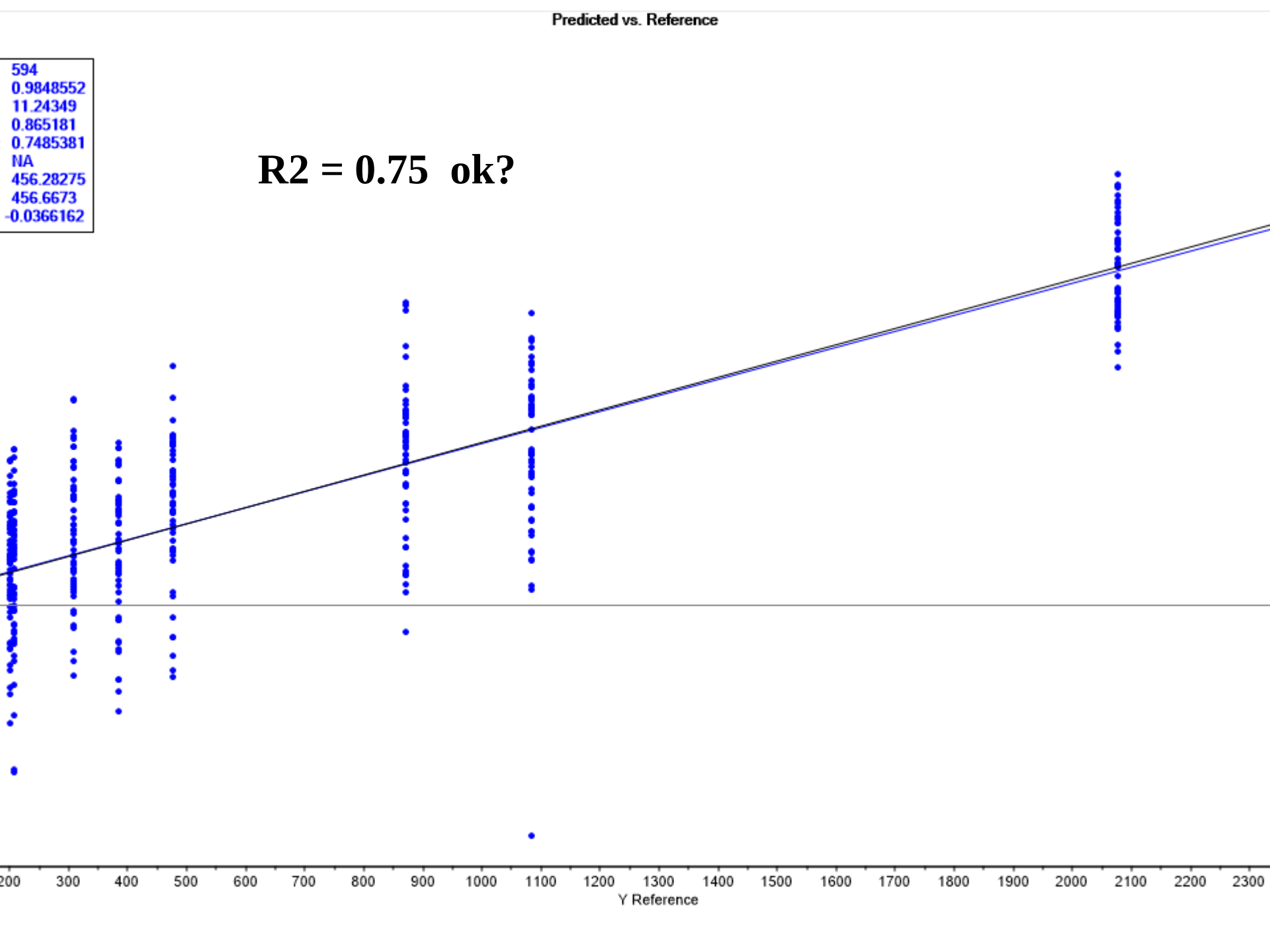
727
1452
6889

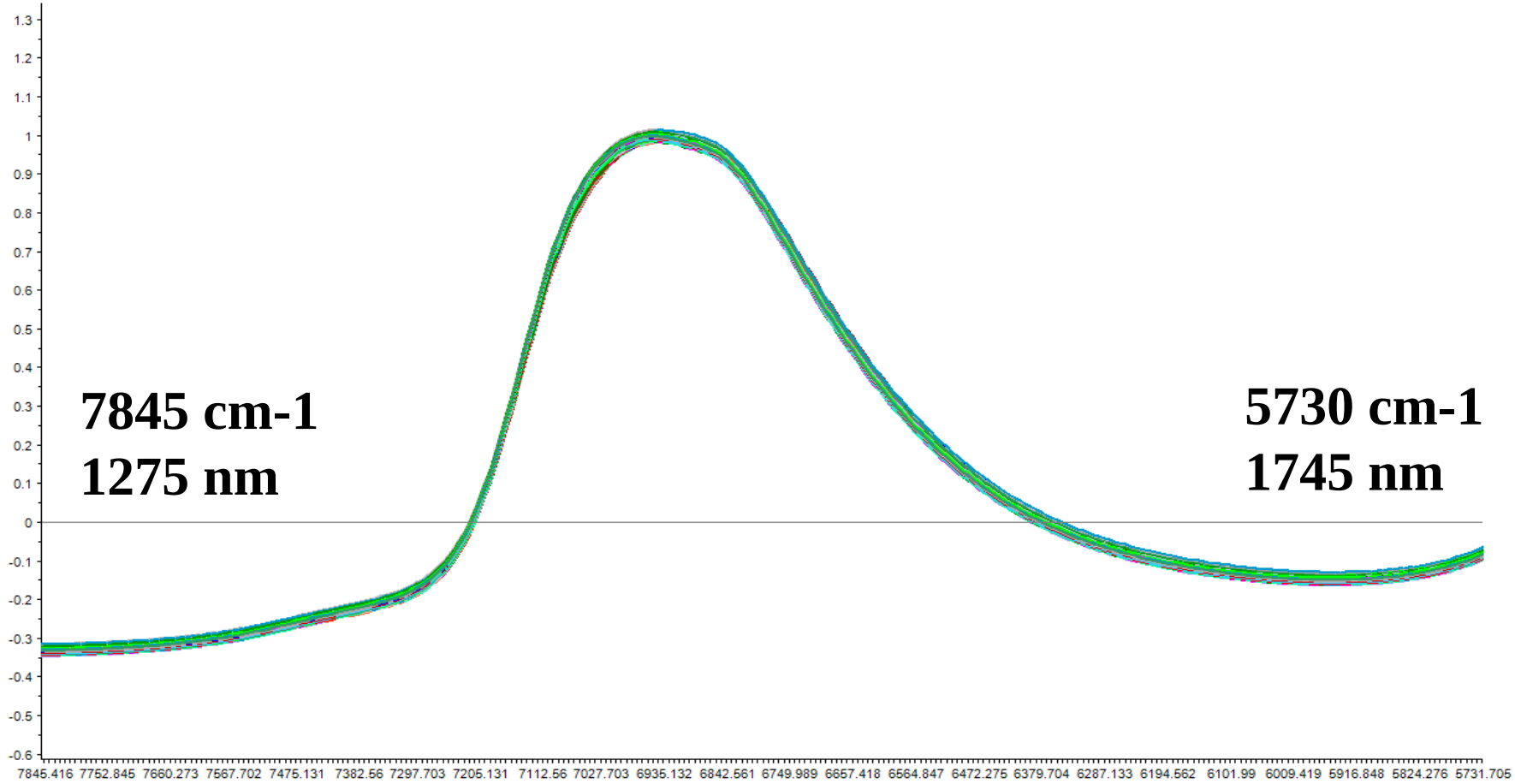
806
1593
6279

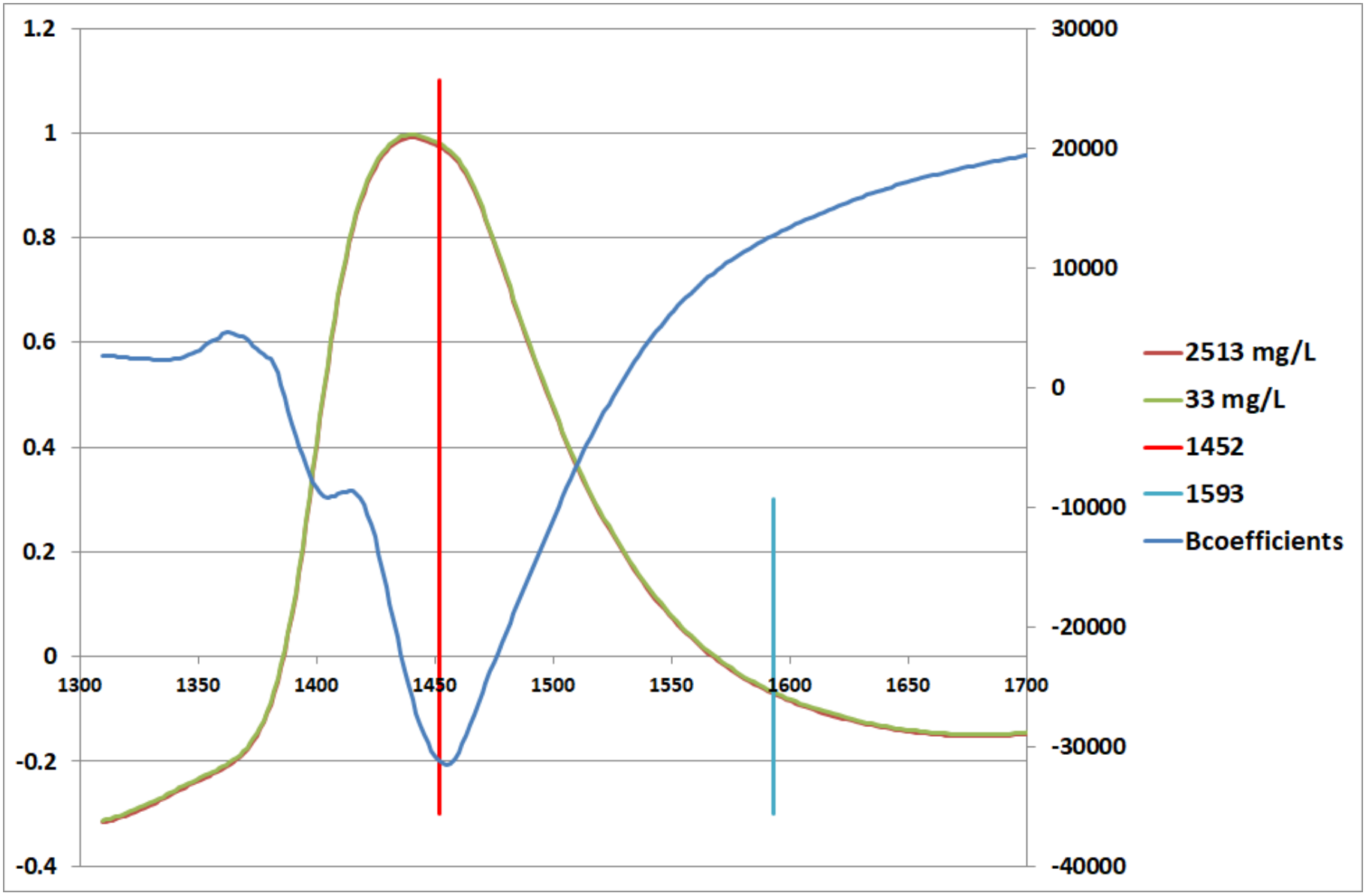
0.003 % - 0.25 % -> b: 1 200 000→ 120

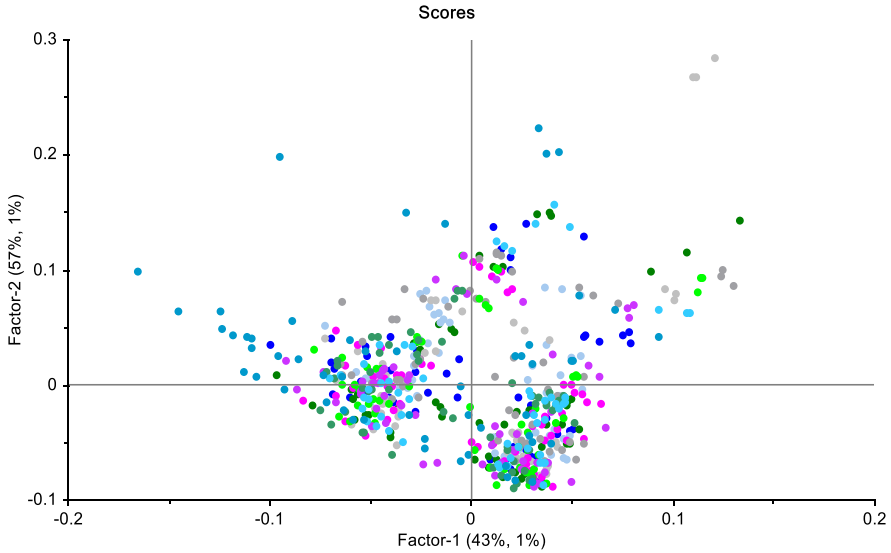
99.75% - 99.997 % H2O

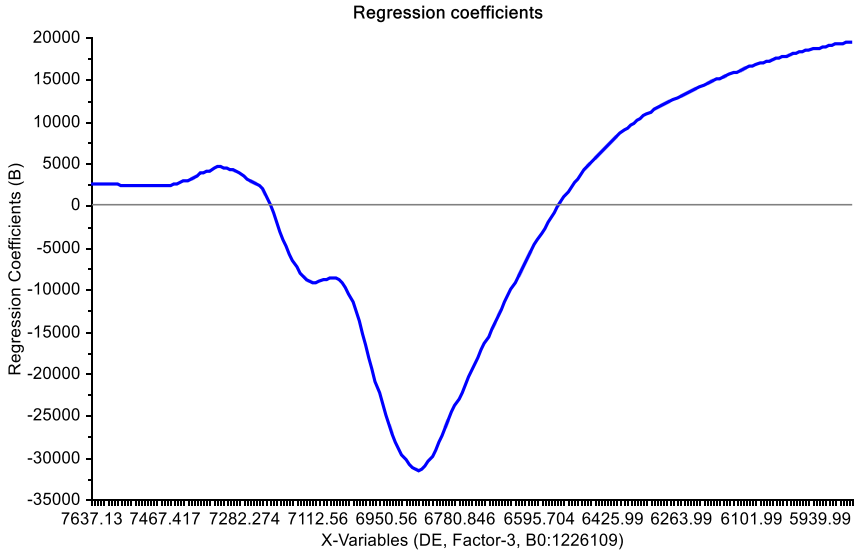

Predicted vs. Reference
Slope Offset RMSE R-Square
0.9848504 11.24959 115.25689 0.9848746
0.9559678 50.33102 144.11452 0.9704292
Predicted Y (DE)
Reference Y (DE)
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600

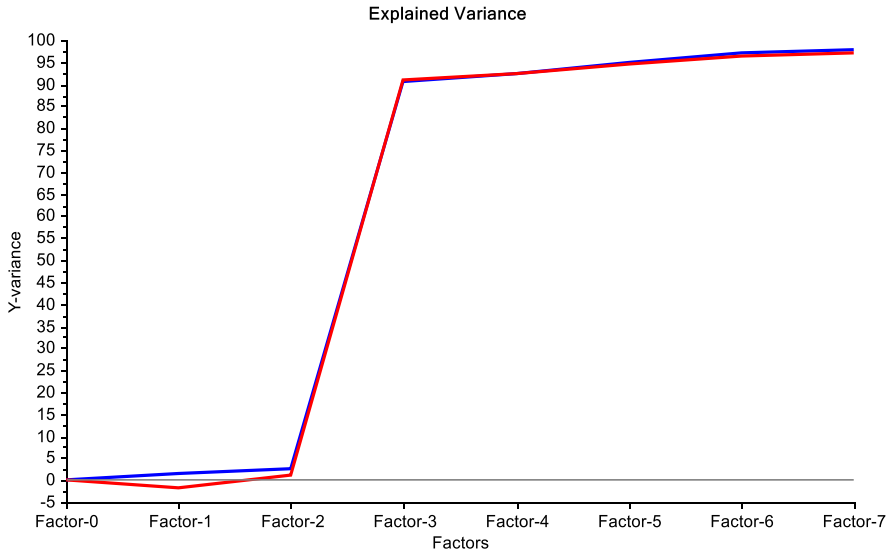

Predicted vs. Reference
594
0.9848552
11.24349
0.865181
0.7485381
NA
456.28275
456.6673
-0.0366162
R2 = 0.75 ok?
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
Y Reference

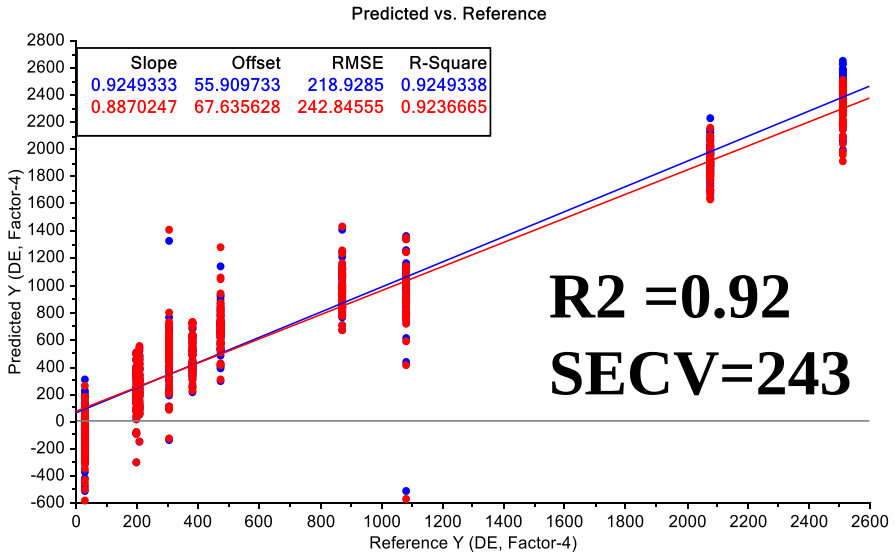

7845 cm-1
1275 nm
5730 cm-1
1745 nm
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
7845.416 7752.845 7660.273 7567.702 7475.131 7382.56 7297.703 7205.131 7112.56 7027.703 6935.132 6842.561 6749.989 6657.418 6564.847 6472.275 6379.704 6287.133 6194.562 6101.99 6009.419 5916.848 5824.276 5731.705

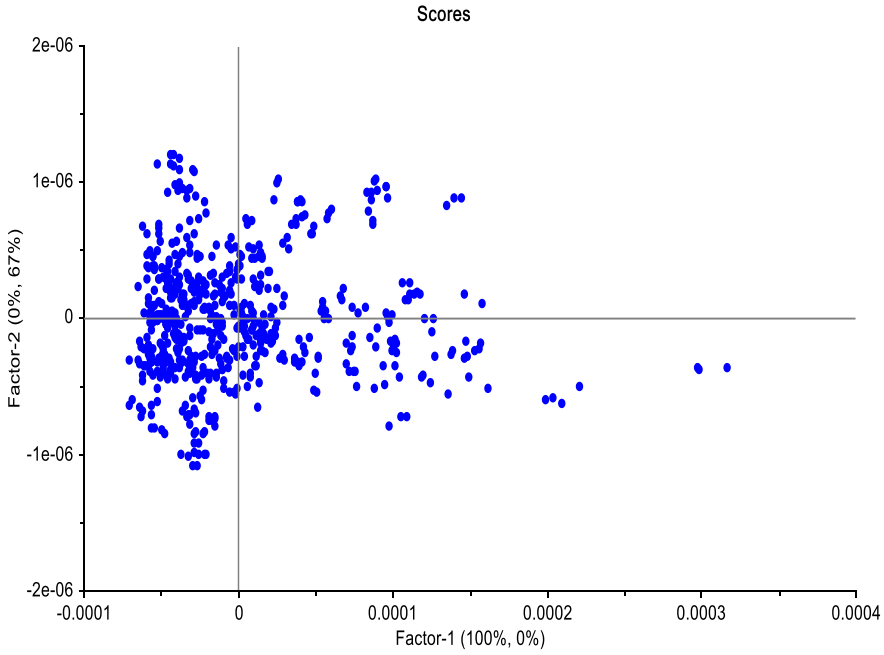

1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
30000
20000
10000
0
-10000
-20000
-30000
-40000
1300
1350
1400
1450
1500
1550
1600
1650
1700
2513 mg/L
33 mg/L
1452
1593
Bcoefficients

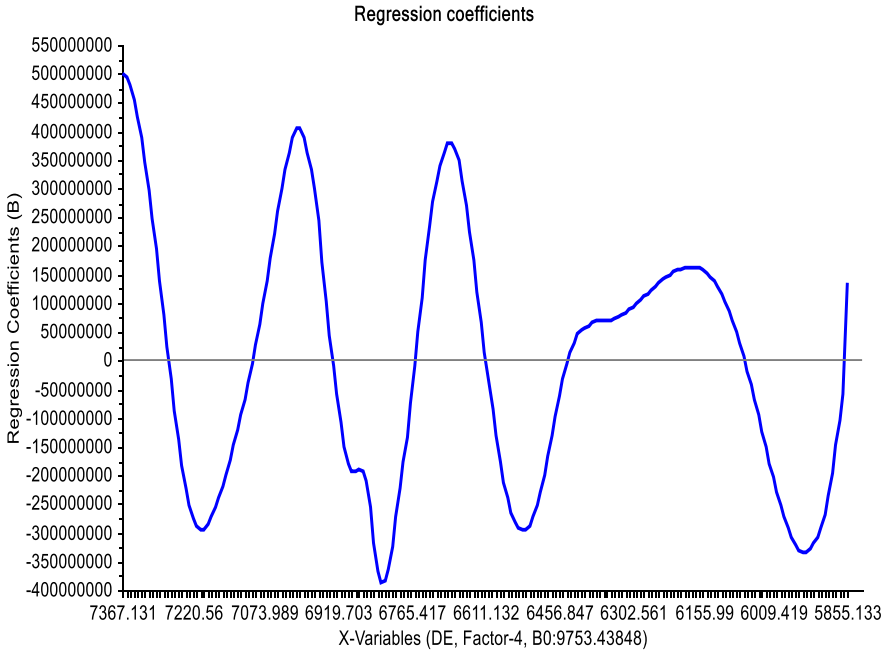

Scores
Factor-2 (57%, 1%)
Factor-1 (43%, 1%)

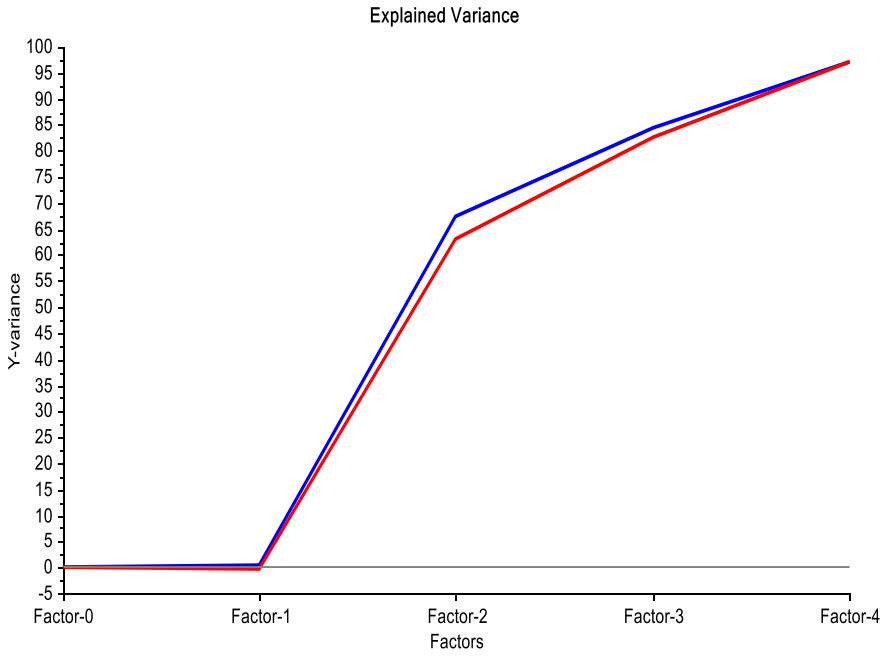

Regression coefficients
Regression Coefficients (B)
X-Variables (DE, Factor-3, B0:1226109)

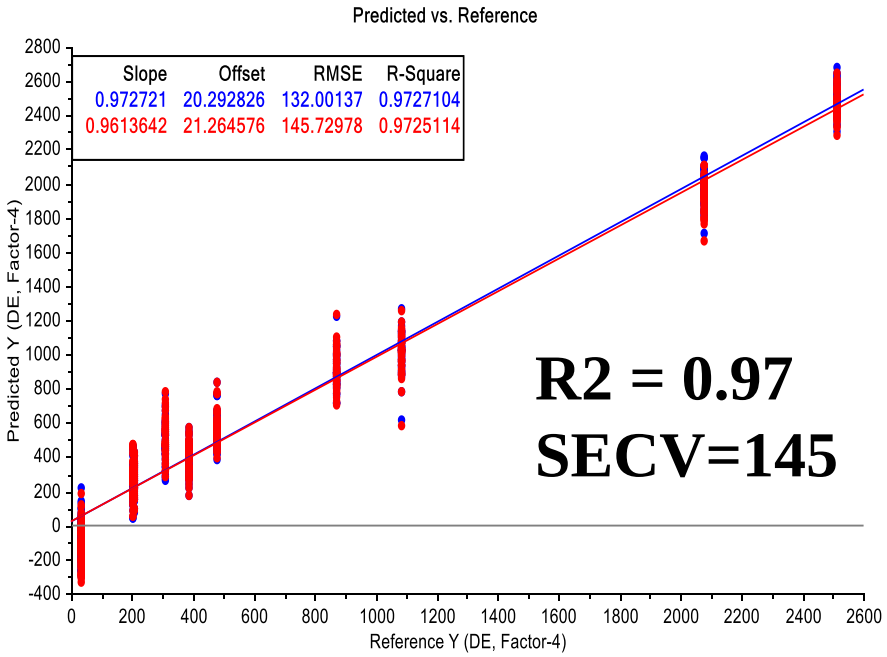

Explained Variance
Y-variance
Factor-0
Factor-1
Factor-2
Factor-3
Factor-4
Factor-5
Factor-6
Factor-7
Factors


Predicted vs. Reference
Slope Offset RMSE R-Square
0.9249333 55.909733 218.9285 0.9249338
0.8870247 67.635628 242.84555 0.9236665
R2 =0.92
SECV=243
Predicted Y (DE, Factor-4)
Reference Y (DE, Factor-4)


Scores
Factor-2 (0%, 67%)
Factor-1 (100%, 0%)
2e-06
1e-06
0
-1e-06
-2e-06
-0.0001
0
0.0001
0.0002
0.0003
0.0004


Regression coefficients
Regression Coefficients (B)
X-Variables (DE, Factor-4, B0:9753.43848)
7367.131 7220.56 7073.989 6919.703 6765.417 6611.132 6456.847 6302.561 6155.99 6009.419 5855.133


Explained Variance
Y-variance
Factor-0
Factor-1
Factor-2
Factor-3
Factor-4
Factors


Predicted vs. Reference
Slope Offset RMSE R-Square
0.972721 20.292826 132.00137 0.9727104
0.9613642 21.264576 145.72978 0.9725114
R2 = 0.97
SECV=145
Predicted Y (DE, Factor-4)
Reference Y (DE, Factor-4)

Full Fat Soya (2000 spl, sorted/oil, average/100

Step-up Regression Statistics

Input File	oila100.cal	REP File	None
Validation File	None	Equation File	None
Math Treatment	0, 0, 1, 1	Number of variables	693
Scatter Corrected	None	Downweight outliers	No
Constituent	OilA_as	Number of samples	20
Cross validation	By groups, no pre-sort, form groups by cycling, group duplicates together		

Mean 19.434 Range 15.89 - 22.49 Standard deviation 1.582

Number of terms 2 SEC 0.324 AdjRSQ 0.958

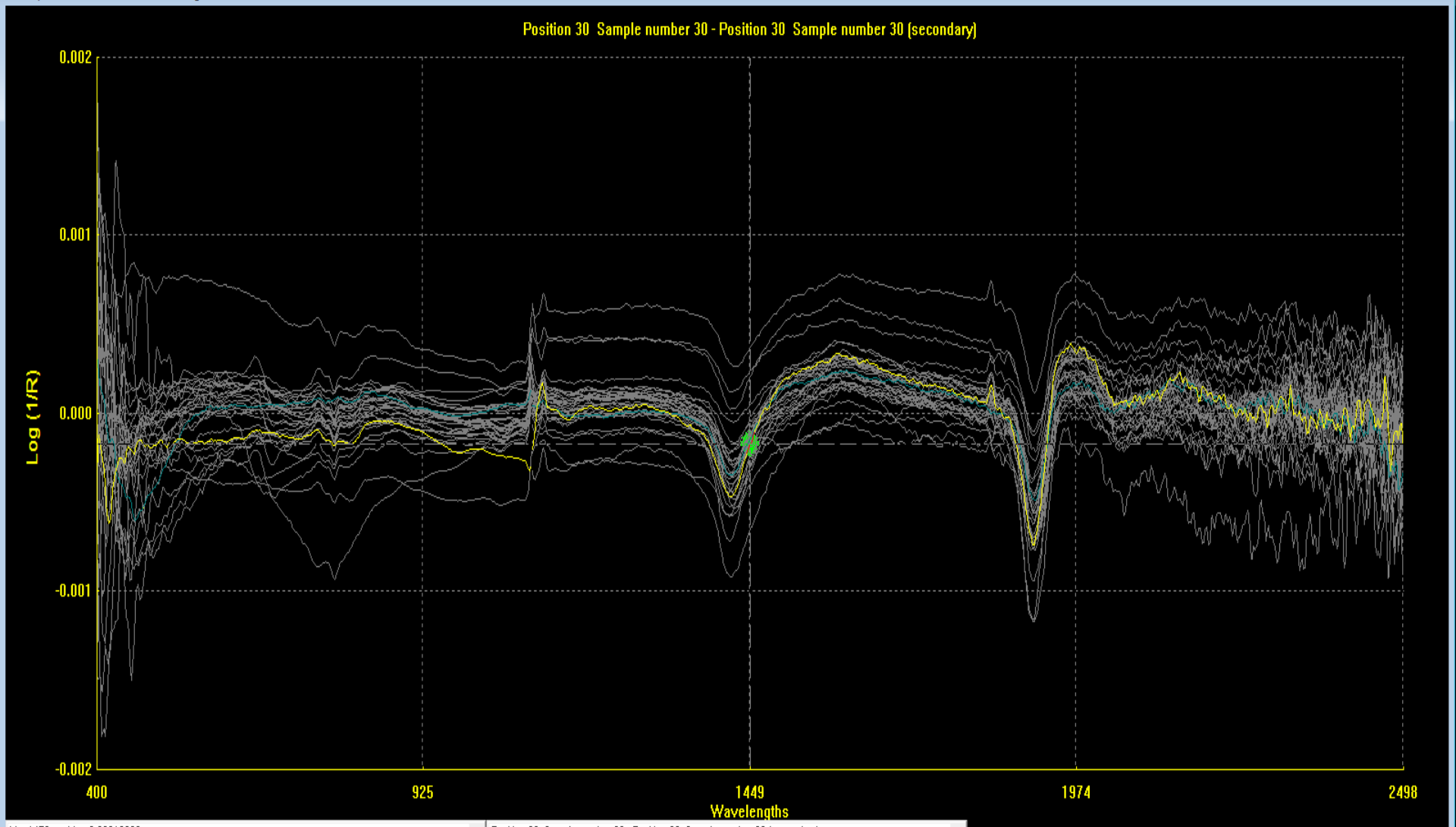
	Coefficient	Data Point	Wavelength	F
B(0) =	25.541			
B(1) =	236.127	313	1724.0	437.15
B(2) =	-178.299	505	2108.0	423.30

	Au	%	Bcoeff
Water	0.02	1	50
DE	0.01	1	100
OIL	0.005	1	200
Melamine	0.002	1	500
	microLog	**100 ppm**	
Water	200	0.01	50
DE	100	0.01	100
OIL	50	0.01	200
Melamine	20	0.01	500

?

STD BOX : 30 sealed cups

<1> Spectrum - C:\&DATA\2nirs\std\sg6120216 a.nir



X = 1450 Y = -0.00016090
NIR region
Absorption by stretching - bending

Position 28 Sample number 28 - Position 28 Sample number 28 (secondary)
Position 29 Sample number 29 - Position 29 Sample number 29 (secondary)
Position 30 Sample number 30 - Position 30 Sample number 30 (secondary)

$$RMS = \sqrt{\frac{\sum_{i=1}^{k}(a_{1i} - a_{2i})^2}{k}} \qquad RMSC = \sqrt{\frac{\sum_{i=1}^{k}(a_{1i} - a_{2i} - bias)^2}{k-1}}$$

Contrast Output

sg6120216 a.nir vs. sg6120216 b.nir:

Pos	Sample No.	Seg	R^2	RMS	Standard Bias	RMSC
		2	1.0000	247	-206	136
28	28	1	1.0000	75	12	74
		2	1.0000	132	79	105
29	29	1	1.0000	169	28	167
		2	1.0000	135	68	116
30	30	1	1.0000	178	-156	84
		2	1.0000	207	67	196
Segment Averages:						
	Segment No.	1	1.0000	273	-30	194
		2	1.0000	258	70	174
	Overall Aves:		1.0000	263	20	181

Contrast Output

sg6120216 a.nir vs. sg6120216 b.nir:

Pos	Sample No.	Seg	R^2	RMS	Standard Bias	RMSC
		2	1.0000	247	-206	136
28	28	1	1.0000	75	12	74
		2	1.0000	132	79	105
29	29	1	1.0000	169	28	167
		2	1.0000	135	68	116
30	30	1	1.0000	178	-156	84
		2	1.0000	207	67	196
Segment Averages:						
	Segment No.	1	1.0000	273	-30	194
		2	1.0000	258	70	174
	Overall Aves:		1.0000	263	20	181

Pos	Sample No.	R^2	RMS	Bias	RMSC
14	15	1.0000	1594	1171	1081
15	17	1.0000	9193	-8789	2695
16	19	0.9997	9086	7067	5716
17	20	0.9998	16823	15188	7242
18	21	0.9998	4002	-883	3907
19	22	0.9999	8049	-7814	1930
20	23	0.9993	14352	-12081	7755
21	24	1.0000	8414	8161	2047
22	25	1.0000	3572	1547	3223
23	26	1.0000	5137	-4963	1330
24	27	1.0000	5701	-5625	930
25	28	1.0000	10316	-10120	2001
26	29	0.9997	8607	-4368	7423
27	30	0.9997	6955	6084	3373
	Overall Aves:	0.9999	9729	-963	3988

Pos	Sample No.	Seg	R^2	RMS	Bias	RMSC
		2	1.0000	89	0	89
28	#28	1	1.0000	46	-19	42
		2	1.0000	90	0	91
29	#29	1	1.0000	197	-24	196
		2	1.0000	106	3	106
30	#30	1	1.0000	78	-14	76
		2	1.0000	123	3	123
Segment Averages:						
	Segment No.	1	1.0000	110	2	108
		2	0.9999	153	-2	153
	Overall Aves:		1.0000	140	0	139

Pos	Sample No.	R^2	RMS	Bias	RMSC
14	15	0.9998	313	-45	310
15	17	0.9996	437	-122	420
16	19	0.9982	1606	288	1581
17	20	0.9991	1324	-372	1272
18	21	0.9993	1063	-152	1053
19	22	0.9990	669	82	665
20	23	0.9981	1378	301	1346
21	24	0.9999	530	19	530
22	25	0.9996	518	-124	503
23	26	0.9999	228	-34	225
24	27	0.9998	329	34	327
25	28	0.9998	298	132	267
26	29	0.9982	1250	400	1185
27	30	0.9988	1077	87	1075
	Overall Aves:	0.9994	826	34	803

1st DERIVATIVE

RMS between SPECTRA

Two consecutive readings

Material	RMS (LOG*10^{-6})
Ceramic	30
Soya meal (0.4 od) (same cup)	200
Rape seed (0.8od) (Whole grains - same cup)	500
Soya meal (Sealed cup) Between 2 STDED instrum.	**1000**
Soya meal (refilling)	2000
Rape seed (Whole grains - refilling)	6000

O Abbas *et al.*, *J. Near Infrared Spectrosc.* **21,** 183–194 (2013)
Received: 16 October 2012 ■ *Revised: 26 February 2012* ■ *Accepted: 14 March 2013* ■ *Publication: 26 March 2013*

JNIRS
JOURNAL
OF
NEAR
INFRARED
SPECTROSCOPY

Detection of melamine and cyanuric acid in feed ingredients by near infrared spectroscopy and chemometrics

O. Abbas,* B. Lecler, P. Dardenne and V. Baeten

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journal homepage: www.elsevier.com/locate/chemolab

Use of a multivariate moving window PCA for the untargeted detection of contaminants in agro-food products, as exemplified by the detection of melamine levels in milk using vibrational spectroscopy☆

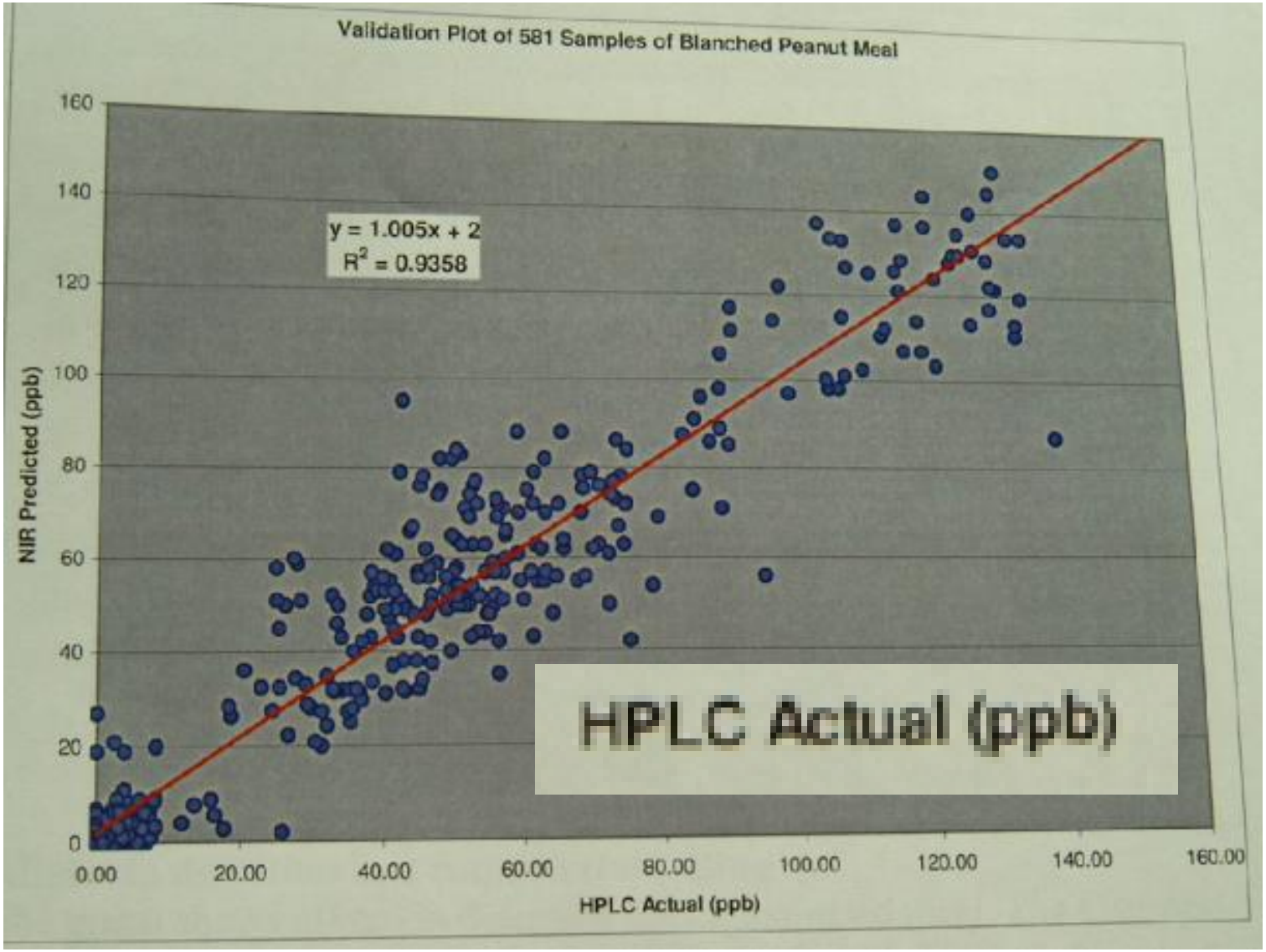
J.A. Fernández Pierna, D. Vincke, V. Baeten, C. Grelet, F. Dehareng, P. Dardenne *

Walloon Agricultural Research Centre (CRA-W), Valorisation of Agricultural Products Department, Chaussée de Namur n°24, 5030 Gembloux, Belgium

MID-IR MILK & Melamine → 250 ppm

NIR SOYAMEAL & Melamine → 1000 ppm
(60 samples at 0.1 = 4 misses)

Rapid and Non-destructive Mycotoxin Assay with NIRS, *Russel Wilkie* (ICNIR2005, Aukland)



Received: 18 January 2015 ■ *Revised: 2 May 2016* ■ *Accepted: 3 May 2016* ■ *Publication: 9 May 2016*

JNIRS JOURNAL OF NEAR INFRARED SPECTROSCOPY

Virtual Issue: Papers Presented at NIR-2015, October 2015, Foz do Iguassu, Brazil

LOCAL regression algorithm improves near infrared spectroscopy predictions when the target constituent evolves in breeding populations

F. Davrieux,[a,*] D. Dufour,[b,e] P. Dardenne,[c] J. Belalcazar,[d] M. Pizarro,[d] J. Luna,[d] L. Londoño,[e] A. Jaramillo,[e] T. Sanchez,[d] N. Morante,[d] F. Calle,[d] L.A. Becerra Lopez-Lavalle [d] and H. Ceballos[d]

carotenoids content of cassava roots

TCC values ranged from 0.11 µg g^{-1} to 29.0 µg g^{-1} (ppm)

>6000 samples and cross year validation

MIXTURE DESIGN

~~a. 1 pure sample~~
~~b. 1 contaminant -> 20 samples by mixing at # %~~

Collect real samples >>

Collect contaminant from different origins if possible

Only use one # at a given %

	Contaminant		
SPL	a	b	c
1	1a5		
2		2b10	
3			1c15
4			4c5
5	5a10		
6		6b15	
.			
.			
n			
1		1b5	
2			2c10
3	3a15		
4		4b10	
5			5c5
6	6a5		
.			
.			
n			

CONCLUSION LOD

When Y < 0.1 %, be sure what you analyze is (significantly) present in the spectra;
Look at the ratio absorptivity/noise

Analytes <0.1 % can be well predicted and provide useful results
But these analytes are likely correlated with something else into the matrix.

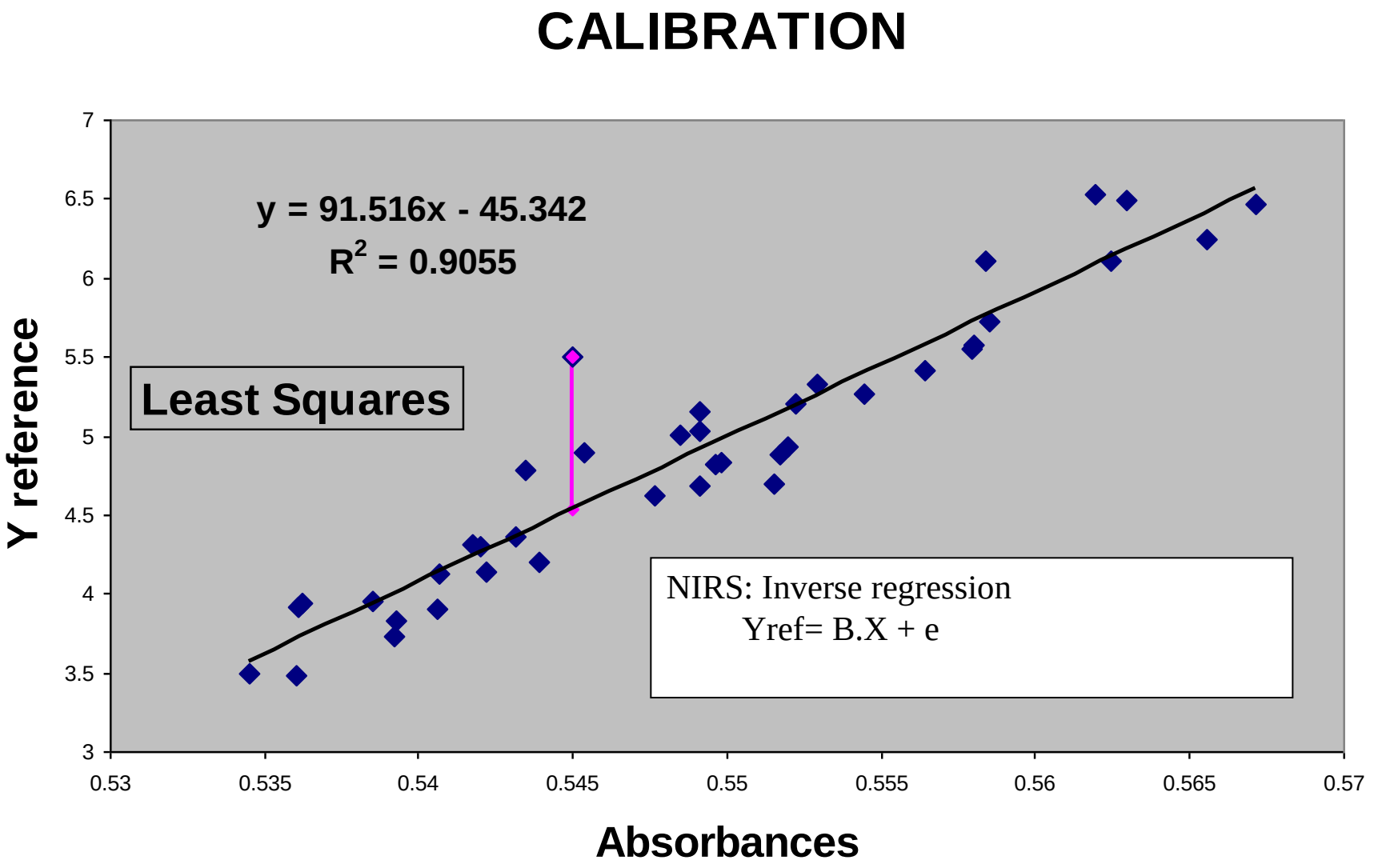
For powders with separated particles,
Hyperspectral Imaging can improve the LOD significantly
→ ppm ?

2

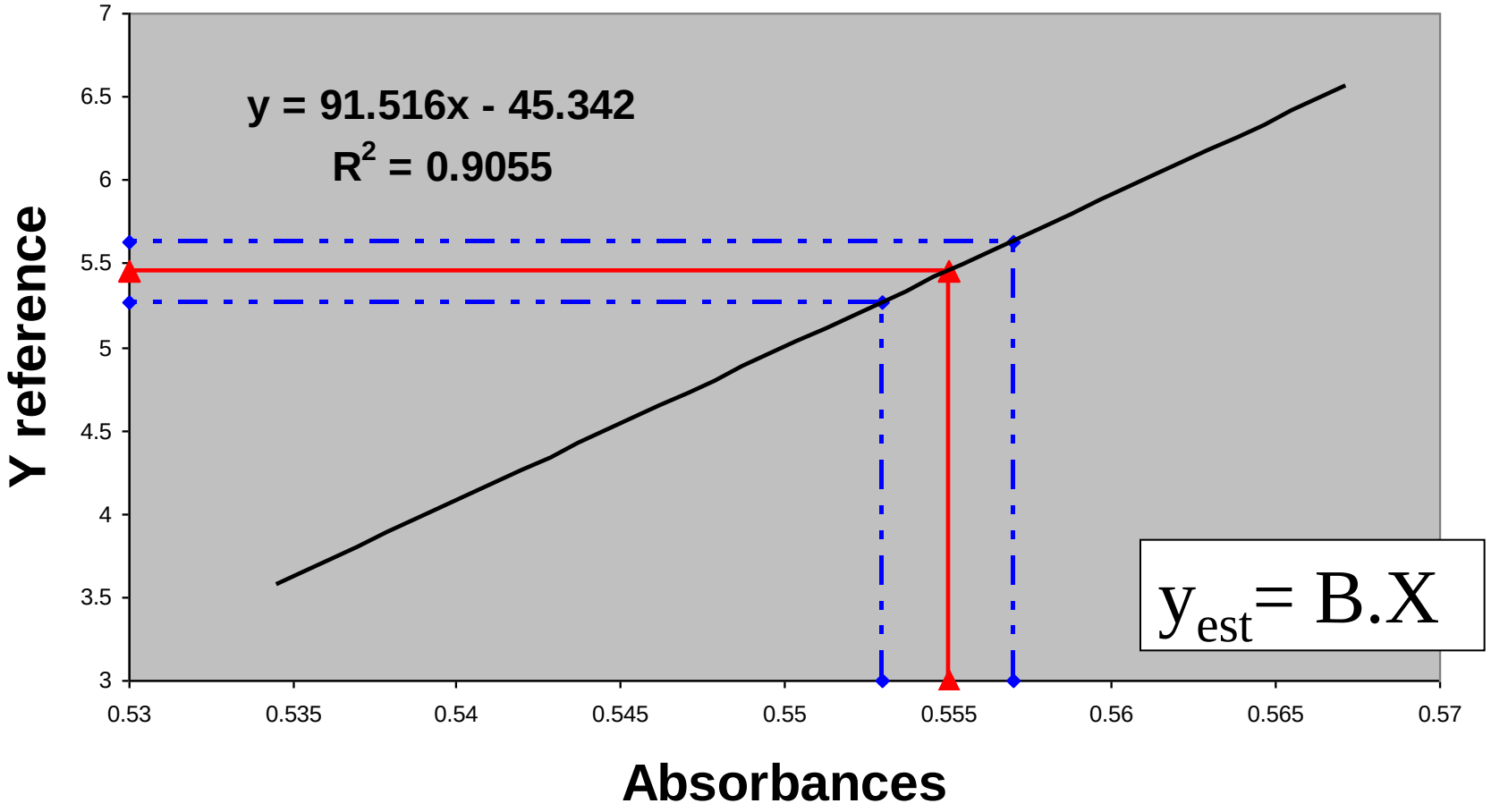
UNCERTAINTY

$$s\left(\hat{y}_i - y_i\right)?$$

uncertainty

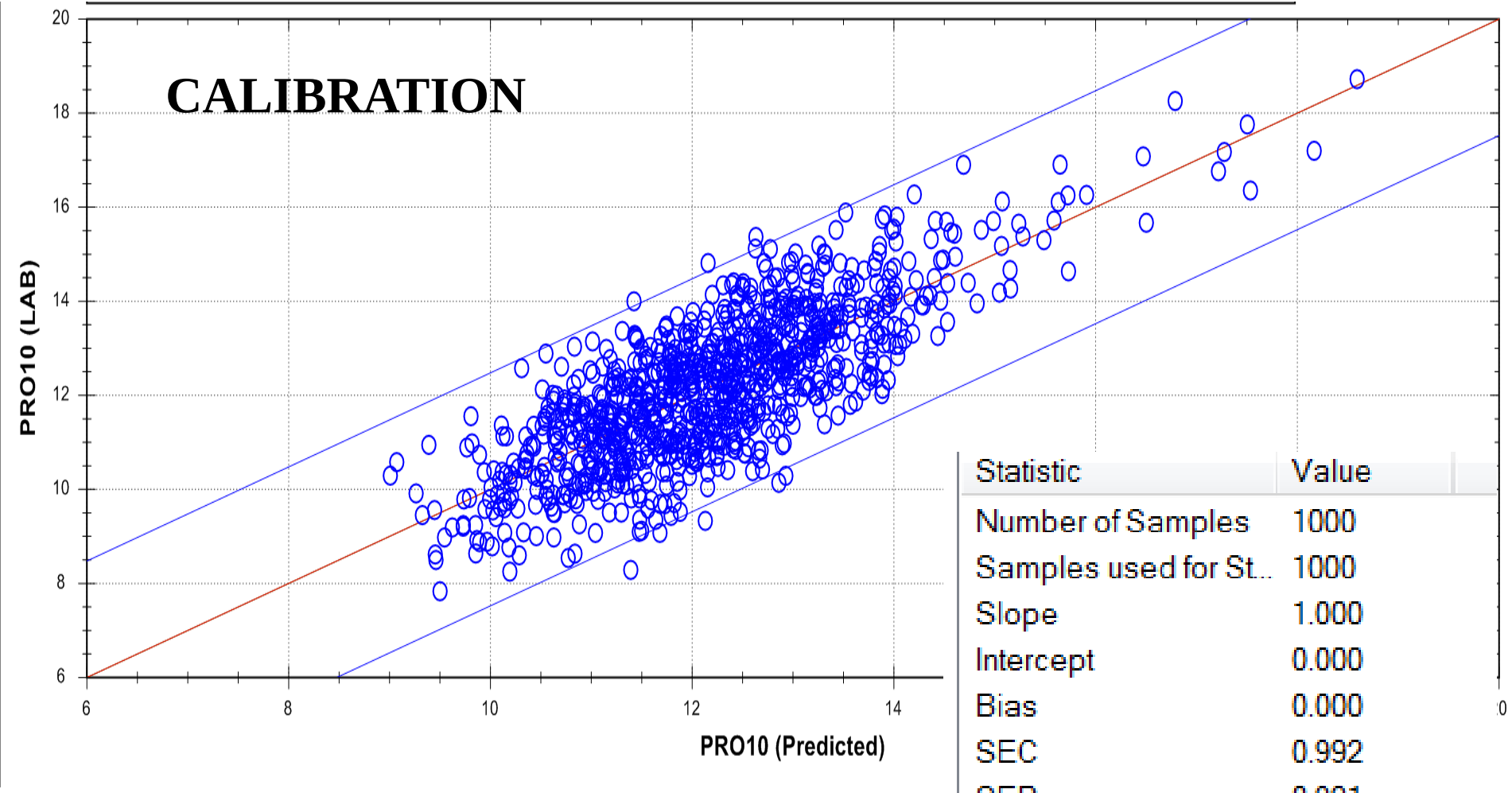


PREDICTION


y = 91.516x - 45.342
R2 = 0.9055
Y reference
Absorbances
7
6.5
6
5.5
5
4.5
4
3.5
3
0.53
0.535
0.54
0.545
0.55
0.555
0.56
0.565
0.57
yest= B.X

2000 spectra of ground wheat
Spilt ½ -> CAL and VAL

CAL y values are modified by a vector of Gaussian noise of mean =0 and sd of 0.1, 0.2, …1.0, ..1.5

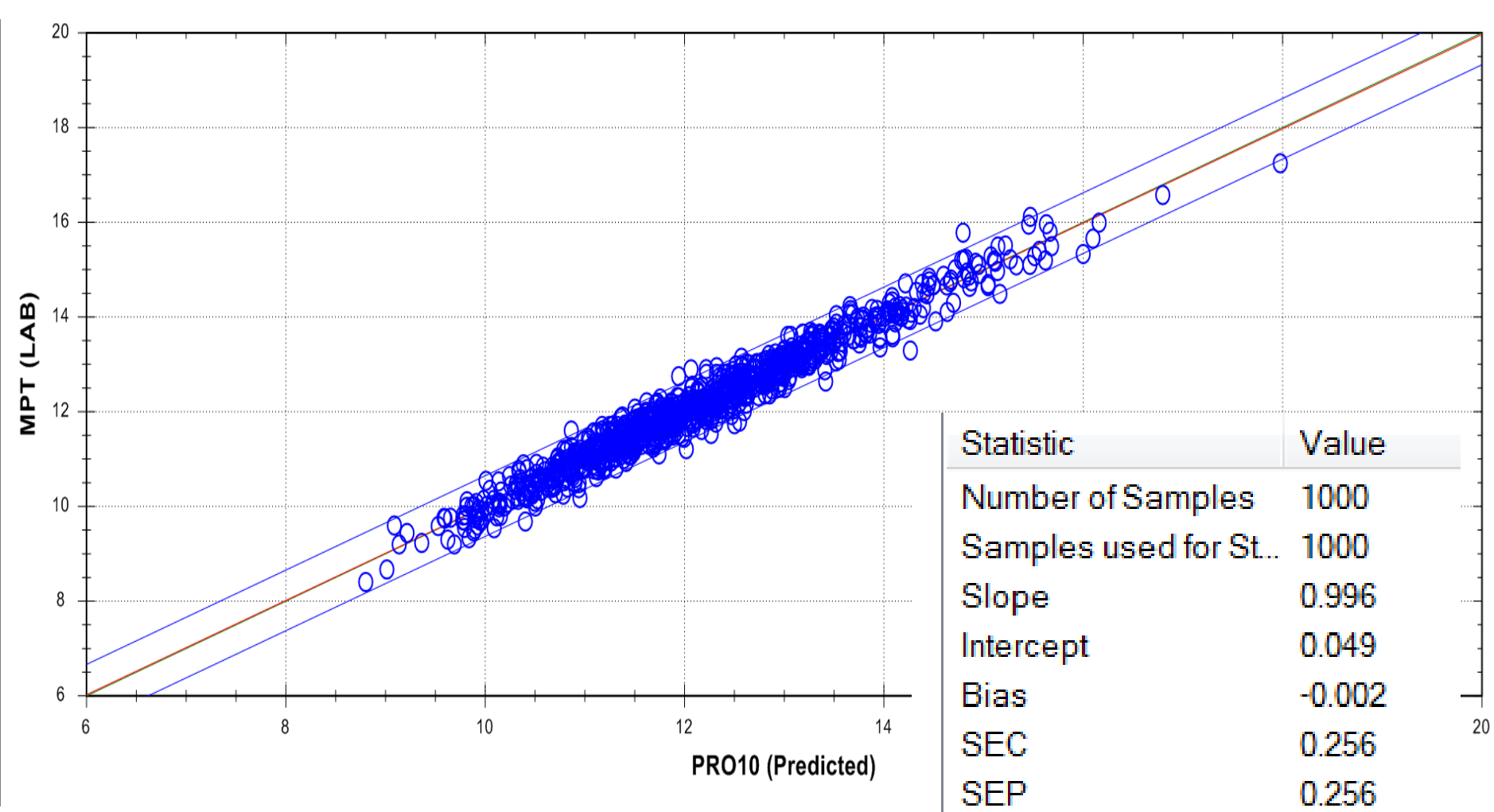


Statistic	Value
Number of Samples	1000
Samples used for St..	1000
Slope	1.000
Intercept	0.000
Bias	0.000
SEC	0.992
SEP	0.991
SEP(C)	0.991
RSQ	0.618
Predicted Average	12.179
Actual Average	12.179
Predicted SD	1.260
Actual SD	1.604

Y modified with noise N(0,1)

mean = 0

sd = 1

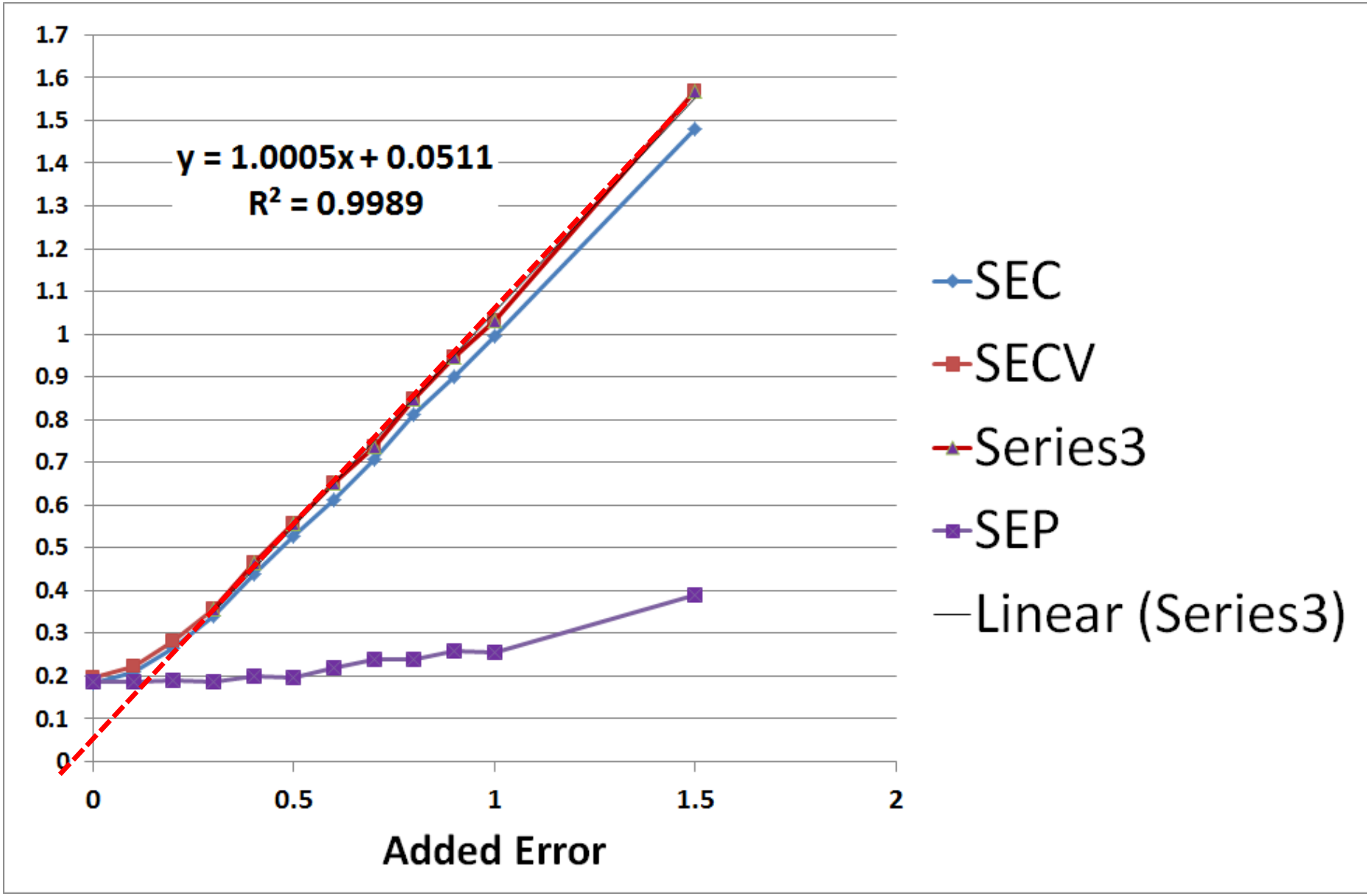


Statistic	Value
Number of Samples	1000
Samples used for St..	1000
Slope	0.996
Intercept	0.049
Bias	-0.002
SEC	0.256
SEP	0.256
SEP(C)	0.256
RSQ	0.960
Predicted Average	12.150
Actual Average	12.148
Predicted SD	1.268
Actual SD	1.288

TEST SET N= 1000

Added

Error	SECV	SEP
0.0	0.20	0.19
0.1	0.22	0.19
0.2	0.28	0.19
0.3	0.36	0.19
0.4	0.47	0.20
0.5	0.56	0.20
0.6	0.65	0.22
0.7	0.74	0.24
0.8	0.85	0.24
0.9	0.95	0.26
1.0	1.03	0.26
1.5	1.57	0.39


y = 1.0005x + 0.0511
R² = 0.9989
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
Added Error
SEC
SECV
Series3
SEP
Linear (Series3)

Uncertainty of the NIR analyses

$$s(\hat{y}_i - y_i) = \left[(1 + h_i).SEC^2 - S^2_{ref}\right]^{1/2}$$

Faber and Bro, *Chemom., Intell. Lab. Syst.* 61, 133 (2002)
Fernandez Pierna & *al.*, *Chemom., Intell. Lab. Syst.* 65,281 (2003)

https://doi.org/10.1016/S0169-7439(02)00139-9

$$SEP^2_{actual} = SEP^2_{observed} - SEL^2_{ref}$$

$$SEP_{actual}^2 = SEP_{observed}^2 - SEL_{ref}^2$$

BIPEA 02/2017
Blé tendre

Critère / Criterion	Unités / Unit	X	u_x	s^*_x	p_x
HECT01	$kg.hl^{-1}$	80,7	0,0	0,1	10
EAUB01	%	12,76	0,01	0,03	14
EAUA01	%	12,76	0,01	0,03	14
PROT01	%	12,32	0,03	0,17	68

An example:

Protein in wheat: SEL = 0,17

SEPobserved = 0,23

SEPactual = SQRT(0,23^2 – 0,17^2) = 0,15

2 FIGURES OF MERIT:

RMSEP

SEL

JNIRS

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25(2) 85–90

DOI: 10.1177/0967033517702395
journals.sagepub.com/home/jns
SAGE

Original Article

Tutorial: Items to be included in a report on a near infrared spectroscopy project

Phil Williams[1], Pierre Dardenne[2] and Peter Flinn[3]

What is the MOST important in a model ?

Not the stats : sec, sep, R2,… = gauges

B coefficients = engine

$$\hat{Y} = X.b$$

$$n.1 = (n.m) * (m.1)$$

CONCLUSION UNCERTAINTY

In NIR applications, NIR values are more accurate than it appears
and sometimes better than the reference method ones.

But it is not easy to prove it!

Do not try to obtain the smallest SEC (outliers)

Just try to compute stable Bcoefficients from spectra containing the expected future variation.

Chimiométrie 2018
30 – 31 Janvier 2018

https://chemom2018.sciencesconf.org/resource/page/id/5

CHALLENGE

dardennepaj@gmail.com

Fichiers à télécharger :

- Description du Challenge : Challenge 2018
- Fichiers CSV : CAL / VAL (2018)

ACKNOWLEGMENTS

The colleagues at CRA-W

Merci bramin p'o m'awès choutè