Prediction of milk coagulation properties by Fourier Transform Mid-Infrared Spectroscopy (FTMIR) for genetic purposes, herd management and dairy profitability

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Introduction

Cheese production is growing worldwide (International Dairy Federation, 2010) with a +2% of rate / year (SCHMIT and KAISER, 2006).

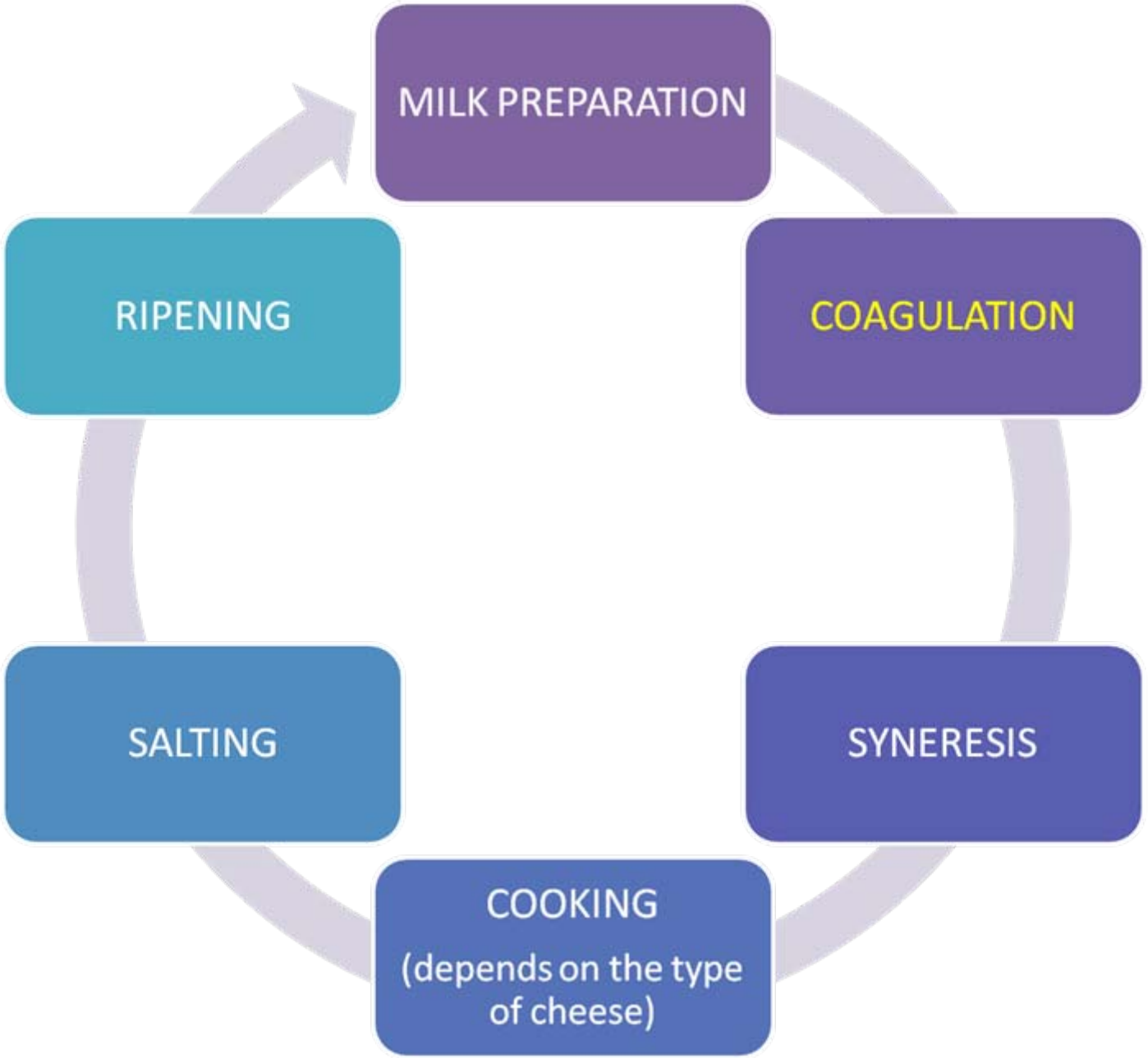
Italy 70% of available milk used for manufacturing typical cheeses, in particular PDO products (Pieri, 2011).

More than 83% of Italian cow milk production is localized in the North regions.

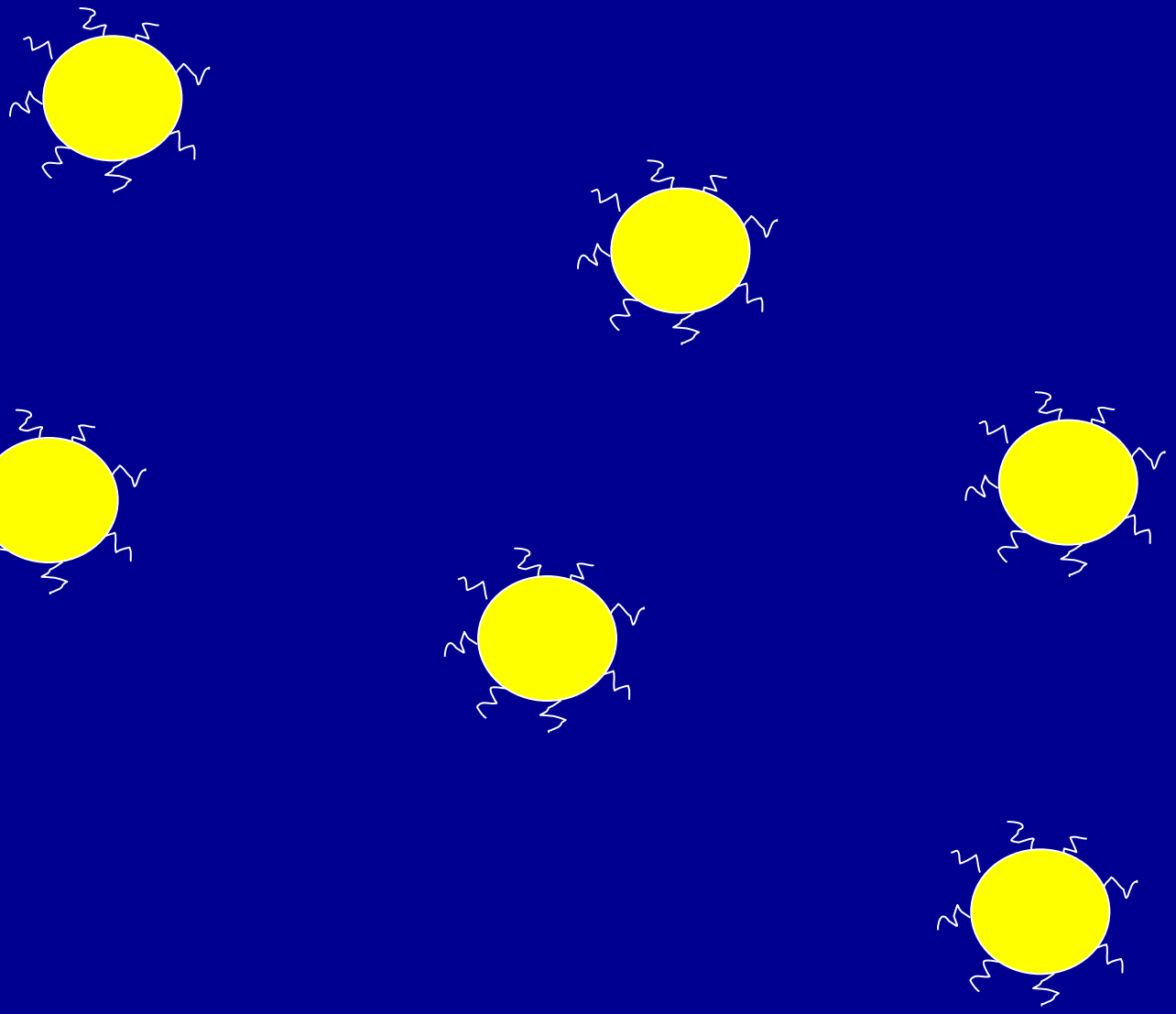
The Veneto Region is 3rd producer of cow milk in Italy.

Since 2008 a regional project "Distretto Lattiero Caseario Veneto" had linked dairy industry stakeholders.

Cheese Making Steps



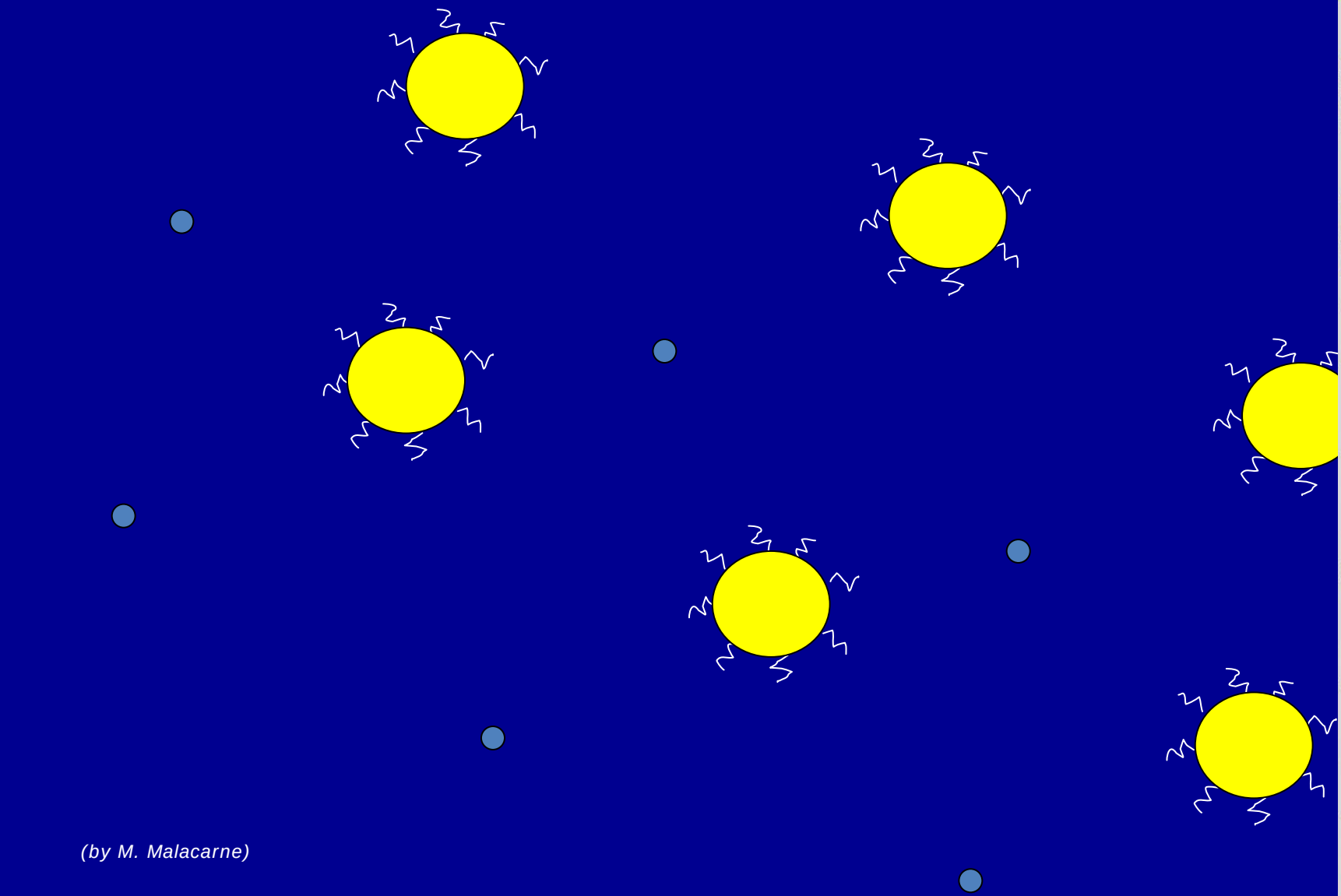
Stability of milk due to the crown of k-casein



(by M. Malacarne)

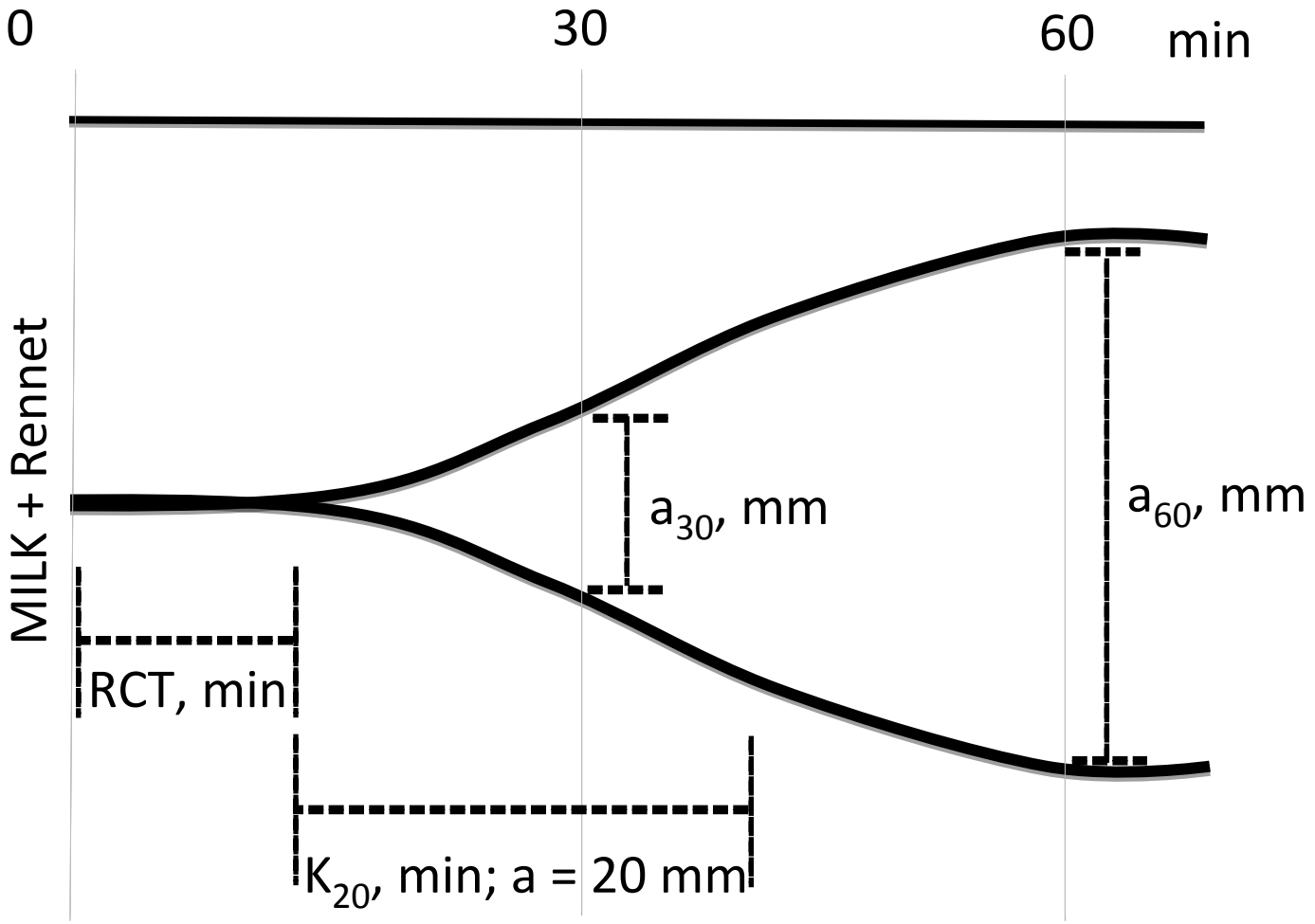
Action of chimosine of rennet

cut K-casein making the coagulation

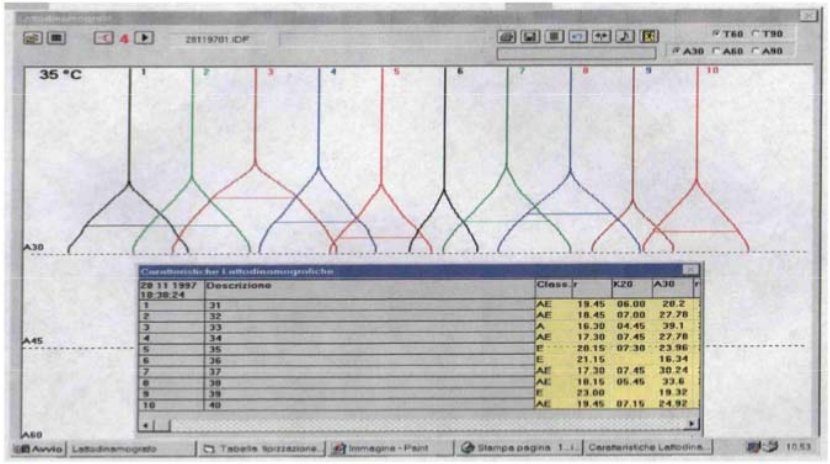


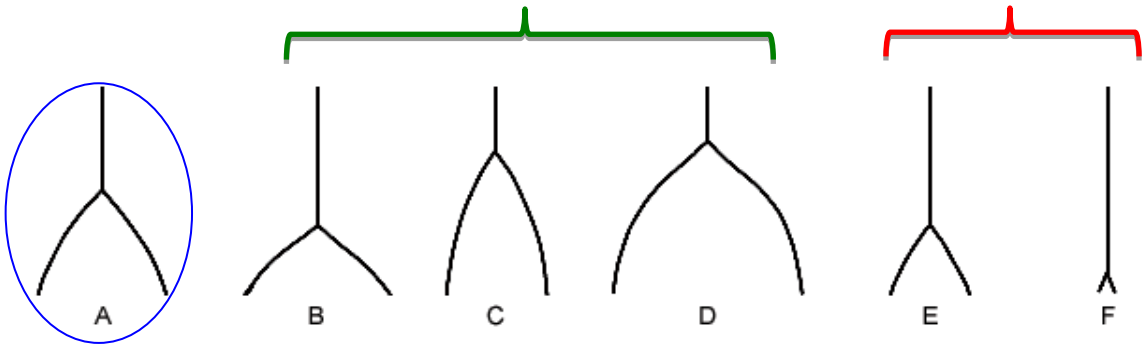
(by M. Malacarne)

Milk Coagulation Properties: scheme



Milk Coagulation Properties: output





MCP: Why and How measured?

Cheese processing, cheese yield, cheese composition and quality → dairy efficiency.

[Aleandri et al., 1989; Ng-Kwai-Hang et al., 1989; Martin et al., 1997; Walsh et al., 1998; Ikonen et al., 1999; Summer et al., 2003; Wedholm et al., 2006; De Marchi et al., 2008].

Mechanic and optical methodology has been studied.

[Laporte et al., 1998; O'Callaghan et al., 2002; Klandar et al., 2007; Cassandro et al., 2008; Dal Zotto et al., 2008; Pretto et al., 2011].

The common method is the lactodynamograph.

Variation Sources of MCP

1. Type of instrument and methodology of analyses [Pretto et al., 2011].
2. Milk quality composition. e.g. protein composition, titratable acidity, somatic cell content [Okigbo et al. 1985; Politis and Ng-Kwai-Hang 1988; Formaggioni et al., 2001; De Marchi et al., 2007].
3. Species, breed, individuals [Macheboeuf et al., 1993; Auldist et al., 2002; Bencini, 2002; Park et al., 2007; De Marchi et al., 2007 and 2008; Martin et al., 2009].
4. Lactation stage
5. Herd and environmental conditions
6. Exploitable genetic variation exist for MCP [Ikonen et al., 1999; Tyrisevä et al., 2004 and 2008; Cassandro et al., 2008; Comin et al., 2008; Vallas et al., 2010]

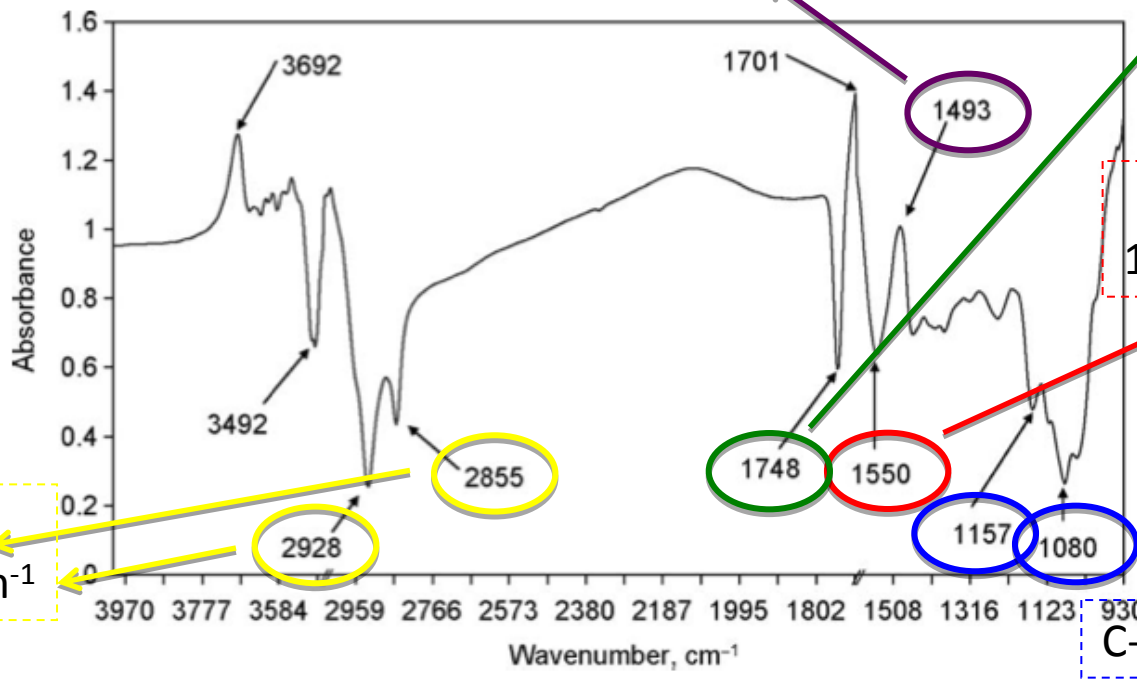
Prediction of MCP by FTMIR

Prediction of MCP by FTMIR

1. Fast / No destructive / Easy to use.
2. Largely used by milk labs to assess milk quality and for milk payment or for routine milk recording analyses.
3. Absorptions of IR at frequencies correlated to the vibrations of specific chemical bonds within a molecule (Coates, 2000).

C-H bending
640-1500 cm^{-1}

Fatty acid carbonyl group
1736; 1805;1745 cm^{-1}



Protein
1570-1550 cm^{-1}

Lipids
3000-2800 cm^{-1}

C-O stretching

Milk/Cheese traits by FTMIR: applications

1. Fatty acids [Soyeurt et al., 2006; Rutten et al., 2009; De Marchi et al., 2011; Soyeurt et al., 2011].
2. Protein composition [Lynch et al., 2006; De Marchi et al., 2009; Rutten et al., 2011].
3. Acetone [Heuer et al., 2001].
4. **MCP** [Dal Zotto et al., 2008; De Marchi et al., 2009; De Marchi et al., 2012].
5. Body energy status [McParland et al., 2011].
6. Sensory texture traits of cheese [Fagan et al., 2007].
7. Melamin [Foss, personal communication].

Prediction of MCP by FTMIR

2009 → 2010÷2011 → 2012

- 1,200 individual milk samples.
- NO preservative / Analysis within 3 hours.
- Computerized renneting meter (Polo Trade).
- Spectra from Milko-Scan FT120.
- RCT (14.96±3.84 min) and a_{30} (41.7±8.76 mm).
- RCT = R^2_{cv} of 0.62; a_{30} R^2_{cv} of 0.37.

RCT model → allows the discrimination between high and low value.

a_{30} → no satisfactory prediction.

K_{20} → no prediction.

Low range of variability (no samples RCT > 29.5 min).

Reference methods / Lab conditions.

De Marchi et al., 2009 J. Dairy Sci. 92:423–432

Prediction of MCP by FTMIR

2009 → **2010÷2011 →** 2012

- 850 milk samples (individual HF and bulk).
- Preservative / Analysis within 3 days.
- Formagraph (Foss Electric).
- Spectra from Milko-Scan FT6000.
- RCT (19.82±4.59 min) and a_{30} (22.63±10.95 mm).
- RCT = R^2_{cv} of 0.66; a_{30} R^2_{cv} of 0.70.

RCT and a_{30} → quite satisfactory prediction models.

K_{20} → no prediction.

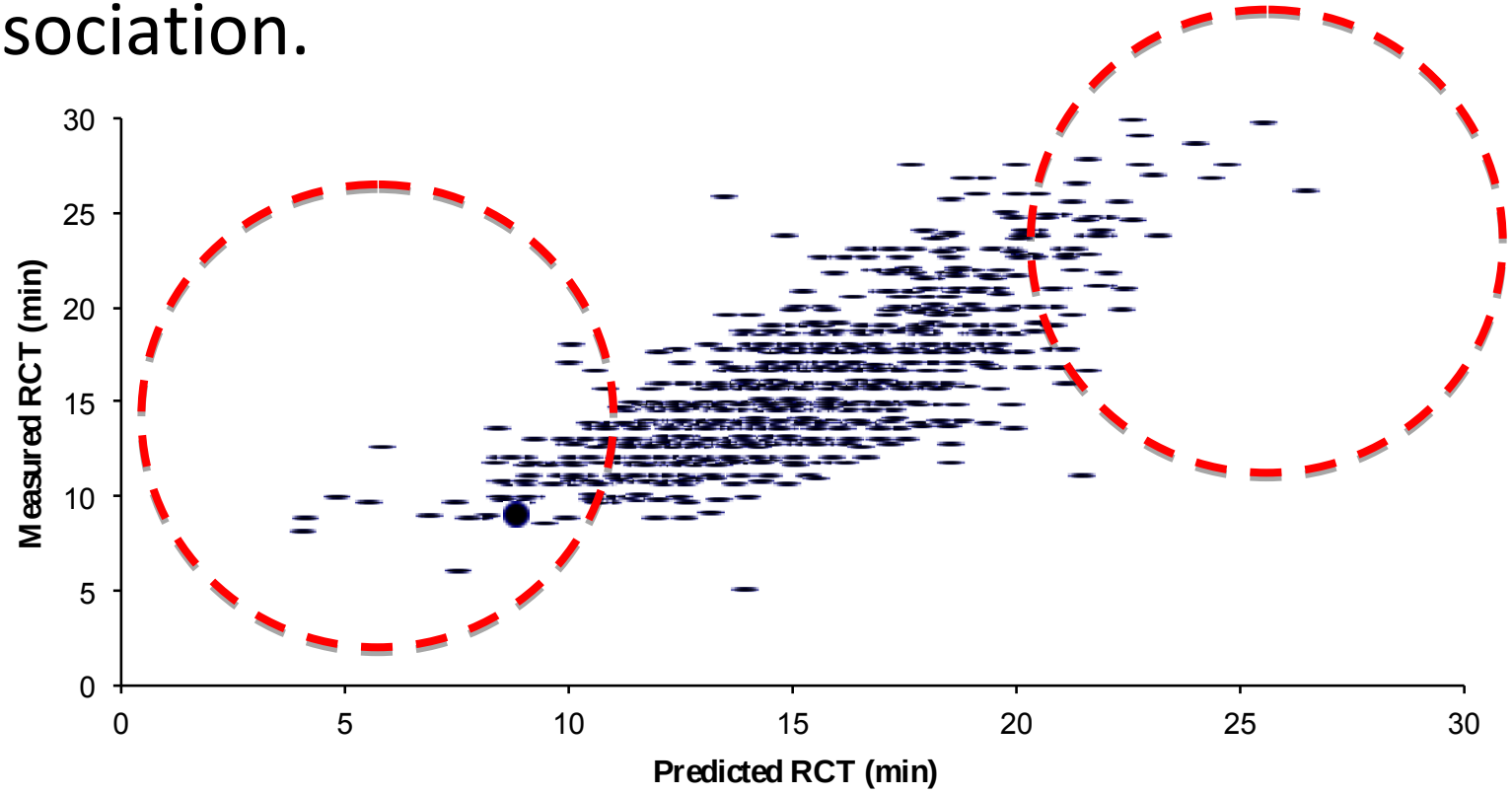
no sample RCT > 29.5 min.

Limited range (RCT from 8 to 25 min).

Prediction of MCP by FTMIR

2009 → **2010÷2011 →** 2012

Summer 2011 - RCT and a_{30} models were installed in Milko-scan FT6000 of Regional breeder association.



Difficult to predict RCT < 8 and > 24 minutes

Prediction of MCP by FTMIR

2009 → 2010÷2011 → **2012**

- 350 milk samples (mainly HF).
- Formagraph (Foss Electric).
- RCT, K_{20}, a_{30} and a_{60}.
- Milko-Scan FT6000.
- RCT (range from 7.55 to 59.00 min)

	RCT, min	K_{20}, min	a_{30}, mm	a_{60}, mm
R^2_{cv}	0.76	0.72	0.70	0.42
RPD	2.03	1.96	1.80	1.26
RER	25.22	14.22	28.20	21.20

1-VR = coefficient of determination of cross-validation.
RER = SEC_{CV}/range. RPD = SD/SEC_{CV}.

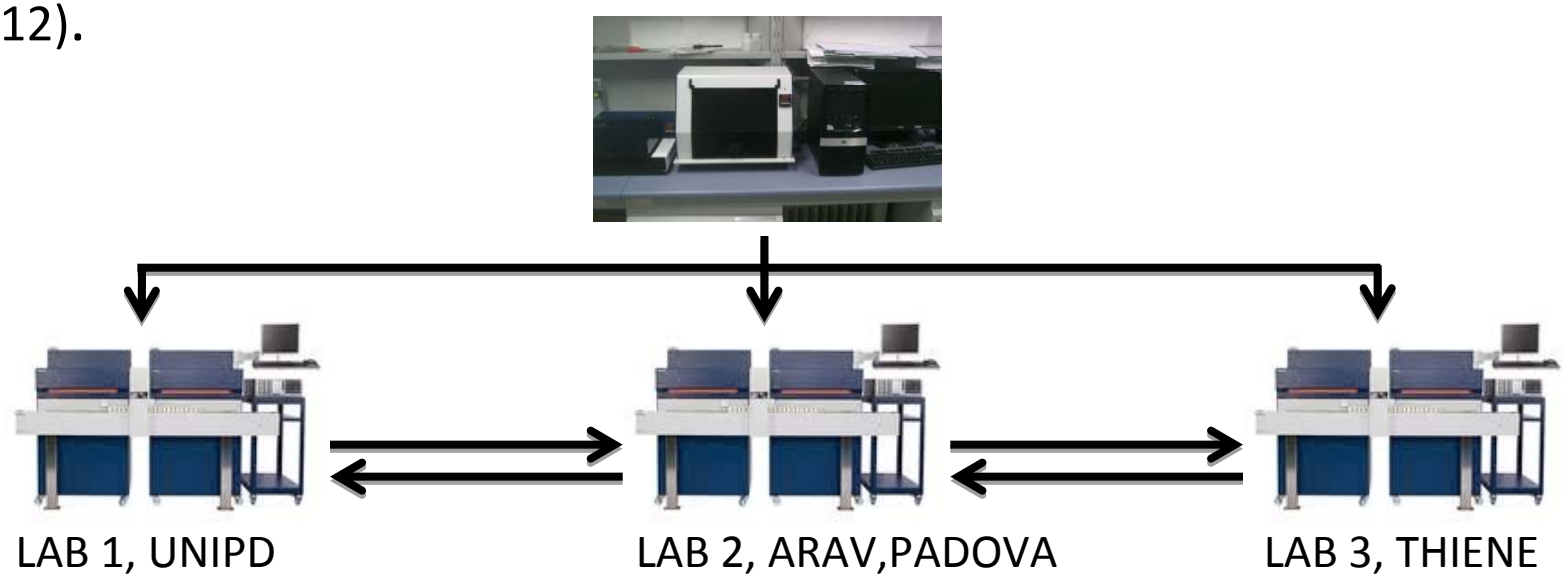
De Marchi et al., 2012

Prediction of MCP by FTMIR

2009 → 2010÷2011 → **2012**

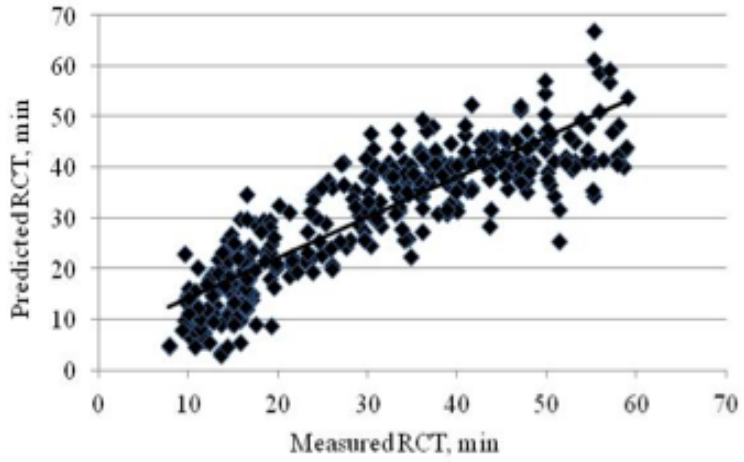
Ring test is carrying out by three labs, twice per month using individual and bulk milk samples to reduce the bias between FTMIR instruments and reference data and among FTMIR instruments.

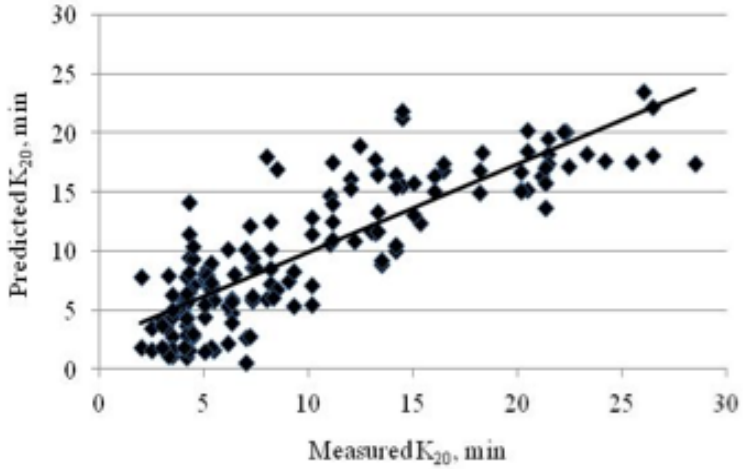
The correlation between MCP values measured by FT6000 and MCP measured by Formagraph in routinely condition range from 0.88 to 0.91 for RCT and a_{30}, respectively (update to April 2012).

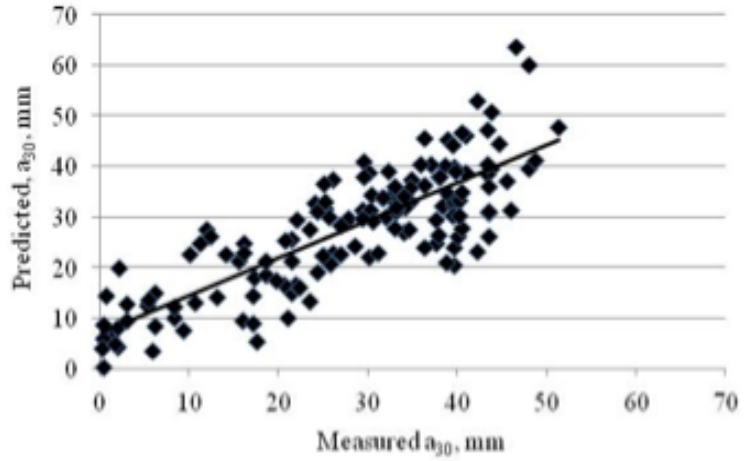


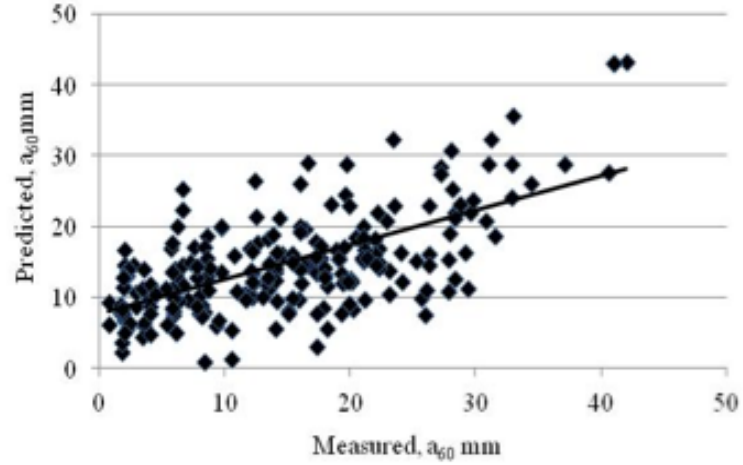
Prediction of MCP by FTMIR

Scatter plots of predicted (y-axis) on measured (x-axis) (RCT = rennet coagulation time; k_{20} = curd-firming time; a_{30} = curd firmness at 30 minutes; a_{60} = curd firmness at 60 minutes).









De Marchi et al., 2012

Predicted MCP Values: applications

Predicted MCP Values: genetic applications

In Veneto region about 25,000 controlled cows/month

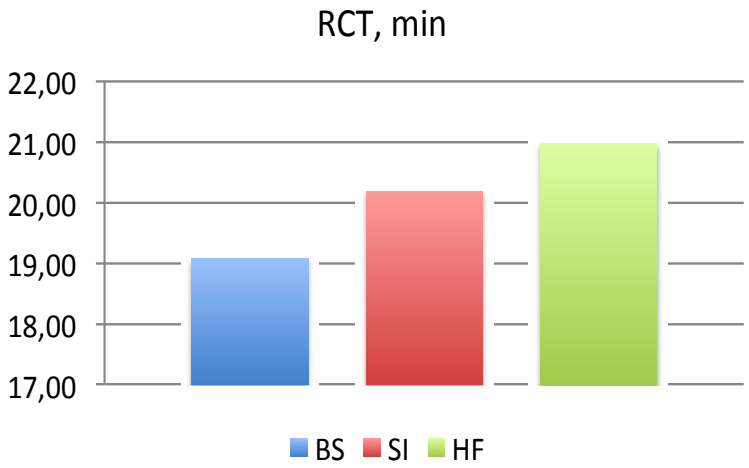
RCT and a_{30} measured using Milko-Scan FT6000 (Foss Electric A/S, Hillerød, Denmark).

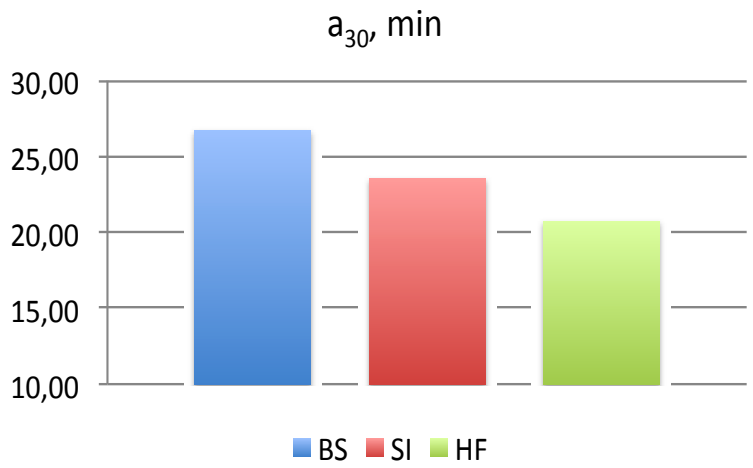
Effect of cow breed on MCP in multibreed herds

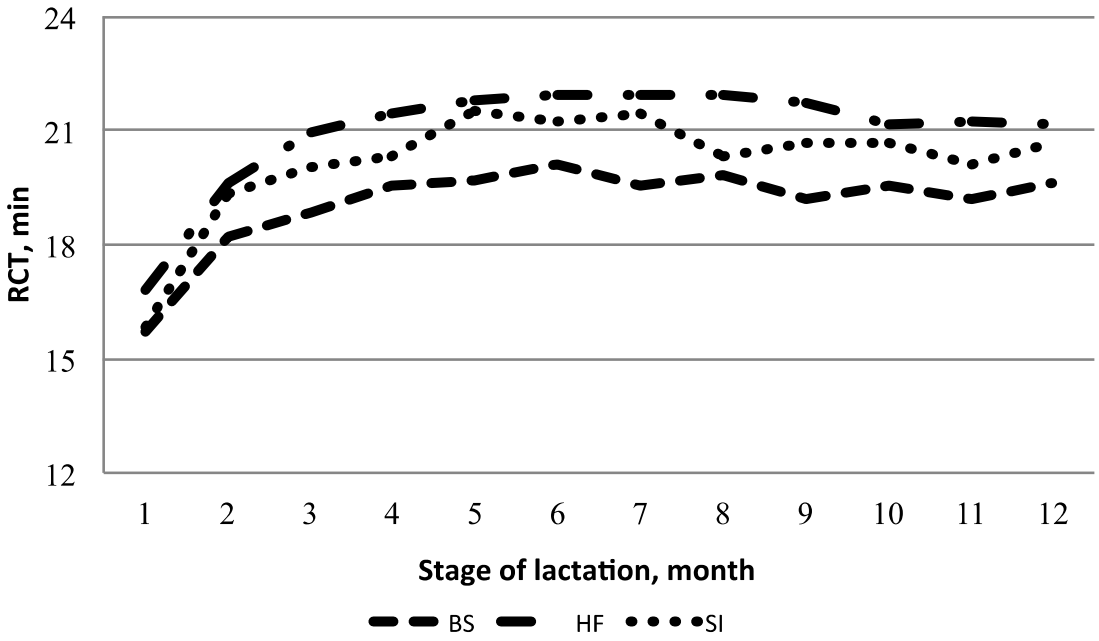
1.39 mixed herds were selected.

2.11,978 individual milk samples collected from 3,279 cows during monthly test-days between September 2011 and May 2012.

Predicted MCP Values: genetic applications







Predicted MCP Values: genetic applications

Genetic parameters for MCP in Holstein Friesian

312 herds - 3,488 HF cows - 140 bulls

	Mean	SD	Range	h^2	SE
Parity, n	1.9	1.1	1-10		
Days in milk, d	198	130	5-982		
Milk Yield, kg/d	30.90	9.60	3.8-88.0	0.12	0.04
Protein, %	3.40	0.40	2.29-5.87	0.20	0.02
Fat, %	3.72	0.75	1.50-8.75	0.29	0.06
SCS, punti	3.08	1.94	-1.64-10.72	0.03	0.02
pH	6.66	0.10	6.17-7.13	0.19	0.04
RCT, min	**19.50**	**5.00**	**2.90-30.00**	**0.17**	**0.05**
a_{30}, mm	**25.00**	**12.50**	**1.00-64.3**	**0.20**	**0.04**

Measured vs. Predicted MCP: Genetic analysis

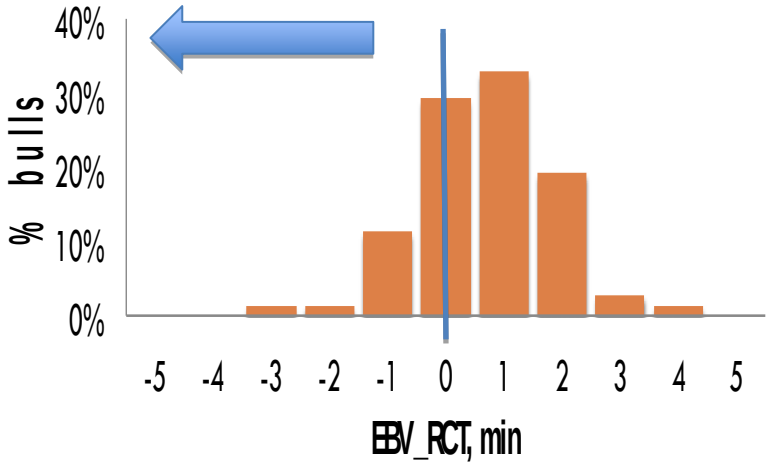
1,200 Brown Swiss cows, 50 sires, 30 herds.
Measured MCP: RCT and a_{30} measured by Coagulometer
Predicted MCP: RCT and a_{30} predicted by Milko-scan FT120

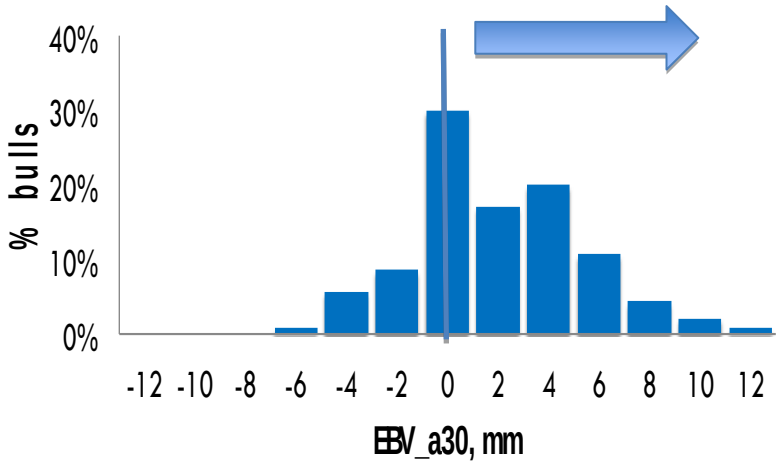
	RCT, min		a_{30}, mm	
	Measured	Predicted	Measured	Predicted
R^2 MIRS	0.64		0.49	
Mean	15.1	14.9	41.5	41.7
σ^2_a	4.9	3.7	19.4	17.2
σ^2_h	1.7	1.5	9.4	5.3
σ^2_e	9.5	4.6	20.6	20.0
h^2	32	37	24	35
r_g	94		77	

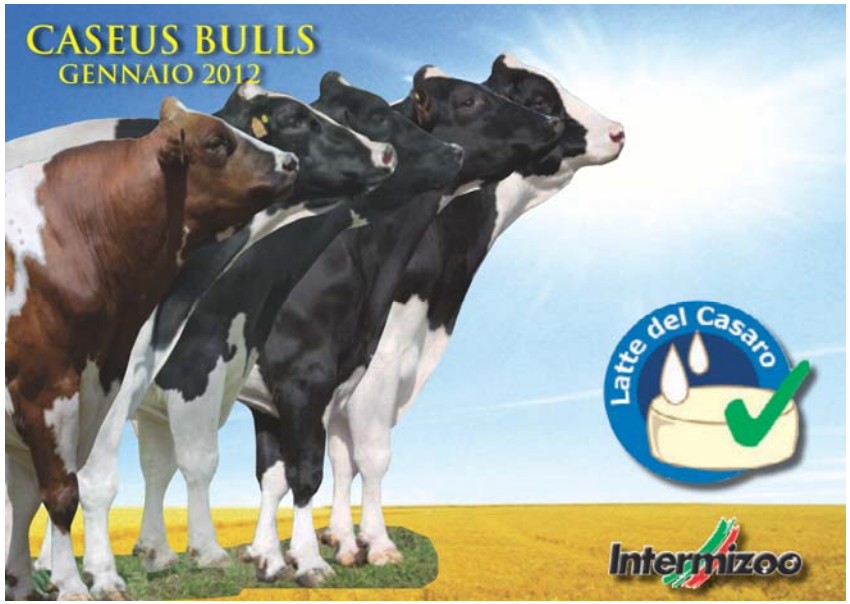
De Marchi et al. 2009. J. Dairy Sci. 92:423-432
Cecchinato et al. 2009 J. Dairy Sci. 92:5304-5313

Predicted MCP Values: genetic applications

Genetic parameters for MCP in Holstein Friesian







Top 12 HF BULLS for MCP

ACTIVE	PRINCE
BROSIO	PURPOSE
DUKO	QUASIMO
LAMBRO	SITTAX
MISIS	TABAIBA
PASSIRIO	WATHA

MCP and Dairy Industry: Variation Sources

1,508 bulk milk samples.

436 dairy herds.

4 dairy cooperatives (Lattebusche, Latteria di Soligo, Latterie Trevigiane, Latterie Vicentine).

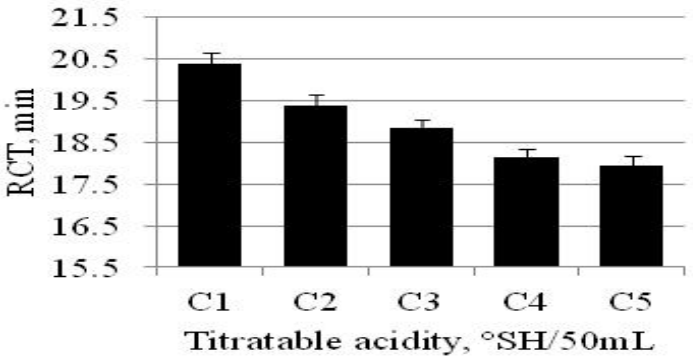
2 years of sampling.

Table 1: Results from ANOVA for milk coagulation properties of bulk milk samples.

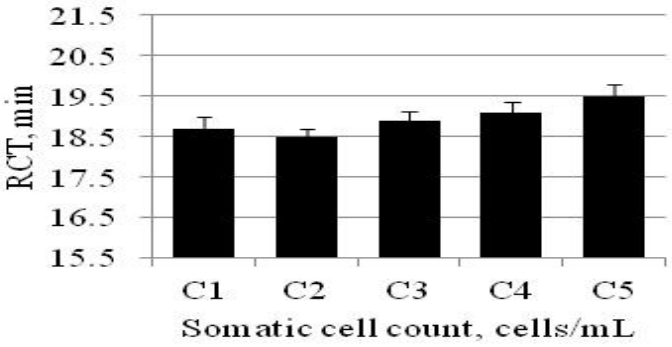
	Trait[1]					
	RCT, min		k_{20}, min		a_{30}, mm	
Effect	F	*P*-value	F	*P*-value	F	*P*-value
Dairy cooperative[2]	25.03	<0.001	9.36	<0.001	25.57	<0.001
Herd (within dairy cooperative)	1.86	<0.001	1.57	<0.001	1.83	<0.001
Year of sampling	19.08	<0.001	1.12	0.290	0.07	0.797
Season of sampling	13.75	<0.001	2.66	0.047	1.51	0.211
Casein, %	0.71	0.585	4.84	0.001	5.88	<0.001
Fat, %	0.58	0.676	1.06	0.376	1.47	0.209
Titratable acidity, °SH/50mL	14.31	<0.001	4.78	0.001	13.63	<0.001
Somatic cell count, cells/mL	2.31	0.056	1.13	0.339	0.97	0.422
Bacterial count, cells/mL	2.48	0.042	1.70	0.148	1.56	0.183
R^2	0.52		0.52		0.52	
RMSE[3]	3.03		1.65		6.72	

MCP and Dairy Industry: Variation Sources

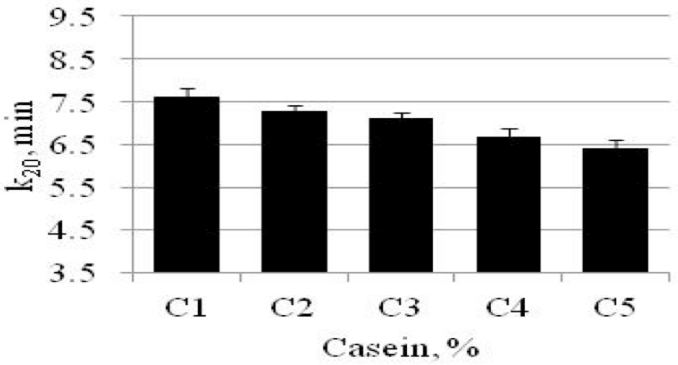
(a)



(b)



(a)



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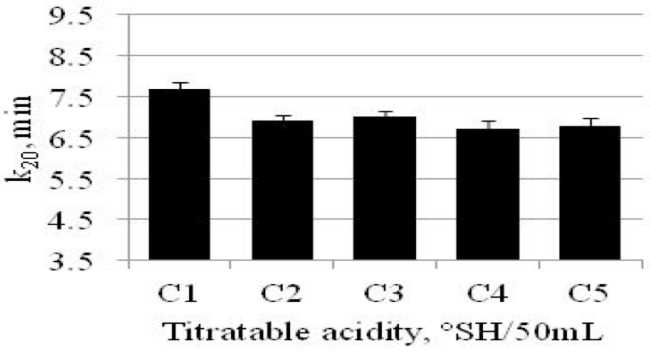
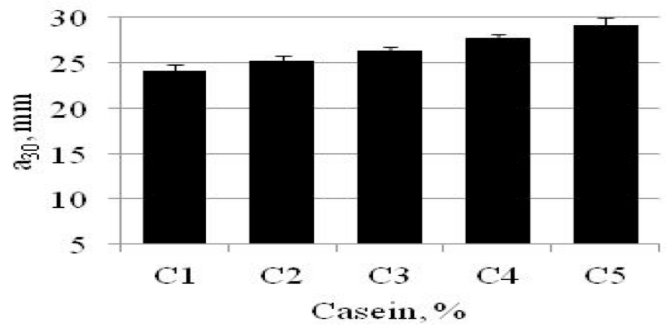


(a)



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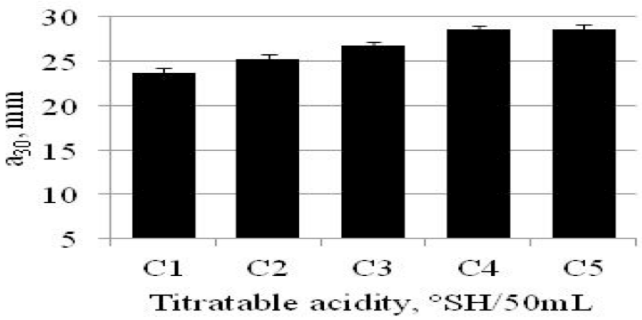
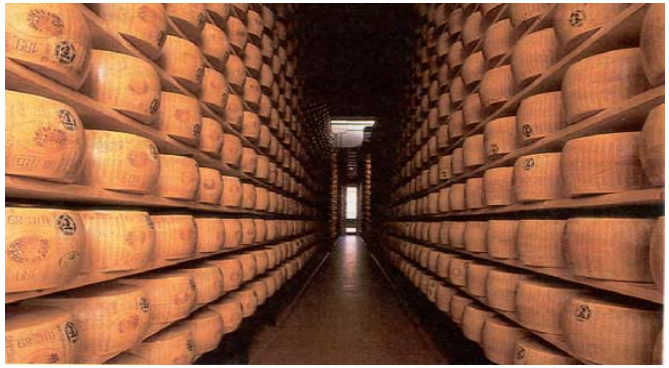
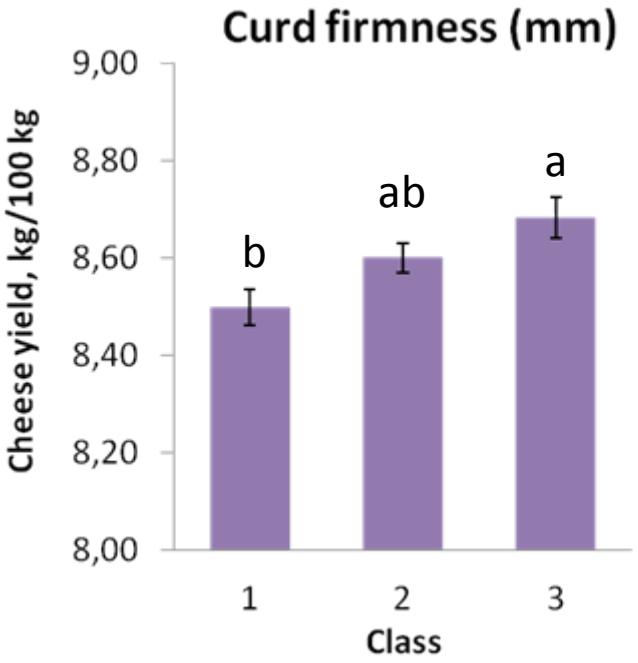


MCP and Dairy Industry: Cheese Yield

		Cheese yield	
Effect[1]	df	SS	P-value
Cheese-making day	11	1.246	<0.0001
Milk fat, %	2	0.525	<0.0001
Milk protein, %	2	0.446	0.0002
TA, SH°/50 mL	2	0.383	0.0006
a30, mm	2	0.175	0.0277

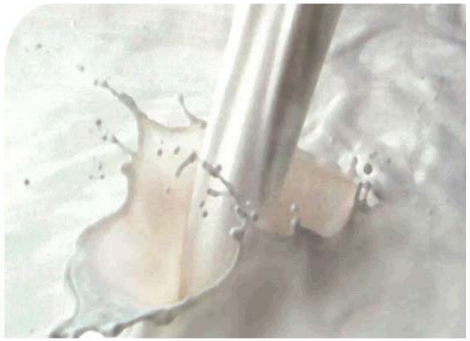




Mean per class: 20.52 - 26.05 - 31.88

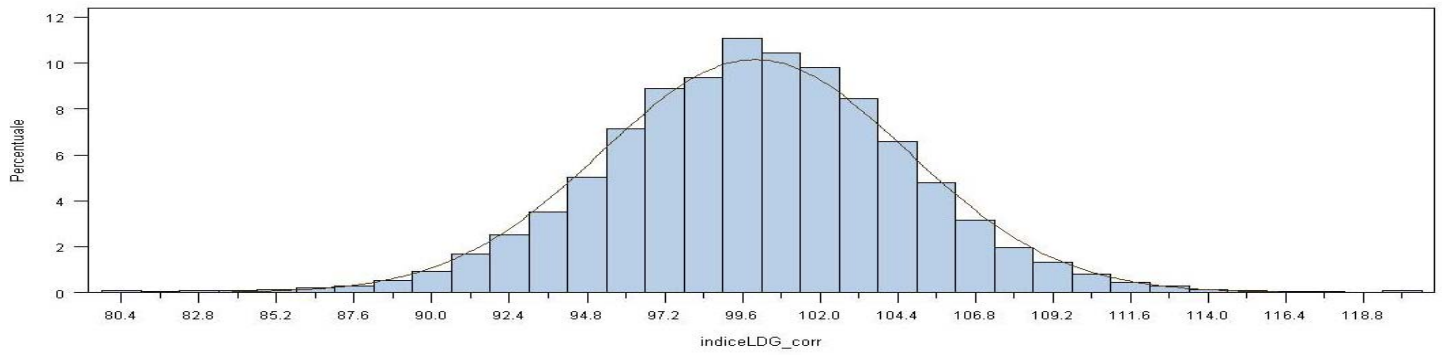
Pretto et al. - Submitted

MCP and Milk Payment System



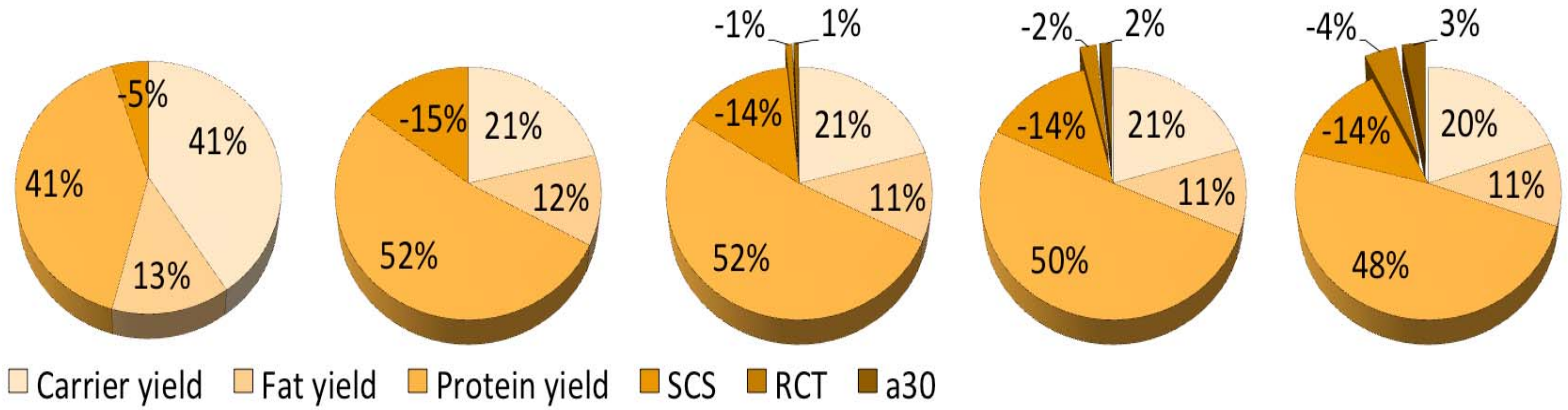
TOTAL INDEX that combine RCT and a_{30}

$$= 100 + \left[\left(\frac{A30 - \text{mean } a_{A30}}{sd\ A30}\right) * 2.5 - \left(\frac{R - \text{mean } r}{sd\ R}\right) * 2.5\right]$$



MCP and Economic Value of MCP under different milk payment systems

Relative Economic Value for the traits standardized by genetic standard deviation (Pretto et al. 2010)



PS_{milk}	PS_{cheese}	$PS_{MCP1\%}$	$PS_{MCP2.5\%}$	$PS_{MCP5\%}$

The weight for MCP ranged from 1.6 to 7.4 % (sum of absolute weight for RCT and $_{a30}$), when the effect on cheese yield ranged from 1 to 5 % from the worst and the best MCP.

Conclusion and Implication

Milk Coagulation Properties (MCP) are depleting and are an important target for improvement in the dairy sector.

Several sources of variation of MCP were detected and quantified.

MIR models showed good predictions for MCP.

The MCP are fairly good for predicting in cheese yield (e.g. Grana Padano).

The Economic Value of MCP should be about 7-8% of the milk price and it is likely to increase if will increased consumption of dairy products and if it will worsen the characteristics of dairy milk.

The development of MCP are indispensable for italian dairy chain.

The model and methods applied for these traits (MCP) and research experience of the Veneto dairy chain might be applied for more novel milk traits with the aim to design a new italian dairy system.

Acknowledgement

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Dott. Marco Cesari

THANK YOU
for
your ATTENTION

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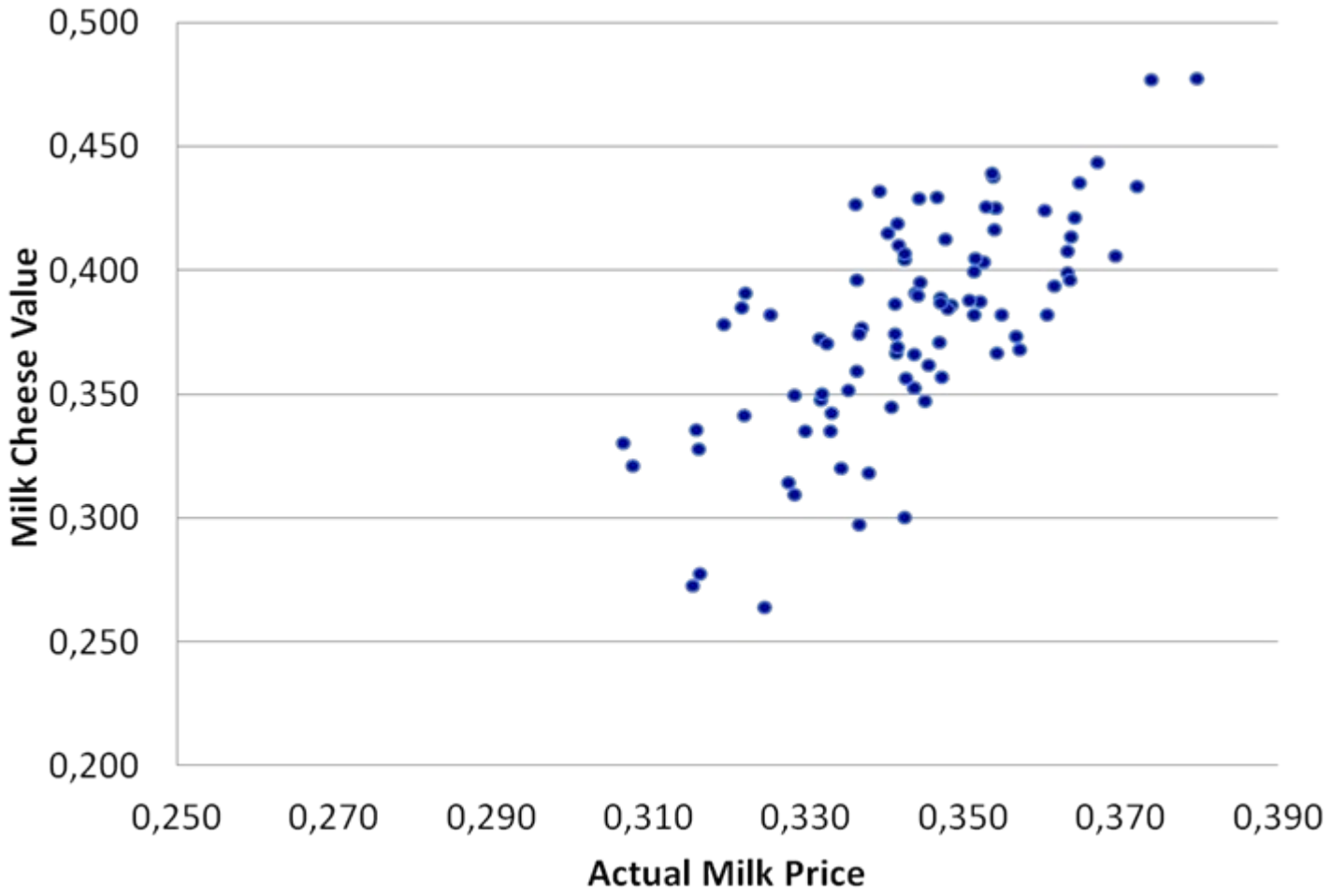
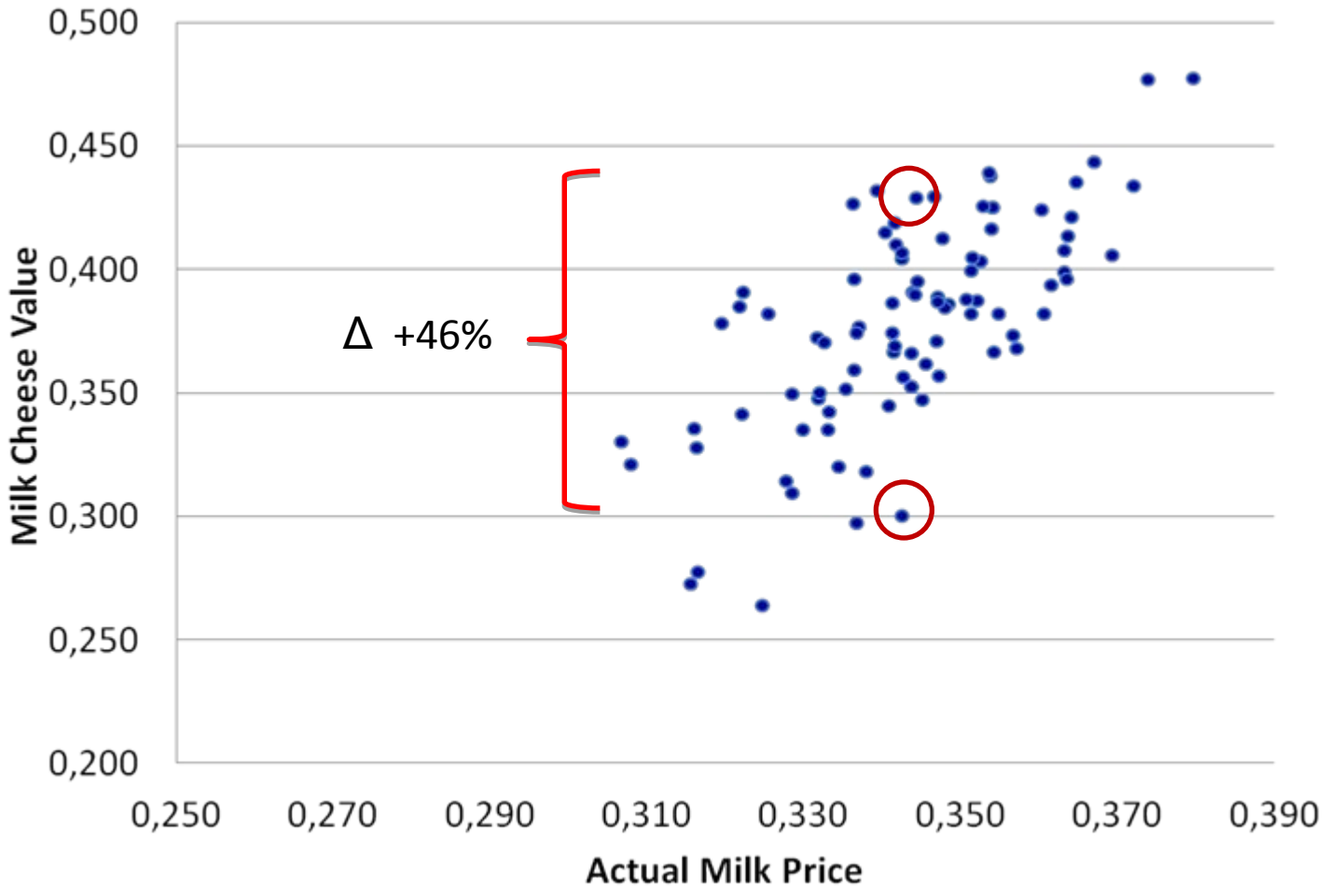
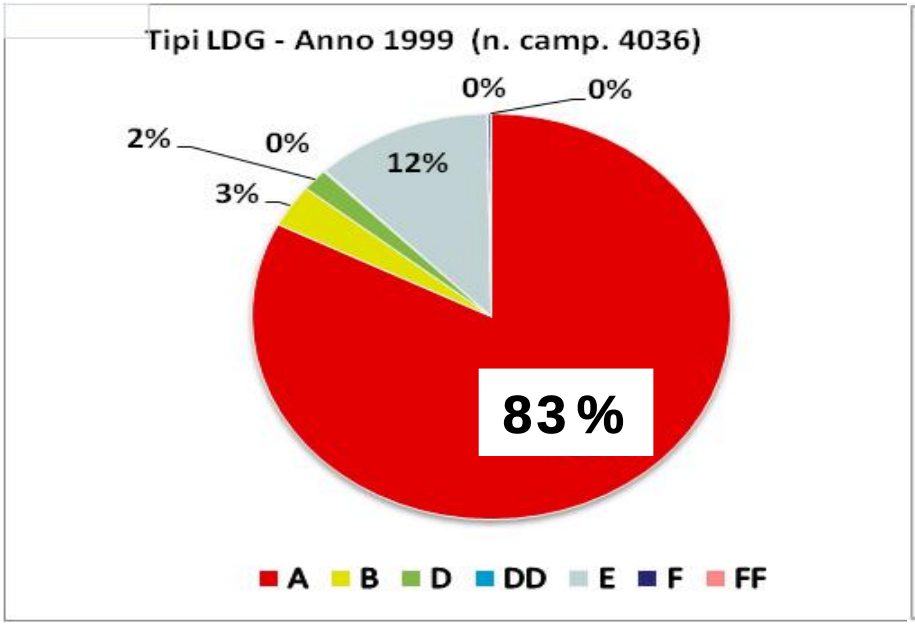
VALUE of CHESSE YIELD and actual MILK PRICE

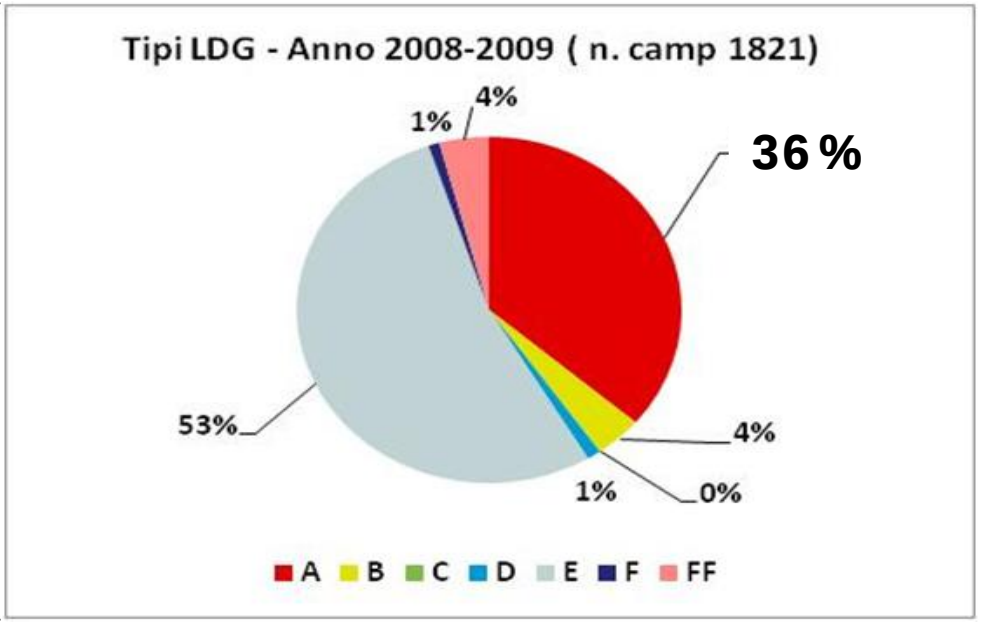


At HERD LEVEL the comparison between VALUE of CHEESE YIELD actual MILK PRICE



MCP in the last 10 years in VENETO





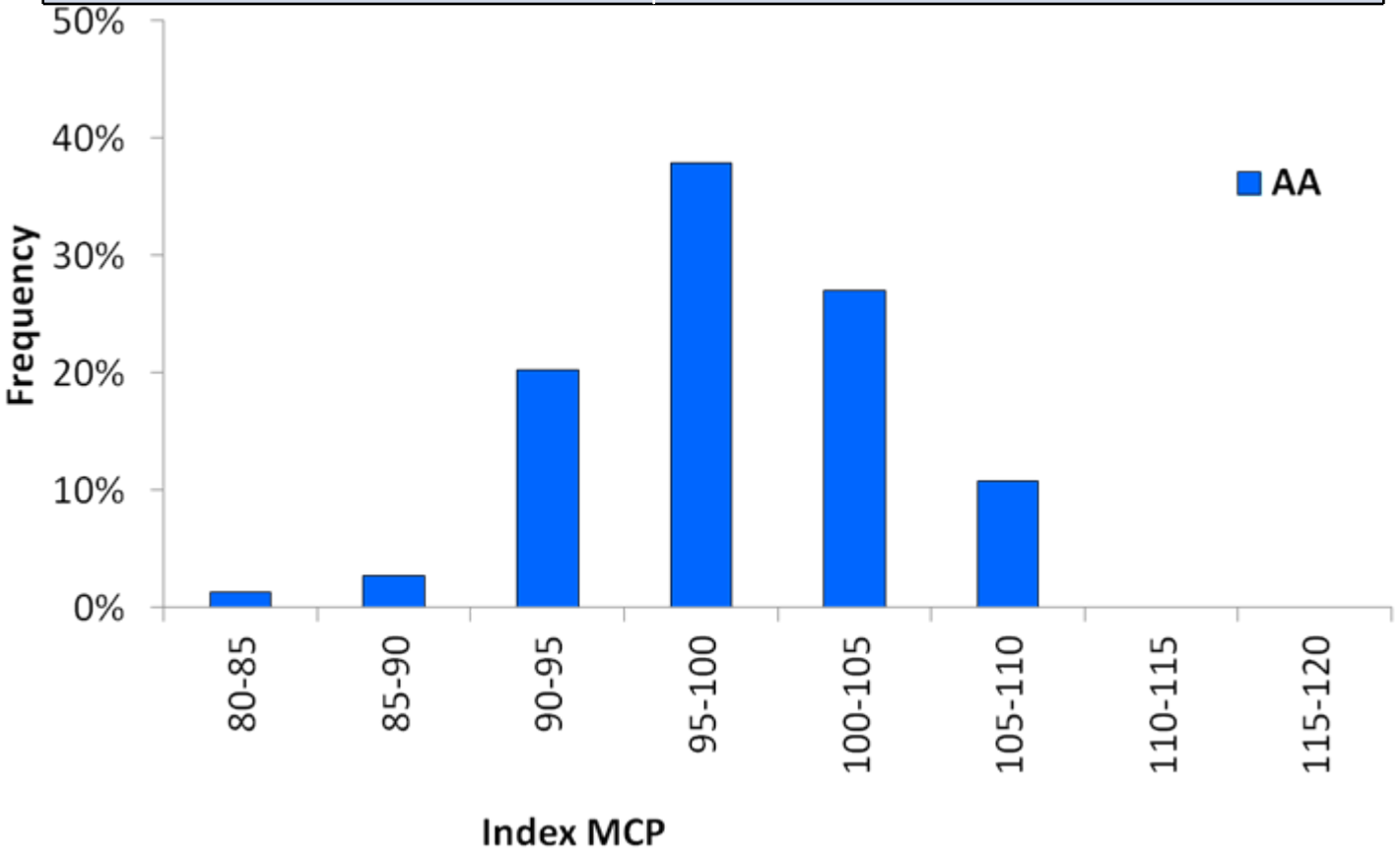
Tipe of LDG	2008-2009			1999		
	r (min)	a 30 (mm)	caseina %	r (min)	a 30 (mm)	caseina %
A	15,77	32,36	2,60	15,314	32,92	2,61
B	19,15	35,18	2,76	19,29	29,21	2,7
D	8,53	39,5	2,44	10,69	40,55	2,62
E	21,25	22,5	2,52	19,69	24,46	2,52
F	> 30,00	< 10,0	2,47	> 30,00	< 10,0	2,49

Relation among MCP index and Protein polymorphism

	MCP index	K- casein	Beta-Lactoglobulin
ACTIVE		AB	AB
BROSIO		AB	BB
DUKO		AA	AB
LAMBRO		BB	AB
MISIS		AB	BB
PASSIRIO		AA	BB
PRINCE		AB	AB
PURPOSE		AA	AB
QUASIMO		AB	AB
SITTAX		AB	AA
TABAIBA		AA	AA
WATHA		AB	AA

❑ Comparison among bulls: k-caseina

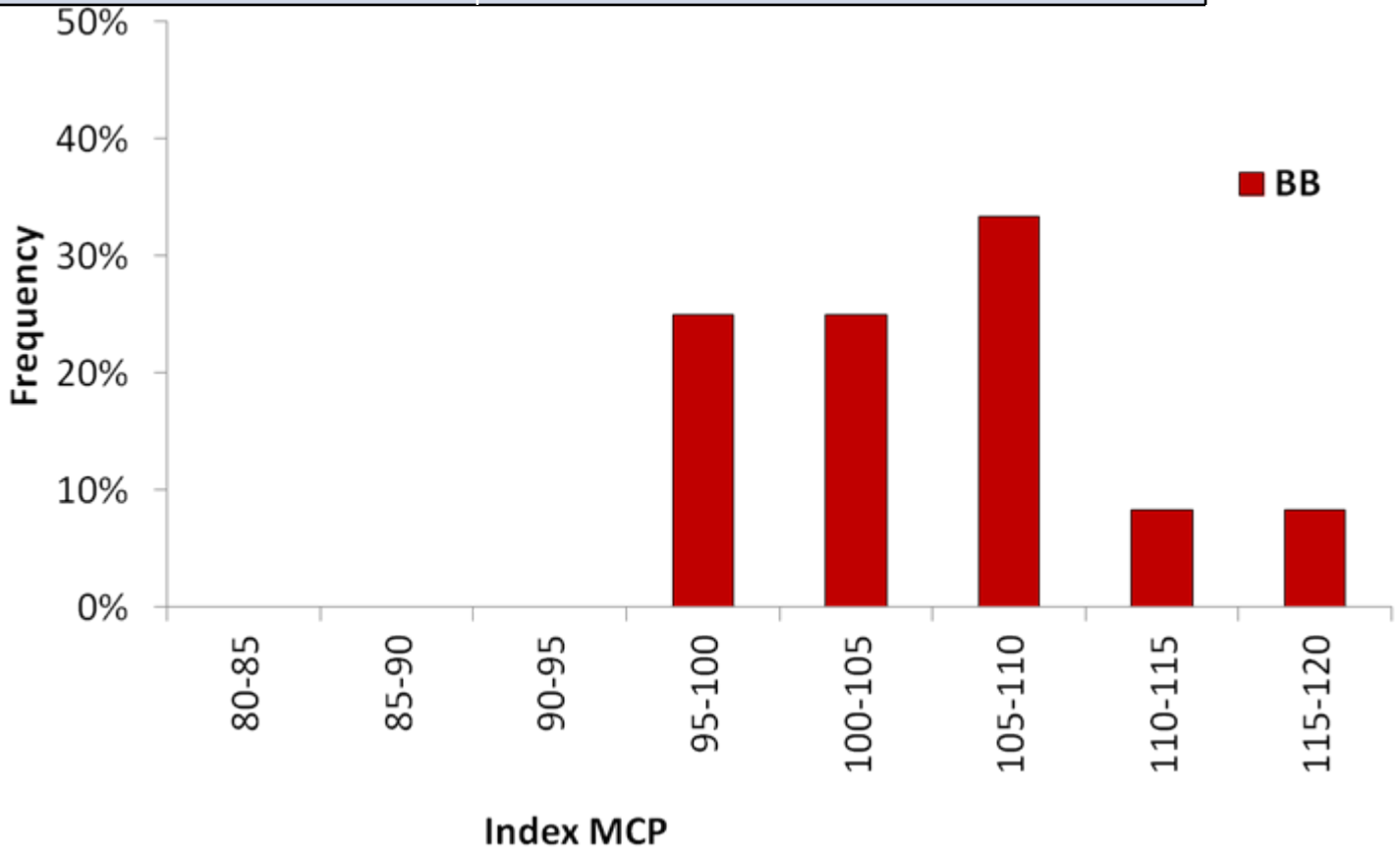
Allele k-casein	Mean MCP
AA	98,4
AB	101,7
BB	105,0



❑ Comparison among bulls: k-caseina

Allele k-casein	Mean MCP
AA	**98,4**
AB	**101,7**
BB	**105,0**

Mean of all 140 bulls evaluated



❑ Comparison among bulls: k-casein

Allele k-casein	Mean MCP index
AA	98,4
AB	101,7
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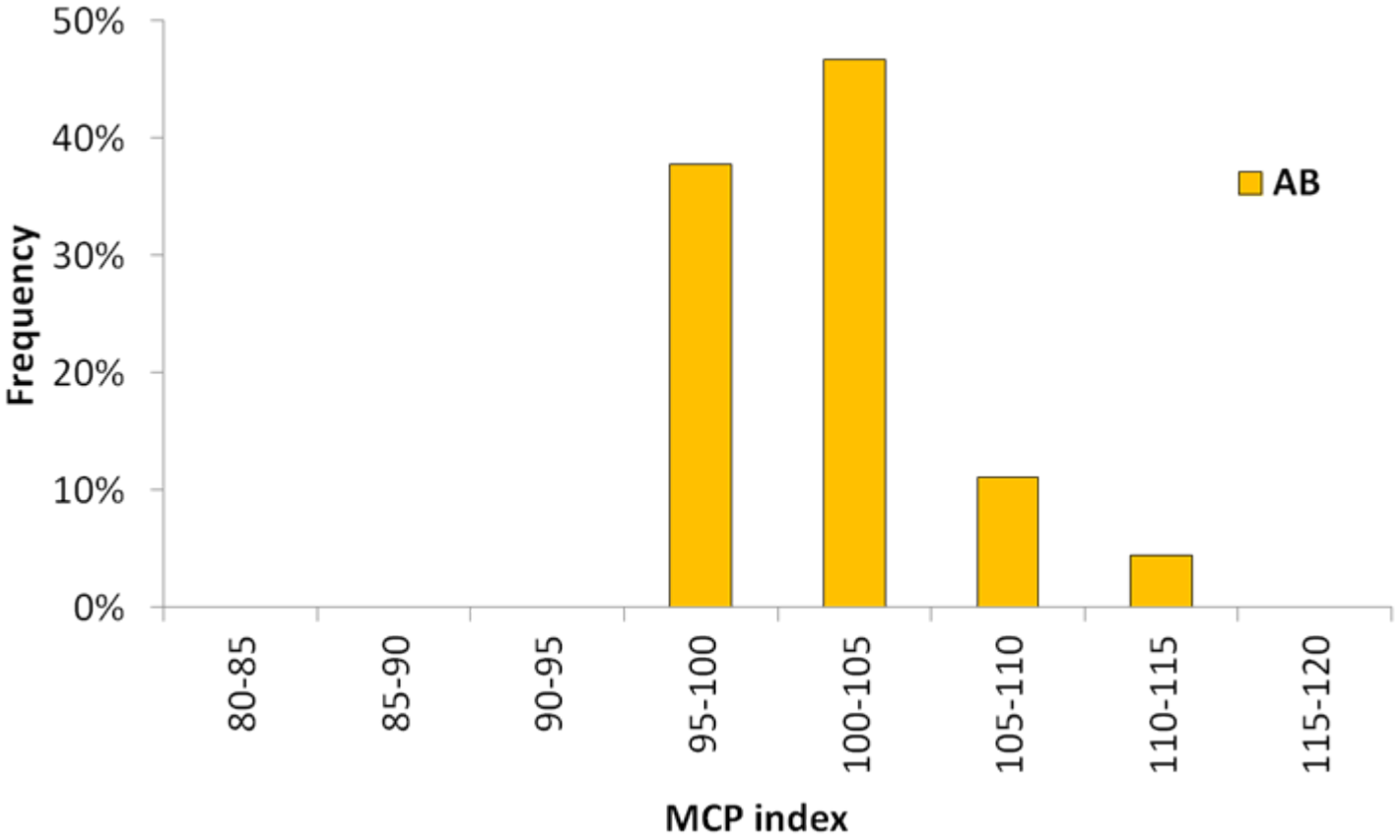
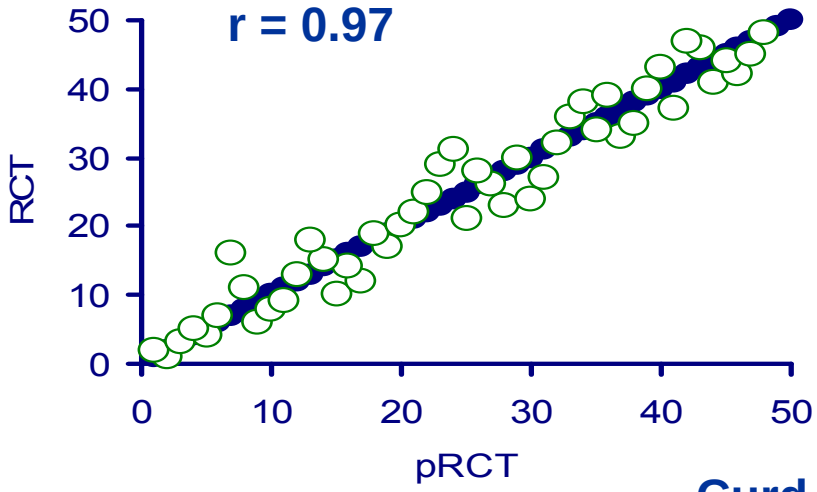
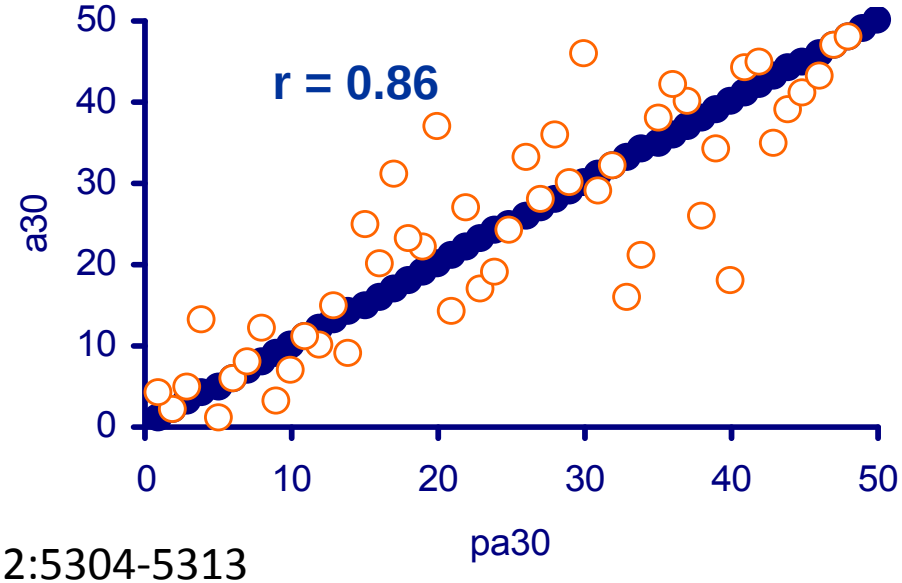


Relationships between sire rankings for RCT observed and predicted

Rennet coagulation time



Curd firmness



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Heritablity of MCP measures (CRM) and predictions (MIR)

Traits	h^2	s.e.
Rennet coagulation time (**RCT**)		
- measured (CRM)	0.32	0.08
- predicted (MIR)	0.37	0.10
Curd firmness ($\mathbf{a_{30}}$)		
- measured (CRM)	0.24	0.07
- predicted (MIR)	0.35	0.10

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Genetic (r_A) and phenotypic (r_P) correlations

Correlations	r_A	r_P
Rennet coagulation time (**RCT**)		
- measured with predicted	0.93	0.67
Curd firmness ($\mathbf{a_{30}}$)		
- measured with predicted	0.77	0.51

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