Statistical Indicators
E-47
Breeding value Resilience

Introduction

Even though the management and climate within a farm is often equal for all cows, not all cows respond equally to conditions of the environment. There are cows that have a stable milk production regardless of environmental conditions. Potentially disruptive conditions such as a warm period or a rainy day during the grazing season do not seem to bother the cow much. Some cows do respond to these disruptive conditions, resulting in a decreased milk production. When the disturbing circumstance ends, the cow will increase her milk production. This leads to fluctuating milk productions from day to day. Ideally, a cow has a stable milk production, and the environmental conditions have no or a minimal effect on milk production. These are resilient cows. Resilience describes the resistance of an animal, meaning the extent to which an animal can cope with disturbances such as diseases or heat stress (Poppe, 2022). Improving resilience is important for animal welfare and beneficial for dairy farmers who want easy manageable cows.

If an animal does suffer from the disturbances, this may also already be manifested by, for example, udder inflammation, lameness or metabolic disorders. The trait resilience is for 55% already expressed in traits for which breeding values are already available (e.g. udder health, claw health, subclinical ketosis, longevity), which means that for 45% of the trait, resilience is not yet taken into account. Since April 2024, Cooperation CRV therefore publishes breeding values for resilience, so that cattle farmers in the Netherlands and Flanders can breed on resilient cows.

The genetic effect of the cow, the breeding value, can be calculated using data on resilience. By using a statistical animal model, environmental factors that influence a cow's resilience are taken into account. This E-chapter will discuss the calculation of the breeding value resilience. Furthermore, presentation, interpretation and publication will be discussed.

Data

The characteristic resilience is derived from the differences between expected daily milk production and actual daily milk production of a cow, based on information from Automatic Milking Systems (AMS) or from a parlour with electronic milk measurers (EMM). Thus, at the base of the resilience trait are individual milkings from the AMS or EMM. The individual milkings are summed into a daily production (24-hour production), which is the base of the resilience trait that applies at lactation level.

The requirement for a milking to be included in the breeding value estimation are:

1. milkings are recorded as 'complete and valid'*;

The requirements for a daily production to be included in the breeding value estimation are:

2. the calculated daily productions are 'valid'**;

3. the calculated daily productions are not more than 6 standard deviations above the average milk production belonging to an animal in the same lactation with the same lactation stage;

On lactation-level or animal-level, requirements that the final observations for calculation of the resilience traits are;

4. an animal is female, pedigree registered (S) and the cow's sire is known;
5. an animal has a bloodline less than 50% Belgian White-Blue;
6. an animal must have a known residence;
7. an animal must not have moved from herd during lactation;
8. an animal must have an observation for lactation 1;
9. the age at first calving is a minimum of 610 days and a maximum of 1095 days;
10. an animal must have calved for the first time at least 90 days prior to the breeding value estimation;
11. an animal has at least 50 days with a known milk yield between day 11 and day 341 in lactation;
12. between the first and last lactation day with a known milk yield, at least 70% of the days must have a known milk yield;

On top of that, for the observations:

13. observations of the animal must not deviate more than four standard deviations from the average for the respective trait in the population.

**A milking is complete and valid if the milking interval with the previous milking is maximum 24 hours, and the milking must be registered as 'complete' by the AMS or EMM. A milking registered as 'incomplete' is removed from the data only if more than three days in a row all milkings are registered as 'incomplete'.*

***A daily production is valid if 1.) it is not the first day in lactation, 2.) all milkings on that day are 'complete and valid'.*

▪ Characteristics

There are two characteristics that indicate the resilience of a cow; the speed with which a cow recovers her milk yield after a disturbance to the level before the disturbance took place (recovery), and the extent to which a cow's milk yield varies with disturbances (stability). Herewith, faster recovery after disturbances and less variation in milk production during disturbances mean higher resilience.

Observation
For each cow with known milkings from an AMS or EMM, milk production on a given day can be calculated if both the milking interval with the previous milking and the milk yield are known. The daily productions serve as the base for creating a lactation curve over the days for which a daily production is known. Here, the lactation curve is estimated based on a polynomial quantile regression. Thus, the curve is nonlinear, and by using a quantile of 0.7, the assumption is that the daily productions that are calculated have been affected by disturbances, so that the cow could have actually achieved a somewhat higher production than was actually achieved. The curve is determined up to a lactation length of 350 days. Figure 1 shows how this looks graphically. The blue line here is the milk yield the cow

actually produced, the orange line is the milk yield based on the polynomial quantile regression.

Then, for each day for which a milk production is known, the difference between the actual amount of milk produced (kg) and the estimated milk yield according to the polynomial quantile regression is calculated. We call this difference the deviation. Only data from a lactation length of 11 days in milk to 340 days in milk are used to calculate the traits. This means that the first 10 days of lactation and days 341-350 are used to create the lactation curve, but are not used for the final calculation of the trait. A graphical representation of the deviations is shown in Figure 2, representing the same cow (and the same lactation) as in Figure 1.

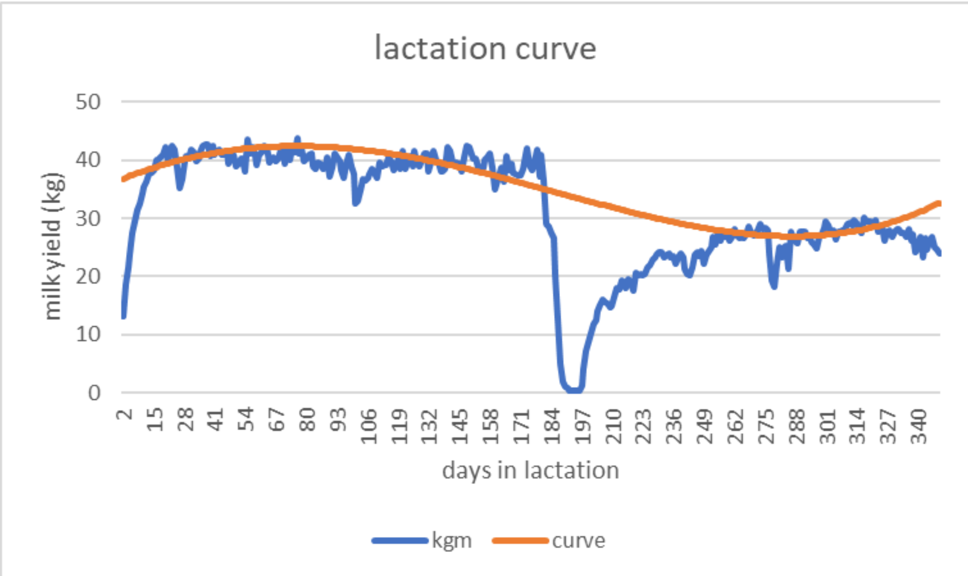

Figure 1. Polynomial quantile regression (curve) based on daily milk yield (kgm).

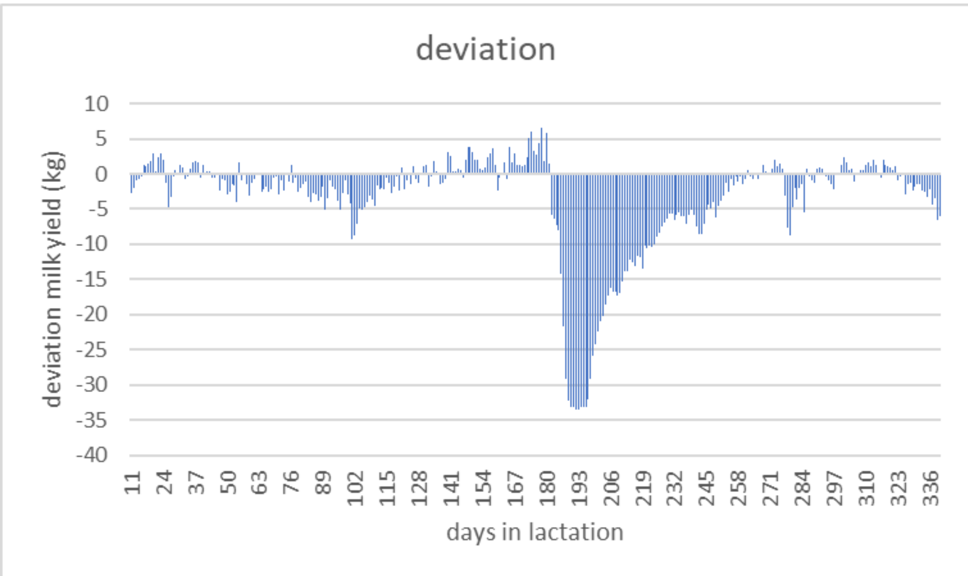

Figure 2. Deviation in milk yield between daily milk yield and expected daily milk yield based on polynomial quantile regression.

A trait is calculated for a cow only if the cow has at least 50 days with a known milk yield between day 11 and day 341 in lactation. In addition, between the first day in lactation and the last day in lactation with a known milk yield, at least 70% of the days must have a known milk yield. This is because the lactation curve becomes inaccurate if too many days are missing.

Trait - recovery
For the trait recovery, each deviation is compared to the deviation one day back. This is a so-called "lag 1 autocorrelation" (Rauto). This involves calculating a correlation between a series of observations over a period of time (deviations in milk yield per day over a lactation) and the same observations one day back in time. By definition, the results of a correlation are between -1.0 and +1.0.

A cow that encounters no disturbances during lactation will have an estimated lactation curve that nearly matches actual daily productions. One day the milk production will be just below the curve, the next day just above. So the deviations fluctuate from day to day around the curve, therefore the deviations from day to day are not very similar, resulting in a low autocorrelation.

If a cow has encountered a disturbance resulting in declining milk production, the deviation for that day will be negative. If the cow does not recover quickly, then subsequent days will all have negative deviations as well. Thus, the successive deviations from day to day are very similar, resulting in a high autocorrelation.

If the cow encounters a disturbance that leads to declining milk production, but then the cow does recover after one or a few days, then the successive deviations are not similar, resulting in a low autocorrelation.

A low value for the trait recovery indicates that the cow is able to quickly return to their original production level, while a high value on the other hand, indicates that the cow takes a long time to return to their estimated production level.

Trait - stability

For the trait stability, the deviations for all days are squared, and then all squared deviations are summed up. This is called the sum of squares. This sum of squares is divided by the number of days with a known milk yield minus one. The result of this is the variance. Then natural logarithm of the variance is taken, and the result of this is the characteristic stability (LnVar). By taking the natural logarithm of the variance, the observations of the trait stability have a better normal distribution, which is a prerequisite for breeding value estimation.

Cows that deviate from the lactation curve more often and more than average due to disturbances will have large deviations, resulting in a higher variance and ultimately larger LnVar. Thus, a high value for the trait stability is a sign that the cow is not very resilient, a low value here indicates resilient animals.

The trait stability is affected by the average milk production per cow. If a cow has a deviation from the estimated milk production of 5% on that day, the deviation is 1 kilogram for a cow with a production of 20 kilogram per day and 3 kilograms for a cow with a production of 60 kilograms. A larger deviation creates more variance (due to squaring). To account for this, a correction for milk production in the animal model for stability is done.

- ## Breeding Values

Four breeding values are estimated for each lactation: recovery and stability for cows milked in an AMS, and recovery and stability for cows milked in EMM. This is done for lactation 1, lactation 2 and lactation 3+ (observations in lactation 3 and above are combined into one breeding value). Thus, a total of 12 breeding values are estimated (2 traits x 2 milking systems x 3 lactations).

A distinction is made between cows milked in an AMS and EMM because the resilience characteristics from both milking systems are not the same. Cows milked in an EMM are milked at a fixed frequency so disturbances do not affect the number of milkings per day, whereas cows milked in an AMS may be affected. The final milking interval affects milk yield. In addition, an AMS normally records all milkings, even from cows whose milk is separated (e.g. in case of antibiotic treatment), whereas in an EMM separated milk is not always recorded. Precisely these milkings are expected at times when a cow is subject to a disturbance. By missing valuable data, variation in phenotype is lost.

- ## Phenotype

The phenotypic statistics of the traits are shown in Table 1. The traits here are also split to lactation 1, 2 and 3+. Observations that deviate from the mean by more than four standard deviations are excluded from the breeding value estimation and thus these observations are also not included in the table.

Table 1. Phenotypic statistics for the resilience traits recovery and stability for three different lactations and two different milking systems (3+ is lactation 3 and higher).

trait	mean	std.dev.	minimum	maximum
recovery 1 ams	0,59	0,19	-0,27	0,98
stability 1 ams	1,53	0,64	-1,16	3,95
recovery 1 emm	0,47	0,19	-0,26	0,97
stability 1 emm	1,69	0,69	-0,66	3,75
recovery 2 ams	0,59	0,18	-0,28	0,99
stability 2 ams	1,82	0,67	-0,95	4,32
recovery 2 emm	0,47	0,18	-0,22	0,97
stability 2 emm	1,95	0,70	-0,41	4,01
recovery 3+ ams	0,58	0,19	-0,38	0,98
stability 3+ ams	2,05	0,70	-0,86	4,74
recovery 3+ emm	0,47	0,18	-0,27	0,97
stability 3+ emm	2,13	0,70	-0,24	4,25

The cow in Figure 1 and Figure 2 has an Rauto (recovery) of 0.97 and a LnVar (stability) of 4.2. These values are very high compared to the mean, and because high values indicate non-resilient animals, this animal cannot be called resilient. This is because the dip in deviations is deep and recovery from this dip takes a long time.

- ## Use of pedigree

The use of parentage in the animal model for resilience is similar to that in the breeding value estimation for milk production traits. See Chapter E-7 for this.

- ## Statistical model

The statistical model for resilience is split into a model for lactation 1 and 2 and a model for lactation 3+. The statistical model for lactation 1 and 2 looks as follows:

$$Y1_{ijklmnoprs} = HYS_i + DIM_j + AFC_k + KF_s + KGM_l + HET_m + REC_n + INB_o + A_p + Rest_{ijklmnoprs}$$

And the model for lactation three and up is:

$Y2_{ijklmnopqrs}$ = $HYS_i + DIM_j + LAC_k + KF_s + KGM_l + HET_m + REC_n + INB_o + A_p + PME_q +$ $Rest_{ijklmnopqrs}$

Where:

$Y1_{ijklmnoprs}$: observation on herd*year*season *i*, with lactation days *j*, age at first calving *k*, deviation in milk production from farm average *s*, average milk production *l*, heterosis effect *m*, recombination effect *n*, inbreeding effect *o*, to animal *p* in lactation 1 or lactation 2;

$Y2_{ijklmnopqrs}$: observation on herd *year*season *i*, with lactation days *j*, lactation *k*, deviation in milk production from farm average *s*, average milk production *l*, heterosis effect *m*, recombination effect *n*, inbreeding effect *o*, permanent environmental effect *q*, to animal *p* in lactation 3 or higher;

HYS_i : herd * year * season *i*;

DIM_j : days in lactation *j*;

AFC_k : age at first calving *k*;

LAC_k : lactation *k*;

KF_s : deviation in milk production from farm average effect *s*;

KGM_l : milk production effect *l*;

HET_m : heterosis effect *m*;

REC_n : recombination effect *n*;

INB_o : inbreeding effect *o*;

A_p : additive genetic effect of animal *p*;

PME_q : permanent environmental effect *q*;

$Rest_r$: residual term *r* of that which is not explained by $Y_{ijklmnopqs}$ and $Y_{ijklmnopqs}$.

Effects A, PME and Rest are random, effects HET, REC and INB are covariables, the remaining effects are fixed. Fixed effects KF and KGM are added to the model for the trait stability.

Pre-correction for dispersion per average daily production (kilograms of milk)
Before observations are used in the model, a correction is made for the dispersion of these observations within the class of average daily production in kilograms of milk per day to which the observation belongs. The purpose is to standardize the dispersion of the observations, because with higher average daily production, the observations have more dispersion. The formula used to standardize the dispersion is as follows:

$S^* = (S - Min)*(STD_{tot}/STD_{in})+Min$

Where:

S* = Standardized observation

S = Observation for characteristic before pre-correction takes place

STD_{tot} = Spread of all observations per trait per average daily milk production

STD_{in} = Spread of all observations

Min = Average score for characteristic per average daily milk production

The effects in the model

The eleven effects in the model are:

1. herd * year * season;
2. days in lactation * 3 years;
3. age at first calving * 3 years;
4. parity * 3 years;
5. deviation in milk production from herd mean * 3 years;
6. average milk production;
7. heterosis;
8. recombination;
9. inbreeding;
10. additive genetic effect or breeding value;
11. permanent environmental effect.

To make the effects days in lactation, age at first calving, lactation number and deviation in milk production from herd mean time dependent, the effects are divided into groups of three years based on the number of years available in the data. Age at first calving applies to the model in lactation 1 and lactation 2, parity applies only to the model in lactation 3.

*Herd * year * season*
Each herd * year * season combination forms a new class in the model. Year and season are the year and season of first calving. Thus, within this class, animals are compared with each other that calved for the first time in the same period on the same herd. Each herd is managed on their own way, which this effect corrects for in the animal model.

*Days in lactation * 3 years*
Not for all cows in the data, all 350 lactation days have a known milkyield. The data may be missing, or the cow was culled at a lactation length less than 350 days. Cows with less data have therefore less risk to be affected by a disturbance. This is corrected for in the model by dividing days in lactation into 7 classes, classified by a minimum lactation length of at least 50, 91, 131, 171, 211, 251 or 291 days.

*Age at first calving * 3 years*
Each age at first calving in months * 3 years constitutes a new class in the model. Animals calving for the first time at 1 year and 8 months of age are still developing, while animals calving for the first time at 2 years and 11 months of age are much further along in their development and need to expend much less energy on their development. On the other hand, animals calving for the first time at a later age may again suffer more from metabolic disorders due to fatigue. Age at first calving thus affects how animals distribute their energy, and how they can cope with disruptive influences. Therefore, age at first calving is taken into account for the traits in lactation 1 and lactation 2.

*Parity * 3 years*
The calving moment in lactation 3 is two years or more after the moment of first calving. For cows in later parities this time period is even longer. Age at first calving is therefore less of an influence in later parities. To still take into account age effects and effects that dry period/calving has on the health and physical state of the cow, the lactation number is taken into account for traits in lactation 3+.

*Deviation in milk production from herd mean * 3 years*
The effect deviation in milk production from herd mean, is added to the model for the trait stability. It is necessary to take this into account because a milk production of 9,000

kilograms in a herd with an average production of 12,000 kilograms is easier to achieve than a milk production of 12,000 in a herd where the average is 9,000. This therefore affects the cow's resilience. Both the average daily milk production of the cow and the herd are divided into groups of 1 kilogram, and thereafter they are converted to 305-day productions. Milk productions per day are based on the estimates from the polynomial quantile regression.

Average milk production
The effect average milk production, is added to the model for the trait stability to take into account the average milk production (kilograms of milk per day) of a cow during the days with a known milk yield. For example, if a cow only has dates between day 250 and day 350 in lactation, then the average milk production per day is taken between day 250 and day 350 in lactation. The milk production is based on the estimated milk production according to the polynomial quantile regression.
The average daily milk production in lactation 1 is 27 kilograms, in lactation 2 it is 32 kilograms and in lactation 3 and above it is 35 kilograms.
It is necessary to take average milk production into account because statistically higher values easily have higher variance. Indeed, a 5% variance for a milk production of 60 kilograms is greater in absolute terms than the same 5% variance for a milk production of 20 kilograms of milk.

Heterosis
Heterosis plays a role in crossbreeding. It is a genetic effect that is not transmitted to the offspring. Research has shown that a correction must be made for heterosis. The amount of heterosis is defined as the difference in level or trait in the crossing, with the average of the parent breeds. For the formula of heterosis, see Chapter E-7. The effect of heterosis is greatest on the trait recovery 3+ emm. Here, one percentage increase in heterosis leads to a decrease in breeding value on a relative scale of 0.026.

Recombination
Recombination is the loss of the usually positive effect of heterosis, and occurs when the earlier achieved crossing product is crossed back with one of the parent breeds. For the formula of recombination, see Chapter E-7. The effect of recombination is greatest at stability 3+ emm. Here, one percentage increase in recombination leads to a decrease in breeding value on a relative scale of 0.014.

Inbreeding
Inbreeding is the making of a mating between two animals whose DNA is more related to each other than the average relatedness in the population. Therefore, inbreeding leads to an increase in homozygosity. By comparing inbred animals with non-inbred animals on a trait, the (negative) effect of inbreeding can be estimated. Inbreeding is not heritable. The effect of inbreeding is greatest at stability 2 emm. Here, one percentage increase in inbreeding leads to an increase in breeding value on relative scale of 0.086.

Additive genetic effect
The additive genetic effect (or animal effect) is the breeding value. This effect contains the genetic contribution of an animal to the observation and determines the breeding value of an animal. In addition, all information from ancestors and offspring is also used in determining the breeding value. Principles of breeding value estimation are explained in Chapter E-7.

Permanent environmental effect

For traits in lactation 3+, an animal can have multiple observations, for example an observation in lactation 3, lactation 4 and lactation 5. The observations of the resilience of one cow are determined by the additive genetic effect as well as all other effects as discussed above. When there are multiple observations on one animal, the observations have more in common than just the additive genetic effect. This extra similarity is called the permanent environment effect, an effect of the constant circumstance a cow is in. For example, if the cow has already suffered a lung injury in her rearing, this may have an effect on the resilience when the cow is in lactation later on. However, this is not a genetic effect, nor is it among the other fixed effects in the model. Through the use of a permanent environmental effect in the model, multiple observations on an animal can be used to arrive at a better estimate of the breeding value.

The additive genetic effect and the permanent environmental effect are random effects, which means that the amount of information available on an animal can be taken into account. If there is little information about an animal (few offspring and few observations on the animal), the additive genetic effect will not deviate much from the parental average and the permanent environment effect will not deviate much from 0.

- ## Heritability and variance components

Table 2 summarizes the genetic, permanent environment, and error ("residual") variance for each resilience trait, followed by the heritability and repeatability of the trait. The observations are multiplied by 1000, so an observation of 1.521 for the trait stability becomes 1,521. This can also be seen in the size of the variance components.
Table 3 shows the heritabilities of the resilience traits (on the diagonal), and the genetic correlations between them.

Table 2. Genetic (gen), permanent environment (pme) and rest (err) variance (var), heritability (h^2) and repeatability (r^2) for the resilience traits.

	gen. var.	pme. var.	err. var.	h^2	r^2
recovery 1 AMS	1,675	-	23,501	0.07	-
stability 1 AMS	23,653	-	239,188	0.09	-
recovery 1 EMM	797		20,354	0.04	-
stability 1 EMM	9,599	-	185,319	0.05	-
recovery 2 AMS	1,004	-	23,065	0.04	-
stability 2 AMS	18,114	-	269,010	0.06	-
recovery 2 EMM	700	-	20,828	0.03	-
stability 2 EMM	10,232	-	186,952	0.05	-
recovery 3+ AMS	948	3,108	21,957	0.04	0.16
stability 3+ AMS	30,767	40,583	266,745	0.09	0.21
recovery 3+ EMM	583	1,826	21,747	0.02	0.10
stability 3+ EMM	10,095	21,704	206,184	0.04	0.14

The heritability degree for recovery AMS is 0.07 in lactation 1, 0.04 in lactation 2 and 0.04 in lactation 3+. For recovery EMM, the heritabilities are somewhat lower, at 0.04, 0.03 and 0.02 in lactation 1, 2 and 3+, respectively.

For stability AMS, heritabilities are 0.09 in lactation 1, 0.06 in lactation 2 and 0.09 in lactation 3+. For stability EMM, heritability degrees are somewhat lower, at 0.05, 0.05 and 0.04 in lactation 1, 2 and 3+, respectively.

Besides the lower heritability degree for the traits based on cows milked in an EMM, both the genetic variance and also the residual variance are lower in absolute terms compared to those of the traits based on cows milked in an AMS. This shows that recovery and stability from the different milking systems should also be considered as different traits.

Table 3. ***Heritability*** *on the diagonal and genetic correlations below the diagonal for resilience traits.*

	recovery 1 ams	stability 1 ams	recovery 1 emm	stability 1 emm	recovery 2 ams	stability 2 ams	recovery 2 emm	stability 2 emm	recovery 3+ ams	stability 3+ ams	recovery 3+ emm	stability 3+ emm
recovery 1 ams	**0.07**											
stability 1 ams	0.08	**0.09**										
recovery 1 emm	0.76	0.57	**0.04**									
stability 1 emm	0.25	0.90	0.39	**0.05**								
recovery 2 ams	0.98	-0.23	0.54	0.21	**0.04**							
stability 2 ams	-0.07	0.98	0.47	0.80	0.11	**0.06**						
recovery 2 emm	0.69	0.57	1.00	0.21	0.63	0.57	**0.03**					
stability 2 emm	0.21	0.72	0.18	0.94	0.39	0.88	0.43	**0.05**				
recovery 3+ ams	0.84	0.18	0.48	0.35	1.00	0.23	0.74	0.38	**0.04**			
stability 3+ ams	0.14	0.91	0.37	0.70	0.15	0.98	0.54	0.65	0.21	**0.09**		
recovery 3+ emm	0.71	0.54	0.90	0.16	0.69	0.45	1.00	0.24	0.35	0.02	**0.02**	
stability 3+ emm	0.21	0.80	0.05	0.97	0.22	1.00	0.07	0.99	0.30	0.91	0.11	**0.04**

Similarly, the genetic correlations between corresponding traits between the AMS and EMM also show that observations from the two systems do not represent entirely the same trait. The genetic correlation between AMS and EMM for recovery 1 is 0.76, for stability 1 it is 0.90. In lactation 2 it is 0.63 for recovery and 0.88 for stability, and in lactation 3 it is 0.35 for recovery and 0.91 for stability. Thus, the difference in trait between AMS and EMM is greater for recovery than for stability.

Table 4 shows the genetic correlations between recovery and stability and some production, functional and health traits.

Table 4. Genetic correlations for recovery and stability with production, health and functional traits.

	recovery	stability
milk production	-0.14	-0.36
life time production	-0.07	0.17
dry matter intake	-0.06	-0.05
safed feed for maintenance	-0.11	-0.17
fertility	0.08	0.31
ketosis	0.16	0.49
longevity	-0.06	0.33
metabolic disorders	0.14	0.48
claw health	-0.03	0.14
reproduction disorders	0.06	0.15
somatic cell count	0.15	0.45
udder health	0.22	0.50

calf vitality	-0.05	-0.01
rate of maturity	0.12	0.40
persistency	0.04	0.02
body condition score	0.07	0.43

The resilience traits are negatively correlated with milk production and feed intake traits. The genetic correlations with functional and health traits are mostly positive, only recovery has a slightly negative correlation with longevity, claw health and calf vitality and stability has a slightly negative correlation with calf vitality. Taking into account the estimation error, this correlation is not different from 0.0. Stability has higher genetic correlations than recovery, especially the genetic correlations with fertility, ketosis, longevity, metabolic disorders, somatic cell count, body condition score and udder health stand out with values between 0.31 and 0.50. Breeding for resilience thus prolongs herd longevity and a higher life time production of the herd.

▪ Breeding values for publication

The breeding values intended for publication are the overall breeding values for recovery and stability. The overall breeding values recovery and stability are calculated from the breeding values for parity 1, parity 2 and parity 3+ based on AMS milkings. The traits based on AMS milkings have more genetic distribution, a higher heritability and in addition, there are over three times more cows with data from the AMS compared to the number of cows with data from the EMM. The formula for the overall breeding value recovery and stability is as follows:

$EBV_i = 0.41 \times EBV_i1 + 0.33 \times EBV_i2 + 0.26 \times EBV_i3$

Where:
EBV_i : breeding value for recovery and stability.

The derivation of the factors (0.41; 0.33; 0.26) is described in E-chapter 7, milk production. Here the weighing factors for parity1, parity 2 and parity 3 and up were determined.

By combining the parities, more information is used. This is visible in a higher heritability for the overall breeding values compared to the breeding values per parity. The heritability of recovery is 0.123, the heritability of stability is 0.197.

In addition to the two overall breeding values, there is also an index resilience that consists of the overall breeding values recovery and stability. The formula for the index resilience is as follows:

Resilience = 0.30 x (EBV overall recovery – 100) + 0.91 x (EBV overall stability – 100) + 100

The derivation of the factors is based on the weighing factors assigned: 1.0 for recovery and 3.0 for stability. These weighting factors were chosen because of the genetic correlations with functional traits. These genetic correlations are three times higher with most traits for stability compared to that of recovery as shown in Table 4.

The heritability of the resilience index is 0.188.

The overall breeding values and index have a mean of 100 and a standard deviation of 4.

▪ Resilience in practice

Resilience traits are based on autocorrelation (recovery) and natural logarithm of the variance (stability) of the deviation between actual daily milk yield and predicted daily milk yield over the lactation. This makes the traits difficult to interpret. Therefore, a translation was made from the breeding value recovery, to the length of a disturbance in days and from the breeding value stability to the number of disturbances during a lactation.

Figure 3 shows for day 11 to day 340 in lactation (the first 10 and last 10 days are not used in the calculation of traits) the percentage of the actual milk yield compared to the predicted milk yield. Figure 3 is based on the same cow and lactation as in Figures 1 and 2. The horizontal lines in Figure 3 indicate the boundaries for determining a disturbance. Figure 4 is the same as Figure 3 , but the red line here indicates that the cow is in a disturbance. During this lactation, this cow had three disturbances.

A disturbance starts when the cow produces less than 97% of the predicted daily milk production, with at least one daily production below 80% of the predicted daily milk production during the disturbance. The disturbance ends when the daily production rises to more than 95% of the predicted daily production. Five consecutive daily productions with a percentage of predicted milk yield of successively 100, 95, 90, 95 and 100 is not considered a disturbance since all five daily productions remain above 80%.

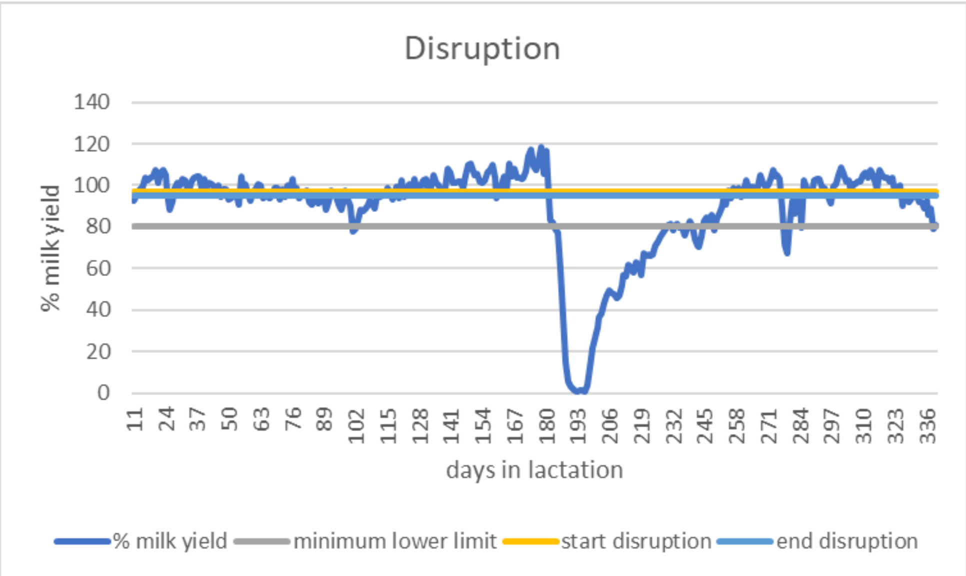

Figure 3. Daily milk production in percentage of the expected daily production.

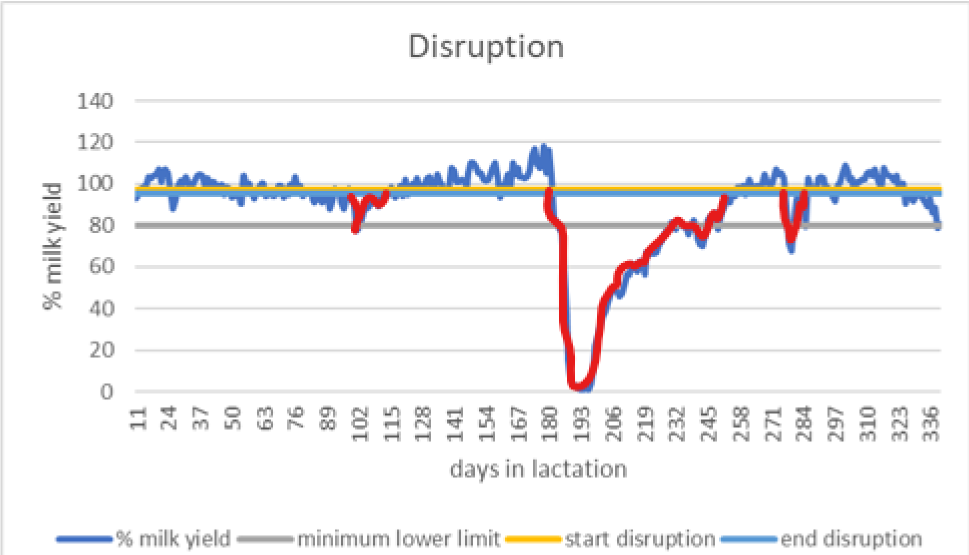

Figure 4. Daily milk production in percentage of the expected daily production, where disruptions are indicated in red. There is a disruption if % milk yield is below the yellow line, followed by at least one day below the grey line, and it ends when % milk yield is above the light blue line.

The length of a drop in milk production is the number of days from when the % milk yield falls below 97% until the % milk yield rises above 95% again (and in the meantime, therefore, the % milk yield must have fallen below 80%). The number of decreases in milk production per lactation is simple to count. However, a fall only counts when the fall has ended. Figure 3 and 4 show that during this lactation the cow also drops below 80% at the end of the lactation, but this is not counted as a drop because the cow no longer comes out of this drop.

Cows that are more resilient than average will produce more milk over the entire lactation than cows with average resilience because they have more stability and faster recovery. Conversely, cows that are less resilient than average will produce less milk over the entire lactation because they have less stability and slower recovery.

Table 5 shows the translation of the breeding values for recovery, stability and the resilience index into practical resilience indicators. Production gain/loss indicates how many kilograms of milk a cow produces more or less over the entire lactation compared to an average cow due to better or worse resilience. Production gain/loss is based on cows with an average lactation production of 30 kilograms of milk per day. At higher average daily productions, the difference in production gain/loss increases.

			Breeding value		
Recovery	**92**	**96**	**100**	**104**	**108**
length of disruption (days)	14.0	12.5	10.9	9.3	7.0
production gain/ loss	-7	-3	0	+2	+5
Stability	**92**	**96**	**100**	**104**	**108**
number of disruptions	4.8	4.2	3.8	3.2	2.4
production gain/ loss	-154	-59	0	+56	+120
Resilience index	**92**	**96**	**100**	**104**	**108**
length of disruption (days)	13.2	11.5	10.7	9.7	8.5
number of disruptions	4.9	4.2	3.8	3.2	2.6
production gain/ loss	-152	-49	0	+60	+105

Table 5. Practical translation from cow breeding value for resilience traits to 'visible' resilience indicators in practice.

In Table 5 it is seen that cows are actually more resilient if they have a higher breeding value for resilience. However, the relationship between breeding value and a resilience indicator is not linear. For example, the difference in number of disturbances between a breeding value 96 and 100 is 0.4, while between 100 and 104 this difference is 0.6.

A disturbance lasts only half as long (7 days) for a cow with a breeding value of 108 for recovery, compared to a cow with a breeding value of 92 for recovery (14 days). A cow with a breeding value of 108 for stability has only half the number of disruptions (2.4) during a lactation, compared to a cow with a breeding value of 92 for stability (4.8).

A cow with a breeding value of 108 for total index resilience has 2.6 disruptions during lactation, with one disruption lasting 8.5 days, and during the whole lactation produces this cow 105 kilograms milk more compared to a cow with a resilience index of 100. In contrast, a cow with a breeding value of 92 has 4.9 disruptions, with one disruption lasting 13.2 days and during the whole lactation produces this cow 152 kilograms milk less compared to a cow with a resilience index of 100. Thus, a cow with breeding value of 108 for total index resilience will lose 257 kilograms less milk during one lactation due to better resilience compared to a cow with a breeding value of 92.

With higher average milk production, this difference in loss of milk production naturally increases.

Base

See chapter 'Bases for breeding values and base differences'.

Publication

In publications the overall breeding values recovery and stability are used, herewith parity 1, parity 2 and parity 3+ are combined into one breeding value with the ratio 0.41, 0.33 and 0.26 for parity 1, parity 2 and parity 3+, respectively. Similarly, the index resilience is used in publications, in which the overall breeding values recovery and stability are combined with the ratio 1.00 : 3.00 for recovery and stability, respectively.

Publication requirements

See chapter 'Publication Requirements Bulls'.

Literature

E-Chapter 7, breeding value estimation milk production traits with test-day model. Quality manual.

Poppe, M. (2022). Genetic improvement of resilience in dairy cattle using longitudinal data (Doctoral dissertation, Wageningen University and Research).