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Assessing the benefits from joining the International beef cattle genetic evaluation (Interbeef) at SLU's Interbull Centre

– Estonia as a case study

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EUROPEAN MASTER IN ANIMAL BREEDING AND GENETICS

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Abstract

In 2019 the Interbeef Working Group started offering a new Service: the “Interbeef Pilot run”. The Service, developed and provided by Interbull Centre, consists in an international genetic evaluation for beef breeds using pre-defined genetic parameters. In 2020, Estonia expressed interest in Interbeef Pilot run for the evaluation of adjusted weaning weight (aww) in Limousin and Aberdeen-Angus breeds. The aim of this project was to perform the Interbeef Pilot run using performances and pedigree information submitted by Estonia jointly with the international data available for the Interbeef Service. The service was expected to offer Estonia access to a wide international panel of animals whose EBVs were expressed on the local scale, additionally to an increase in EBV reliabilities of animals in Estonia. This would facilitate the selection of the bulls with best EBVs at national and international level.

International EBVs and reliabilities were obtained using a multi-trait animal model where aww performances from different organisations are considered as different traits. Across country genetic correlations for Estonia were set as the average of the correlations estimated for the other participating organisations in the Interbeef routine aww evaluation.

Pseudo-national EBVs were computed by setting the across country genetic correlations in the model to zero. The pseudo-national and international EBVs and reliabilities were compared assessing the theoretical benefit of joining the international genetic evaluation.

As a result from the Pilot run, Estonia received international EBVs on its own scale for all animals included in the international pedigree. An average increase in international EBV reliability of 0.12 and 0.09 was observed for Estonian Limousin and Aberdeen Angus respectively.

The main foreign sire countries were DFS (Denmark, Finland, Sweden) for Limousin and the UK in Aberdeen Angus. The number of connecting sires between Estonia and the participating countries in Interbeef was limited, which should be taken into account in case Estonia would join the international evaluations in the future.

Based on the Pilot run results, Estonia would benefit from joining the Interbeef evaluation.

Keywords: Estonia, reliability, Interbeef, International genetic evaluation, beef cattle, weaning weight

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Abbreviations

AACA	Age at calving
AAN	Aberdeen Angus
ASEXTWIN	Sex of the animal and presence of twins
AUS	Australia
AUT	Austria
aww	Adjusted weaning weight
BEL	Belgium
BGR	Bulgari
bwt	Birth weight
cae	Calving ease
CAN	Canada
CHA	Charolais
CHE	Switzerland
CZE	Czech Republic
DEU	Germany
DFS	Denmark, Finland, Sweden
DNK	Denmark
EBV	Estimated breeding values
ESP	Spain
EST	Estonia
FIN	Finland
FRA	France
GBR	Great Britain
HER	Hereford
HUN	Hungary
HYS	Herd Year Season
ICAR	International Committee for Animal Recording
IDEA	Interbull Data Exchange Area

Interbeef	ICAR’s working group for International cattle genetic evaluation
Interbull	ICAR’s sub-committee for International Bull Evaluation Service
IRL	Ireland
ITA	Italy
LAV	Latvia
LIM	Limousin
LTU	Lithuania
LUX	Luxemburg
NLD	Netherlands
NOR	Norway
NZL	New Zeeland
POL	Poland
SIM	Simmental
SLU	Swedish University of Agricultural Sciences
stb	Still birth
SVN	Slovenia
SWE	Sweden
URY	Uruguay
USA	United Stated of America
YEAR	Year of birth
ZAF	South Africa

1. Introduction

Technical developments in cattle reproduction increased the possibilities of the international exchange of genetic material by using frozen semen and frozen embryo transfer. As a result, cattle populations rapidly incorporated genes from other populations (Philipson, 1987; Eriksson *et al.*, 2007). Countries that imported semen faced the problem of choosing between local bulls and bulls from a worldwide gene pool when selecting the most suitable breeding stock for their own breeding goals and needs; this led to the interest of finding methods to express bulls' estimated breeding values (EBVs) on the scale of other countries (Fikse & Philipsson, 2007; Philipsson, 2011). Therefore, cattle genetic evaluation models which allowed the comparison of EBVs across countries were developed (Schaeffer, 1994; Venot *et al.*, 2006).

In beef cattle, farming systems and environmental conditions can be very different between countries and even between regions within countries (Journaux *et al.*, 2006; Renand *et al.*, 2003). In 2006, the International beef evaluation service (Interbeef) was established as a working group of ICAR with the goal of offering international genetic evaluations for beef cattle breeds to members of ICAR (Journaux *et al.*, 2006). The main benefit obtained from the international genetic evaluation is that breeders get access to an international panel of animals whose EBVs are expressed on the local scale (Renand *et al.*, 2003; Venot *et al.*, 2007). In addition, sires with foreign progeny are expected to show an increase in EBV reliabilities (Venot *et al.*, 2008, 2009, 2014).

In 2019, a country pilot run service was introduced to Interbeef´s portfolio. The service offers the possibility to any ICAR member to try the international evaluation (using assumed parameters) without being an official member of Interbeef. In late 2020, Estonia expressed interest in assessing the benefits from joining Interbeef services and requested a pilot run for weaning weight in Aberdeen Angus and Limousin breeds.

The aim of this thesis was to assess the impact that joining the international beef cattle genetic evaluation has on the breeding values calculated for Estonian animals.

2. Literature Review

2.1. Beef cattle breeding

The beef cattle industry consists basically of seedstock and commercial producers. Generally, the genetic improvement (the increase in breeding values), occurs in the seedstock sectors, which then flows to the commercial industry through the purchase of semen or bulls. The selection of breeding animals can be made based on a wide range of information, however, breeding values or expected progeny differences (EPDs) are considered the most informative (Spangler, 2013).

In beef cattle breeding, the use of artificial insemination (AI) is less common than in dairy cattle (Spangler, 2013). Nevertheless, it has become more frequent over the years; Fontes *et al.* (2020) reported that from 1990 to 2017 the number of dairy semen units sold in the United States of America increased by 84%, while the number of beef semen units increased by 145%.

The breeding pyramid in species like poultry or swine is much more clearly defined than in beef cattle, due to the formalized breeding companies that exist. However, this pyramid does exist also in beef cattle (Marquez *et al.*, 2010). At the nucleus level, animals (particularly sires) are mainly produced for their use in the multiplier level, even though some of the nucleus animals could be sold directly to commercial herds (Spangler, 2013). The drivers of genetic change are the nucleus herds. The multiplier herds expand the genes from the nucleus populations to produce animals for the commercial sector.

According to the University of Arkansas (2021) the main performance traits of beef cattle that influence the productive efficiency of desirable beef are: Reproductive Performance, Maternal Ability, Growth Rate, Feed Efficiency, Body Measurements, Longevity, Carcass Merit and Conformation or Structural Soundness.

In beef cattle, the largest portion of response to selection is directly influenced by the breeders' choice of sires because of the intensive use of this bulls in the herd. Therefore, the selection of the best sires is desirable as a way of increasing male performance for productive traits and also to improve the maternal performance of females (Campêlo *et al.*, 2004).

As the demand of beef increased, also did the need of beef cattle with better productivity (Smith *et al.*, 2018). This led countries to increase the use of AI and embryo transfer (ET) for the wide spreading of genes from genetically superior bulls and dams (Ferraz *et al.*, 2018; Magnabosco *et al.*, 2013; Moore & Hasler, 2017). However, with the international trade of genetic material, it occurred that producers selected international sires that showed improved performance in the exporting country which was not observed in the performance of the offspring in the importing country (Wakchaure *et al.*, 2016).

2.2. Weaning weight

Since the mid-90s, selection on growth performances have been taking place. High positive correlations between traits like birth weight, weaning weight and yearling weight were found. This was not entirely desirable as increased birth weight was also associated with dystocia (Mathews, 1989; Stanforth & Fralim, 1957; Lopez *et al.*, 2020). Additionally, the selection for increased weaning weight was also reported to prolong gestation length and increased age at first calving (Lopez *et al.*, 2020).

Weaning weight is one of the main traits selected for the genetic improvement of beef cattle. This trait (which is expressed by the calf) is often regarded as a characteristic of the dam, as it represents the saleable production of the cow. It is of direct economic importance and is a major reason for considering the culling of a cow from the herd (Chantalakhana, 1968; Szabo &Bene, 2013). Also, it is considered to be a complex trait as four components are associated with it: direct additive genetic effect (half of the direct additive genetic value given by the sire and the other half by the dam), direct genetic maternal effect (influencing e.g. milk yield and milk quality of the dam), a permanent maternal environmental effect (specific to the dam) and environmental factors such as season and/or year of birth, age of the dam, age at weaning, etc (Quintero *et al.*, 2007).

2.2.1. Genetic evaluation of weaning weight

Animal models used in the analysis of maternally influenced traits generally include direct and maternal effects (along with the covariance between them) and a permanent environmental effect of the dam (Dodenhoff *et al.*, 1988). The presence of maternal effects in the models used in genetic evaluations reduces the variance of the direct genetic effects (Meyer, 1992). A proportion of this variance reduction is explained by the maternal genetic and maternal permanent environmental variances. Several studies have reported to use a single or multi-trait animal model that includes maternal effects for the estimation of genetic parameters of weaning weights in national herds (Campêlo *et al.*, 2004; Szabo &Bene, 2013; Quintero *et al.*, 2007; Graser *et al.*, 2005).

Direct heritabilities for weaning weight of 0.14 and 0.17 in crossbred populations have been reported by Demeke *et al.* (2003) and Splan *et al.* (2002), while heritabilities in different pure-bred populations have been reported from 0.10 to 0.51 (Phocas & Laloë, 2004; Lopez *et al.*, 2020). In regards of maternal heritabilities for weaning weight, these are generally reported around 0.10 and up to 0.20 (Splan *et al.*, 2002; Lopez *et al.*, 2020; Phocas & Laloë, 2004).

2.3. Genotype by environment

Genotype by environment interaction (GxE) is defined as the change in the relative performance of two (or more) genotypes which are measured in two (or more) environments. GxE generally appears when the performance of the different genotypes is not influenced in the same way by the distinct environments. The difference in response of the genotypes could lead to the reclassification or re-ranking of the genetic values (Falconer & Mackay, 1996).

In order to assess the effect of GxE, the same trait in two different environments must be treated as two separate traits and the genetic correlation between the genotypic values of trait in the different environments must be estimated. Low correlations between the genotypic values of the trait means that GxE is present, while in absence of GxE the correlation is expected to be close to one. The efficiency of selection programs may be affected by GxE. The response in the performance traits of animals that were raised under environmental conditions different than those of the selected ones may be reduced. Also, the economic performance of animals with a genotype that is not adapted to a specific environment can be reduced (Wakchaure *et al.*, 2016).

In beef cattle, De Mattos *et al.* (2000) investigated the presence of G×E interactions for adjusted weaning weight in Hereford animals of different regions of the USA and across USA, Canada and Uruguay. The estimated genetic correlation for direct and maternal genetic effects for USA – Canada, USA – Uruguay and Canada – Uruguay were all between 0.8 and 0.9, showing that there were no strong GxE. Similar results were found for Hereford animals from Argentina, Canada and the USA (Lee & Bertrand, 2002). Nevertheless, the farming conditions and systems in beef cattle breeding can be far more heterogeneous than in dairy cattle (Journaux *et al.*, 2006). In the case of dairy cattle, genetic correlations lower than 0.8 were found between North and South America (Ceron-Munoz *et al.*, 2004) and across some eastern European countries (Rekaya *et al.*, 2001).

In order to be able to compare the genetic merits of an animal in different countries, an international genetic evaluation should also consider GxE, as this may result in scaling or re-ranking of evaluated animals across different countries (Ahlqvist, 2010). In addition, another important aspect of an international evaluation is the genetic linkage (or connectedness) between the populations of each country (Phocas *et al.*, 2005; Fouilloux *et al.*, 2006; Venot *et al.*, 2007; Venot *et al.*, 2008).

2.4. Connectedness

"Connectedness" is a term commonly used in animal breeding associated to genetic evaluations and comparison of EBVs across herds. It can be described as the measurement of the relationships among herds (or contemporary groups). In genetic evaluation models, the contemporary groups (or herds) represent the pairs of fixed factors whose differences need to be estimated to make it possible to compare genetic evaluations of animals from these groups. The accuracy of the differences among individuals of the subclasses is affected by the degree of connectedness between subclasses (Mathur, 2005).

In occasions, there is an interest of knowing if there is enough connectedness between two groups in order to include them in a common genetic evaluation. This is useful in the ranking of individuals across herds and for identifying the best individuals for genetic improvement and selection (Mathur, 2005; Phocas *et al.*, 2005; Fouilloux *et al.*, 2006). Comparisons of EBVs tend to be biased when low connectedness exists across groups. The lower the connectedness across groups is, the larger the bias and therefore, the accuracy of comparison of EBVs among groups is decreased (Zhang *et al.*, 2018).

In beef cattle, low genetic connectedness has been reported between herds of different countries as a consequence of the less frequent use of AI (Bonifazi *et al.*, 2020b; Fouilloux *et al.*, 2006; Berry *et al.*, 2016). On the other hand, the situation is the complete opposite for dairy cattle (Berry *et al.*, 2016).

2.5. International genetic evaluation in cattle.

With the international exchange of genetic material, importers and exporters grew interested in obtaining methods for comparing bulls' EBVs in different countries' scales (Dürr &Philipsson., 2012). Therefore, international genetic evaluations in both dairy and beef cattle were developed (Schaeffer, 1994; Venot *et al.*, 2006).

In dairy cattle, the ICAR's sub-committee "Interbull", performs the international genetic evaluation of dairy bulls through the Multi-trait Across Country Evaluation (MACE)

(Schaeffer, 1994). In the case of beef cattle, the ICAR's working group "Interbeef" offers international genetic evaluations for 5 breeds (Charolais, Hereford, Aberdeen Angus, Limousin and Simmental) and three traits (weaning weight, calving ease and birth weight) (Interbull, 2020).

2.5.1. ICAR, the "International Committee for Animal Recording".

On 9th March 1951, the "International Committee for Animal Recording" (ICAR) was founded. Today ICAR is the leading global provider of Guidelines, Standards and Certification for animal identification, recording and evaluation counting 115 members from 57 countries all around the world (https://www.icar.org/).

ICAR technical activities are managed by a group of technical bodies which are formed by subcommittees and working groups. Some of the tasks of these bodies are related to provide guidelines and standardize the collection of animal data, its storage and its use for a range of purposes that are directed to support the strategic directions of ICAR. Subcommittees are considered as "long term" to "permanent" ICAR entities that can have members of their own to whom they provide services. Working groups, on the other hand, are considered long term entities which will exist until the fulfilment of their task, and their activities are focused on the development and recommendation of new services and methodologies to ICAR members (https://www.icar.org/index.php/technical-bodies/instructions-for-scs-wgs-and-tfs/).

2.5.2. Interbull

The International Bull Evaluation Service (Interbull) is a permanent subcommittee of ICAR. It was founded in 1983 in a joint project among ICAR, the International Dairy Federation (IDF), and the European Association for Animal Production (EAAP) as a response to cover the desire of the dairy breeders for an accurate comparison between animals across countries. Interbull became a permanent member of ICAR in 1988 Today Interbull is a worldwide network that provides genetic information services for the genetic improvement of dairy cattle (https://www.icar.org/index.php/technical-bodies/sub-committees/Interbull-sub-committee/)..

The Interbull genetic evaluations of dairy sires started in 1994 using MACE, the multiple-trait across country evaluation (Schaeffer, 1994). The routine evaluation considers bulls' EBVs estimated from different Interbull members. EBVs submitted by each member are considered as a unique trait and the genetic correlations among the countries are estimated from common bulls that have progeny in multiple countries (Hammami & Gengler, 2009). The value of the correlations between countries has an effect on the re-ranking of bulls in other country scales. If the genetic correlations are equal to one, the ranking of the bulls will be the same in all countries. However, if the correlation is smaller than one, re-ranking will occur. Generally, the smaller the correlation, the more re-ranking of bulls (Jakobsen *et al.*, 2009).

In order for MACE to work properly, bulls need to have a unique identification number, unbiased national evaluations, known (co)variances and the genetic links between countries must be present (Schaeffer, 1994).

2.5.3. Interbull Centre

In 1991 Interbull founded its operational unit, Interbull Centre, with the aim of providing genetic information services and applied research for improvement of livestock to a worldwide network (https://www.icar.org/index.php/technical-bodies/sub-committees/Interbull-sub-committee/)

The main services offered by Interbull Centre are:

1. Dairy international genetic and genomic evaluations.

2. Parentage SNP Exchange ("GenoEx-PSE"): This is a service for exchanging standardized sets of SNPs for animals that are genotyped in order to facilitate the parentage analysis activities (https://interbull.org/ib/genoex_pse).

3. European Union Reference Centre (EURC) for Zootechnics: Interbull Centre was designated by the European Commission to act as the centre for the *"scientific and technical contribution to the harmonisation and improvement of the methods of performance testing and genetic evaluation of purebred breeding animals of the bovine species*" (https://interbull.org/ib/eurc).

Administratively, the Interbull Centre is a section of the Department of Animal Breeding and Genetics of the Swedish University of Agricultural Sciences (SLU), which has been contracted by ICAR to be the operational unit for both Interbull and the Interbeef working group (Swedish University of Agricultural Sciences (SLU), 2019; https://Interbull.org/ib/Interbullcentremain).

2.5.4. Interbeef Working Group

The Interbeef WG is the ICAR working group in charge of coordinating the development and provision of services for the international genetic evaluation of beef cattle breeds.

Beginnings of the European joint beef genetic evaluation

Since the 90s several groups of countries developed joint genetic evaluations in beef cattle and becuase these groups had the same rules for recording performance and had similar farming conditions and systems, the existing models for genetic evaluations between countries assumed no genotype by country interaction (GxE), and therefore, no re-ranking of bulls due to GxE could happen (Journaux *et al.*, 2006).

In 2001, a European joint project was conducted for the genetic evaluation of beef breeds across countries (EUBEEVAL), which had the goal of enlarging the catalogue of breeding animals to choose from based on an objective method (Venot *et al.*, 2007). The feasibility of an across country model that would consider, among others, the genotype by country interaction was positively assessed by Quintanilla *et al.* (2002) and Renand *et al.* (2003).

The EUBEEVAL project provided a within-country ranking of bulls in France, UK and Ireland, but it also underlined the need of a unique international identifier for every animal that was exchanged (Journaux *et al.*, 2006; Venot *et al.*, 2006). In Phocas *et al.* (2005) it was determined that the most fitting model for beef evaluations was an animal model across-country evaluation using raw data (AMACI model), which accounts for heterogeneous variances and different genetic correlation between countries. In this way, the best consistency between national and international ranking of animals, and the best estimates of genetic parameters across countries were achieved.

Creation of Interbeef

Through a general survey, several countries (France, Ireland, the UK, Sweden, Denmark and Finland) expressed their desire to ICAR of having an international beef evaluation service, and in June 2006 “Interbeef” was founded as a working group for ICAR, which aimed at developing international beef cattle genetic evaluation (Journaux *et al.*, 2006; Venot *et al.*, 2007).

Before the first official Interbeef evaluation was performed, preliminary research runs took place in the evaluation of adjusted weaning weight (aww) in Limousin and Charolais across European countries (Venot *et al.*, 2007, 2009a, 2009b, 2014). The base for Interbeef evaluation protocol were reported by Venot et al (2007). The genetic model used for these evaluations was a multi-trait animal model which included maternal genetic effects and maternal permanent environment (Phocas *et al.*, 2005). All environmental effects were specific to each country.

In practice, the estimation of genetic connectedness is estimated by counting the number of bulls with offspring in more than one country (Venot *et al.*, 2007, Bonifazi *et al.*, 2020a). However, an alternative approach was proposed by Venot *et al.* (2008) based on a measure of the potential bias between the genetic levels of the different countries. This methodology was used in further research runs (Venot *et al.*, 2009a, 2009b) as a way of facing the low connectedness found among countries. The low connectedness resulted in low accuracies for the international EBVs and in difficulties in the estimation of genetic correlations.

The research for the performance of an international genetic evaluation of calving traits took place in 2013. The model evaluated “birthweight”, “calving ease”, and “stillbirth” for Charolais and Limousin breeds (Vesela *et al.,* 2013). The genetic correlations among countries were eventually obtained in 2014 (Interbull, 2015).

The first Interbeef test runs for weaning weights were performed in 2013 and 2014, the benefits gained from the usage of the Interbeef international genetic evaluation for weaning weight were published. The impact of the joint genetic evaluation on each country was assessed through the comparison of the reliability and the ranking of sires between Interbeef EBVs and pseudo-national evaluations’ EBVs (Venot *et al.*, 2014). The pseudo-national evaluations mimic the real national evaluations by setting covariances used in the multi-trait model between countries to zero, in this way, performances from other countries are not taken into account for the prediction of EBVs in each country (Venot *et al.*, 2009b; Venot *et al.*, 2014). These evaluations are as close as possible to the real national evaluations; however, some particularities (e.g. multiple-breed evaluation) cannot be taken into account (Venot *et al.*, 2009b). Also, the process of reliability estimation of some countries may differ, resulting in not comparable reliabilities.

Interbeef today

Among the services offered by Interbeef, through Interbull Centre, are: management of a pedigree, identification, and performance database; routine genetic evaluations for beef traits and breeds; and a Pilot run for potential new members. The management of pedigree and performances information is through the “Interbull Data Exchange Area” (IDEA) database, where Interbeef members are allowed to upload and edit their information.

Routine genetic evaluations are performed twice a year, following ICAR’s service calendar (Interbull Centre, 2019b).

The countries that participate in Interbeef routine genetic evaluations are the Czech Republic **(CZE)**, Australia **(AUS)**, **DFS** (Denmark , Finland and Sweden), France **(FRA)**, Germany **(DEU)**, South Africa **(ZFA)**, Switzerland **(CHE)**, Ireland **(IRL)**, United Kingdom **(GBR)**, Slovenia **(SVN)** and Latvia **(LAV)**.

Interbeef evaluations are available for the breeds: Charolais **(CHA)**, Limousin **(LIM)**, Simmental **(SIM)**, Hereford **(HER)** and Aberdeen Angus **(AAN)**.

The participation of the different country members of Interbeef in aww evaluation, as well as the breeds they are participating with during 2020 are illustrated in Table 1.

Table 1. Breeds and participating countries in the international evaluation for adjusted weaning weight (Interbull, 2020)

Breed	Countries
CHA	AUS,CZE,DEU,DFS,FRA,IRL,ZAF,CHE, SVN,LAV
LIM	AUS,CZE,DEU,DFS,FRA,IRL,CHE,GBR,SVN,LAV
SIM	CZE,DEU,DFS,IRL,CHE
HER	CZE,DEU,DFS,IRL,CHE
AAN	CZE,DEU,DFS,IRL,CHE

AUS= Australia; CZE = Czech Republic, DEU= Germany; DFS = Denmark, Finland and Sweden, IRL = Ireland, FRA = France; CHE = Switzerland; LAV=Latvia; SVN= Slovenia; ZAF= South Africa

The participation of the different country members of Interbeef in calving traits evaluation, as well as the breeds they are participating with during 2020 are illustrated in Table 2.

Table 2.Breed-trait-country groups participating in the research project for the calving traits 'birth weight' (bwt), and 'calving ease' (cae) (Interbull, 2020).

Breed	Trait	Countries
CHA	cae	CZE,DFS,FRA,IRL, SVN
	bwt	CZE,DFS,FRA,IRL,ZAF,SVN
LIM	cae	CZE,DFS,FRA,IRL,GBR,SVN
	bwt	CZE,DFS,FRA,IRL,GBR,SVN
SIM	cae	CZE,DFS,IRL
	bwt	CZE,DFS,IRL

CZE = Czech Republic, DFS = Denmark, Finland and Sweden, GBR = Great Britain, IRL = Ireland, FRA = France; CHE = Switzerland; SVN= Slovenia; ZPA=South Africa

Interbeef Technicalities

Interbeef EBVs are currently estimated using MiX99 (Mix99 Development Team, 2017) software and the reliabilities are calculated using MTEDC5 (Sullivan, 2020). The variance components for aww are estimated using the DMU programme, and the variance components for calving traits are estimated using BLUPF90; variance components are estimated during the test runs (Interbull, 2020).

For a country to join the international evaluation system, the national pedigree information should be uploaded into the Interbull Data Exchange Area (IDEA) database, for which each animal should have its own and unique international identification. This unique international identification is used in the international genetic evaluation system and is referred to as the "Animal International Identification" (AIID). The AIID is compounded by the breed, sex, country and the national registration number of each animal. Performance records for crossbred animals in weaning weight evaluation should also be included in the IDEA database (Interbull Centre, 2019a).

Benefits of Interbeef evaluation

Summarising, according to Venot *et al.* (2014), the benefits offered by the Interbeef international genetic evaluation are: the possibility for the breeders to have access to a much larger panel of new favourable bulls selected on EBVs specific to their country scale; to provide objective information for exporting their breeding animals to other country members. Alongside, adding Interbeef information has shown to be beneficial for a large majority of participating countries by increasing the national reliability (Bonifazi *et al.*, 2020a).

2.5.5. Pilot Run

In 2019, the country pilot run service was introduced to the Interbeef's portfolio. This gives the possibility to any ICAR's member which may be interested to become a member of Interbeef to try the international evaluation beforehand. A clone of IDEA database is dedicated to the run and the country joining the service can test all the functionalities provided by Interbeef (international pedigree, data checking, international EBVs), without being official member. The pilot run is similar to a test run with a few exceptions.

Pilot runs are not scheduled in the calendar of ICAR Interbeef services, these must be asked for by a written request and should be accepted by ICAR. No variance components are estimated during the pilot run evaluation, this means that official parameters for the Interbeef member organisations (obtained during the last test run), and the assumed parameters, for the requesting new organisation (calculated as the average of the parameters of the member organisations) are jointly used during the pilot run (Interbull Centre, 2019b). The requesting organisation should upload the pedigree information and the data (performances and the model used for their parameters) to the clone of IDEA database. The pilot run results are delivered only to the requesting organisation, also the resulting EBVs and reliabilities should not be published (Interbull Centre, 2019b). This service has already been used by two countries, SVN in late 2019 testing aww evaluation in LIM and CHA, and Italy in early 2020 testing the aww evaluation for LIM (Interbull, 2020).

In late 2020, Estonia (EST) expressed interest in assessing the benefits from joining Interbeef services and requested a pilot run for aww in Aberdeen Angus and Limousin breeds.

2.6. Estonia

Estonia is located on the southern coast of the Gulf of Finland in the Baltic Sea. It has a coast length on the mainland of 1 242 km, and the length of coast of the islands is 2 552 km. The climate in Northern and Western Estonia is of the maritime type, while in Eastern and South-Eastern Estonia it is continental. The weather changes from year to year, which makes agricultural crop yields unstable. For years animal husbandry provided 74 % of the total agricultural production, of this, cattle breeding accounts for 62-65 % (Saveli, n.d.).

2.6.1. Beef breeding in Estonia

In 2001, the Estonian Beef Cattle Breeders Association was established and, since then, the recording of beef cattle performances has been conducted. Over the years, fluctuations in the population of beef cattle in Estonia have been reported. In the year 2005, a decrease in beef cattle population occurred, however, a recovery in numbers happened during the year 2010; the tendency of increasing beef cattle population has continued since then (Eesti Põllumajandusloomade Jõudluskontrolli AS, 2020; Saveli, 2011).

In 2001, beef breeding was performed over 14 counties, whereas more than 50% of the cattle were concentrated in Hiiu, Saare and Lääne counties. Over a half of the Estonian beef breeders keep relatively small cattle herds, which can go up to 10 individuals (Institute of Animal Science of Estonian Agricultural University *et al.*, 2001). By the year 2010, 39,000 heads of beef cattle were kept in 1108 holdings (Saveli, 2011).

Currently, beef cattle breeding is quickly developing. A report of animal breeding in Estonia that covered the development of this area from the year 2004 to 2011 mentioned that the population of beef cattle in Estonia has been consistently rising (Saveli, 2011).

On the 1st of January, 2019, there were 77,721 beef animals recorded in Estonia, of the following breeds: Aberdeen-Angus (23%), Limousin (22%), Hereford (16%), Simmental (14%) and Charolais (12%) (Interreg Central Baltic Programme 2014-2020, n.d.).

2.6.2. The Estonian Livestock Performance Recording Ltd

The Eesti Põllumajandusloomade Jõudluskontrolli AS (Estonian Livestock Performance Recording Ltd) has as main task the improvement of the efficiency of animal husbandry by performing animal recording and independent testing of the quality of raw milk. The Estonian Livestock Performance Recording Ltd also records the performance of beef animals, pigs and goats (Eesti Põllumajandusloomade Jõudluskontrolli AS, 2019).

Up until 2019, the Estonian Livestock Performance Recording organisation recorded the performance of the following breeds: Aberdeen-Angus, Hereford, Simmental, Charolais, among others (Eesti Põllumajandusloomade Jõudluskontrolli AS, 2020). The population size of pure-breds animals from previously mentioned breeds are reported in Table 3.

Table 3. Population of beef breeds in Estonia in year 2019 (Eesti Põllumajandusloomade Jõudluskontrolli AS, 2020).

Breed	Total	Suckler cows	Heifers
CHA	2225	995	818
LIM	2859	991	1229
SIM	1751	788	653
HER	2067	1014	632
AAN	3619	1569	1280

The beef traits recorded in Estonia are birthweight and average daily gain (until 200 and 365 days of age). In addition, the cow's culling reasons are also recorded (Eesti Põllumajandusloomade Jõudluskontrolli AS, 2020).

By the end of 2019, Estonia reported 15,237 pure-bred beef cattle individuals under performance recording. Among those, 3,619 were Aberdeen Angus and 2,859 were Limousin. (Eesti Põllumajandusloomade Jõudluskontrolli AS, 2020).

3. Materials and methods

3.1. Data analysis for Estonia

Descriptive statistics of the performance data submitted by Estonia for 4565 LIM and 4798 AAN was performed using the software R studio (RStudio Team., 2020).

At national level, Estonia performs a multi-breed genetic evaluation fitting a model which considers the animal's breed as fixed effect. In order to join the international evaluation, which is performed considering each breed independently, Estonia provided an ad-hoc version of the model used at national level, which is described below.

1. The effects fitted by Estonia in the model provided for the Pilot run were independently analysed; a brief description of each effect is reported below:

    a. "ASEXTWIN" is the fixed effect for the animal sex and the presence of twin siblings. The effect was coded as: "11" (males without twin siblings), "12" (males with twin siblings), "21" (females without twin siblings) and "22" (females with twin siblings).

    b. "AACA", fixed effect for age at calving. The levels were: "1" (youngest dams), "2", "3" and "4" (oldest dams).

    c. "YEAR", fixed effect for year of birth. Birth years for LIM animals with performances ranged from year 2000 to 2020, for AAN animals from 2002 to 2020.

    d. "HYS", fixed effect for contemporary groups concerning herd, year, and season for animals with performances. There were total of 160 contemporary groups for LIM and 155 for AAN.

    The minimum size declared by Estonia for contemporary groups was 3. In Estonian LIM, more than 80% of the contemporary groups were represented by less than 50 animals each, while 32% of the total contemporary groups consisted of less than 10 animals each (Figure 1).

For Estonian AAN, more than 70% of the contemporary groups had less than 50 animals each and 24% were formed with less than 10 animals each (Figure 2).

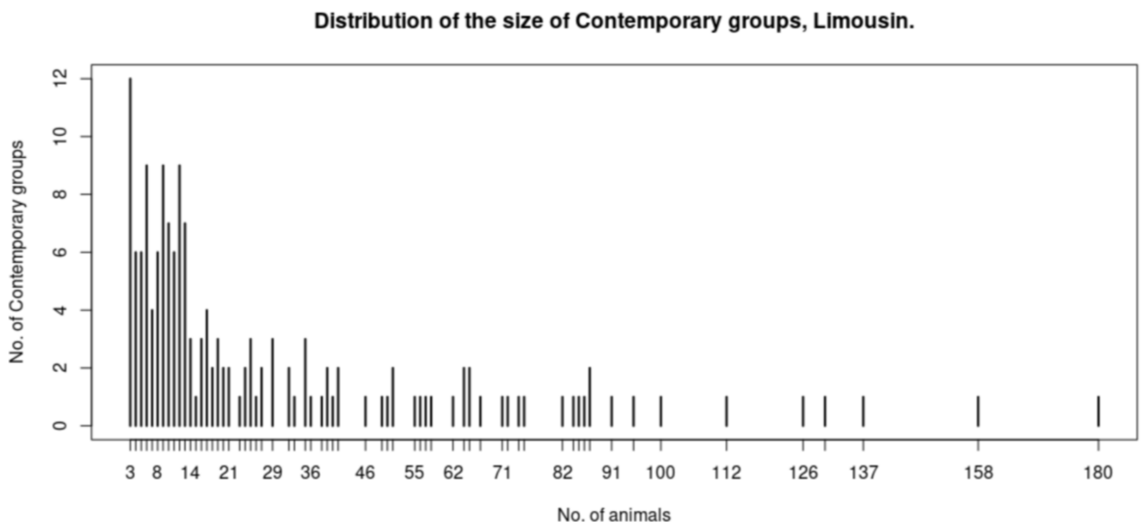

Figure 1. Distribution of number of animals in contemporary groups for adjusted weaning weight, Limousin.

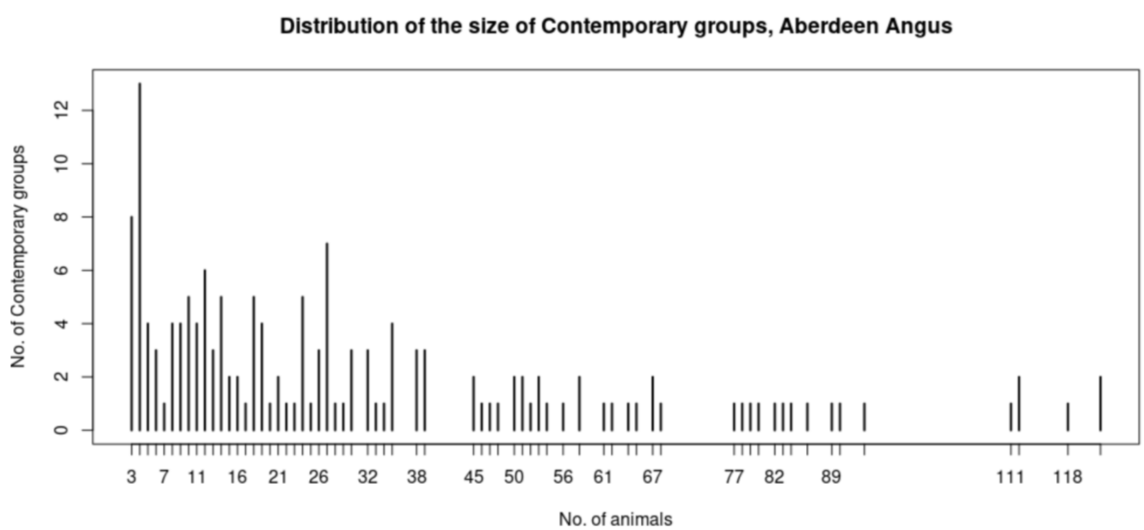

Figure 2. Distribution of number of animals in contemporary groups for adjusted weaning weight, Aberdeen Angus.

2. LIM and AAN aww performances submitted by Estonia were subjected to a multi-factor ANOVA with all the effects fitted in the model as source of variation.

   Aww performances were analysed with the “lm” R package adopting the following statistical model:

$$y = HYS + AACA + YEAR + ASEXTWIN + e$$

where *y* is the observation of aww; *HYS*, *YEAR*, *ASEXTWIN, and AACA* are the fixed effects previously decribed and e is the random residual term to be normally and independently distributed.

Least squared means were calculated for the levels in ASEXTWIN and AACA effects of both breeds using “lsmeans” R package. Pairwise differences between the means were estimated through a Tukey HSD test using R studio (RStudio Team, 2020).

All calculations and analysis were performed using R studio software unless otherwise specified.

3. EBVs in Estonian scale and their reliabilities were obtained for all individuals in the international pedigree through the pseudo-national and international evaluations (methodology explained in chapter 3.2.3). Pseudo-national evaluations mimicked the national evaluation in order to obtain national-like EBVs (pseudo-national EBVs) and reliabilities.

   The distribution of pseudo-national and international EBVs of 11618 Estonian LIM and 11751 Estonian AAN was computed and compared. Also, the difference between pseudo-national and international EBV reliabilities, both expressed from 0 to 1, were computed.

4. To investigate the behaviour of the reliability gain within Estonian populations, the pseudo-national and international reliabilities for Estonian LIM and AAN were compared using different reliability thresholds: 0.05, 0.10, 0.30 and 0.50.

   The correlation between pseudo-national and international EBVs within each reliability threshold level was calculated as a way of estimating consistencies between EBVs.

5. The siring countries of Estonian LIM and AAN animals with performances within EST were obtained through the pedigree information submitted to IDEA, in order to investigate the links across countries.

   Estonian individuals were grouped according to the country of origin of their sires. The average pseudo-national and international reliabilities of each group were calculated to observe its change in both genetic evaluations.

6. Genetic links between EST and other countries was investigated through the count of LIM and AAN sires shared between EST and at least one other country. Also, the country of origin of the common sires was obtained through IDEA’s pedigree data.

3.2. Interbeef workflow

3.2.1. Data checking and editing

The data submitted to IDEA by each participating organisation was checked and edited under the following criteria:

- Pedigree pruning: checks on the pedigree, sex of the animal, animal's date of birth and its compatibility with parents' date of birth were performed. All generations were extracted and kept from the animals that had performances recorded.
- Duplicate filter: if an animal with recorded performances was duplicated a single record was kept; if the animal had performances in more than one country then the performance submitted by the Authoritative country was kept.
- Twin filter: each organisation can choose if twins with performances are kept in the evaluation or not. For traits in which the twin status would affect the performance, either a twin effect is included in the model and twins are kept, or twins are discarded.
- Contemporary group filter (CG): Each organisation must provide the environmental effect related to CG. Each organisation also must provide a minimum size (number of animals with performance) for the CG. The CG (and related animals) below the minimum size were discarded.
- Breed filter: Only performances related to purebred animals (identified with international ID breed code equal to the evaluated breed) can be uploaded to IDEA database. To be included in the evaluation, both parents of the animal must be identified as purebred for the evaluated breeds.
- Crossbred animals: In the case of aww evaluation, crossbred animals are also accepted. The ICBF organisation (IRL) submitted crossbred animals with breed code "XXX". These animals were accepted in the evaluation if their sire was from the evaluated breed. It must be mentioned that if the animal with performance was not coded as "XXX", but had a dam from other breeds rather than the evaluated one, the animal was not included in the evaluation.

  To accommodate the evaluation model with cross-bred animals, IRL submitted the breed percentage of the animal (a limited number of breeds were considered; non-listed breeds were coded as "other"), the breed percentage of the dam, an estimation of heterosis and of recombination as fixed effects using covariates.

3.2.2. Input data

The data set for aww/LIM evaluation had a total of 3,736,097 performance records, representing 12 populations. The data set for aww/AAN evaluation had a total of 305,111 performance records, representing 6 populations.

Participating organisations in the evaluation of LIM were: AUS, CHE, CZE, DEU, DFS, ESP, EST, FRA, GBR, IRL, LAV and SVN. The organisation with the biggest amount of performance records was FRA with almost 3 million recorded animals while SVN had the smallest amount (2,685 animals). EST participated with 4,565 performance records.

In the case of AAN, the participating organisations were: CHE, CZE, DEU, DFS, EST and IRL. The organisation with the biggest amount of performance records was DEU (117,809 animals) while the organisation with the smallest amount was EST (4,798 animals).

3.2.3. Model description

The aww performances were analysed using a multiple trait animal model with direct and maternal genetic effects, including a maternal permanent environmental effect (Phocas, *et al.*, 2005). This is mathematically equivalent to a bi-trait model (Renand *et al*., 2003), that is used due to extensive memory requirements, low convergence speed and the CPU time needed, therefore, the matrices of genetic parameters are constructed by successive 2 by 2 estimations (Venot *et al.*, 2009a):

$$\mathbf{y} = \mathbf{X}b + \mathbf{Z_d}u_d + \mathbf{Z_m}u_m + \mathbf{W_m}e_m + \mathbf{e}$$

where y is the vector of performance ordered by country y'= (y1', y2'); b is the vector of fixed effects for each country, u_d and u_m are the direct and maternal genetic effects, respectively; and e_m is the permanent environmental effect provided by the dam.

It allows to consider heterogeneous genetic, maternal permanent environment and residual variances, additional to genetic correlations between countries. The whole set of parameters for two countries can be described as (Venot *et al*., 2006):

$$Var(e) = \begin{bmatrix} e_1 & 0 \\ 0 & e_2 \end{bmatrix} \qquad Var(e_m) = \begin{bmatrix} e_{m1} & 0 \\ 0 & e_{m2} \end{bmatrix}$$

$$Var\begin{bmatrix} u_{d1} \\ u_{m1} \\ u_{d2} \\ u_{m2} \end{bmatrix} = G \otimes A = \begin{bmatrix} \sigma^2_{d1} & \sigma_{d1m1} & \sigma_{d1d2} & \sigma_{d1m2} \\ \sigma_{d1m1} & \sigma^2_{m1} & \sigma_{m1d2} & \sigma_{m1m2} \\ \sigma_{d1d2} & \sigma_{d2m1} & \sigma^2_{d2} & \sigma_{d2m2} \\ \sigma_{d1m2} & \sigma_{m1m2} & \sigma_{d2m2} & \sigma^2_{m2} \end{bmatrix} \otimes A$$

G being the genetic variance matrix among countries and *A* being the relationship matrix of the animals.

The model is based on performance data and considers the trait evaluated in each country as a different trait. The effects fitted for each country-trait in the evaluation were chosen by the submitting organisations.

For the LIM evaluation, 78 effects were fitted in the multi-trait model (12 traits), 44 were fixed effects (Table 4), 26 covariates (Table 5) and the rest were random effects (Table 4). For AAN 48 effects in total were fitted to the multi-trait model (6 traits), being 21 fixed effects (Table 4), 24 covariates (Table 5) and the rest random (Table 4).

Random effects also consider the maternal permanent environment provided by the dam. Covariances between countries for environmental random effects were fitted to zero, as they were considered independent of each other. A maternal permanent environmental effect was fitted for the following organisations: AUS, CHE, CZE, DFS, ESP, FRA, GBR, IRL.

DEU, LAV, SVN and EST did not fit a maternal permanent environmental effect in their model. For EST, the direct maternal genetic effect was not fitted in the model.

In order to obtain both pseudo-national and international breeding values, two different evaluations were performed:

1. The International evaluation represented the official Interbeef pilot run for aww. Table 6 and Table 7 present the correlations between countries (estimated in the last test run) used for LIM and AAN evaluations, respectively. The correlations between EST and other countries were set as the average correlation among the rest of the countries.
2. The pseudo-national evaluation was performed setting all the genetic covariances among countries to zero. This prevented international data from influencing the estimation of EBVs and their reliabilities. However, a common international pedigree was used.

Mix99 software was used for the computation of EBVs; the variance components assumed for each organisation are presented in Table 8, heritabilities of the trait for each organisation can be found in the diagonals of Table 6 and Table 7.

The MTEDC5 software was used for the computation of reliabilities in both evaluations, following the methodology developed by Sullivan *et al.* (2006).

Table 4. List of fixed and random effects per population, Limousin and Aberdeen Angus.

Breed	Country[1]	Fixed[2]										Random[2]	
LIM	CZE		ASEXTWIN	AACA	AACA2	YEAR						CG	MPE
	DFS	HYS	ASEXTWIN	AACA		SEAS	TWIN						MPE
	ESP	H-BC	ASEX	AACA									MPE
	GBR	HYS _mgt	ASEX			Birth Month		ET Status	Fostered	Birth type	w_Dam_b		MPE
	IRL	HYS	Sex	paridamage									MPE
	FRA	HY-asex-mgt		pari_aaca		SEAS					Individual		MPE
	DEU		ASEX	parity		Birth Month	TWIN					HY	
	CHE		ASEX			yearmonth					alpine	HY	MPE
	AUS	CG											MPE
	SVN	CG	SEX	pari_class								Herd	
	LVA		SEX	agedam		yearseason						HY	
	EST	HYS	ASEXTWIN	AACA		YEAR							
AAN	CZE		ASEXTWIN	AACA	AACA2	YEAR						CG	MPE
	DFS	HYS	ASEXTWIN	AACA		SEAS	TWIN						MPE
	DEU		ASEX	parity		Birth Month	TWIN					HY	
	IRL	HYS	Sex	PARIDAMAGE									MPE
	CHE		ASEX			yearmonth		alpine				HY	MPE
	EST	HYS	ASEXTWIN	AACA		YEAR							

[1]CZE = Czech Republic, DFS = Denmark, Finland and Sweden, ESP = Spain, GBR = Great Britain, IRL = Ireland, FRA = France, DEU = Germany, CHE = Switzerland; AUS= Australia; SVN = Slovenia, LVA = Latvia, EST= Estonia.

[2]*AACA* = age at calving; *AACA2* = age at calving squared; *alpine*= access to alpine grazing for calves; *asex*= sex of the animal; *asextwin* = interaction between asex and twin; *Birth Month*= month of birth; *CG*= Contemporary group; *fostered*= foster yes/no; *H_BC*= contemporary group defined based on the herd and birth date; *HY*= Herd-Year; *HY-asex-mgt* = contemporary group defined based on HY, asex and management group; *HYS* = Herd-Year-Season; *HYS_mgt*= contemporary group defined by herd, management group and year of birth; *individual* = individual situation; *parity*= parity number; *pariaaca*= interaction between parity and aaca; *paridamage*= interaction between parity and agedam; *MPE*= maternal permanent environmental effect; *SEAS*= season; *SI*= Simmental breed percentage; *twin*= twinning; *UN*= Unknown breeds percentage; *w_Dam_b*= breed of the weaning dam; *YEAR*= year of birth; *yearmonth*=interaction between year and month of birth.

Table 5. Covariate effects per population, Limousin and Aberdeen Angus.

Breed	Country[1]	Covariates[2]																					
	CZE																						
	DFS																						
	ESP																						
	GBR	agedam	agedam2																				
	IRL	agedam2	AAWG	HET	REC	AA	BB	CH	HE	HO	SI	UN	OB	OD	DAA	DBB	DCH	DHE	DHO	DSI	DUN	DOB	DOD
	FRA																						
LIM	DEU																						
	CHE	agedam	agedam2																				
	AUS																						
	SVN																						
	LVA																						
	EST																						
	CZE																						
	DFS																						
	DEU																						
AAN	IRL	agedam2	AAWG	HET	REC	AA	BB	CH	HE	HO	SI	UN	OB	OT	DAA	DBB	DCH	DHE	DHO	DSI	DUN	DOB	DOD
	CHE	agedam	agedam2																				
	EST																						

[1]CZE = Czech Republic, DFS = Denmark, Finland and Sweden, ESP = Spain, GBR = Great Britain, IRL = Ireland, FRA = France, DEU = Germany, CHE = Switzerland; AUS= Australia; SVN = Slovenia, LVA = Latvia, EST= Estonia.
[2]*AA*= Aberdeen Angus breed percentage; *AAWG*= age at weighting; *agedam*= age of the dam; *agedam2* = age of the dam squared; *BB*= Belgian Blue breed percentage;*CH*= Charolais breed percentage; *DAA*= Aberdeen Angus percentage in the dam; *DBB*= Belgian Blue percentage in the dam; *DCH*= Charolais percentage in the dam; *DHE*= Hereford percentage in the dam; *DHO*= Holstein percentage in the dam; *DSI*= Simmental percentage in the dam; *DUN*= percentage of unknown breeds in the dam; *DOB*= percentage of other breed bulls in the dam; *DOD*= percentage of other breed dams in the dam; *HE*= Hereford breed percentage; *HET*= heterosis estimation; *HO*= Holstein breed percentage; *HY*= Herd-Year; *HYS* = Herd-Year-Season; *OB*= Other breed bull percentage; *OD*= Other breed Dam percentage; *SI*= Simmental breed percentage; *UN*= Unknown breeds percentage.

Table 6. Direct and Maternal correlations within and across participating organisations and heritabilities in aww evaluation, Limousin.

		Direct												Maternal											
		CZE	DFS	ESP	GBR	IRL	FRA	DEU	CHE	AUS	SVN	LAT	EST	CZE	DFS	ESP	GBR	IRL	FRA	DEU	CHE	AUS	SVN	LAT	EST
Direct	CZE	**0.41**																							
	DFS	0.84	**0.27**																						
	ESP	0.78	0.82	**0.26**																					
	GBR	0.79	0.83	0.88	**0.34**																				
	IRL	0.81	0.81	0.84	0.88	**0.35**																			
	FRA	0.78	0.86	0.79	0.83	0.79	**0.35**																		
	DEU	0.76	0.85	0.76	0.78	0.76	0.79	**0.21**																	
	CHE	0.82	0.84	0.77	0.77	0.77	0.76	0.76	**0.29**																
	AUS	0.76	0.8	0.77	0.78	0.76	0.77	0.76	0.76	**0.15**															
	SVN	0.69	0.7	0.69	0.77	0.69	0.72	0.67	0.69	0.68	**0.41**														
	LAT	0.74	0.75	0.74	0.76	0.75	0.75	0.73	0.74	0.74	0.67	**0.12**													
	EST	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	**0.46**												
Maternal	CZE	**0.12**	0	0.02	0.5	0	0.03	0	-0.01	0.03	-0.12	0	0	**0.12**											
	DFS	0.01	**0.12**	0.02	0.04	0.03	0.02	0.02	0.02	0.03	-0.1	0.02	0	0.68	**0.09**										
	ESP	0.01	0.03	**0.13**	0.03	0.01	0.03	0.02	0.03	0.03	-0.1	0.01	0	0.67	0.73	**0.08**									
	GBR	0.03	-0.02	-0.16	**0.7**	0.02	0.01	0.03	0.04	-0.11	0.01	0.01	0	0.67	0.74	0.67	**0.08**								
	IRL	0.01	0.04	0	0.02	**0.15**	0.03	0.01	0.03	0.03	-0.1	0.02	0	0.67	0.76	0.72	0.68	**0.04**							
	FRA	0.01	-0.01	0.02	0.03	0.02	**0.1**	-0.01	0.03	0.02	-0.11	0.01	0	0.64	0.67	0.67	0.66	0.71	**0.09**						
	DEU	0.01	0	0.02	0.04	0.02	0.01	**0.18**	0.02	0.02	-0.1	0.01	0	0.66	0.68	0.68	0.68	0.73	0.65	-					
	CHE	0	0.02	0.03	0.05	0.03	0.03	0.02	**0.07**	0.03	-0.11	0.01	0	0.64	0.72	0.7	0.73	0.72	0.68	0.67	**0.06**				
	AUS	0.02	0.03	0.02	0.04	0.03	0.03	0.02	0.02	**0.09**	-0.1	0.02	0	0.69	0.76	0.73	0.74	0.74	0.71	0.7	0.73	**0.1**			
	SVN	-0.08	-0.06	-0.08	-0.14	-0.07	-0.11	-0.1	-0.08	-0.09	**0.22**	-0.1	0	0.54	0.57	0.56	0.56	0.57	0.54	0.57	0.55	0.58	-		
	LAT	-0.03	0.01	-0.02	0.01	-0.02	-0.01	-0.05	-0.02	-0.04	-0.12	**0.02**	0	0.54	0.59	0.58	0.56	0.59	0.54	0.58	0.57	0.6	0.46	-	

CZE = Czech Republic, DFS = Denmark, Finland and Sweden, ESP = Spain, GBR = Great Britain, IRL = Ireland, FRA = France, DEU = Germany, CHE = Switzerland; AUS= Australia; SVN = Slovenia, LVA = Latvia, EST= Estonia. Heritabilities of the trait for each organisation is shown in bold on the diagonals.

Table 7. Direct and Maternal correlations within and across participating organisations and heritabilities in aww, Aberdeen Angus.

		Direct						Maternal					
		CZE	DEU	DFS	IRL	CHE	EST	CZE	DEU	DFS	IRL	CHE	EST
Direct	CZE	**0.42**											
	DEU	0.8	**0.21**										
	DFS	0.77	0.77	**0.22**									
	IRL	0.7	0.7	0.7	**0.35**								
	CHE	0.7	0.75	0.76	0.7	**0.29**							
	EST	0.74	0.74	0.74	0.74	0.74	**0.46**						
Maternal	CZE	**0.12**	-0.04	-0.01	0	0.01	0	**0.13**					
	DEU	-0.02	**0.18**	-0.01	0	-0.01	0	0.64	**-**				
	DFS	0	-0.01	**0.17**	0	0	0	0.68	0.67	**0.14**			
	IRL	0	0	0	**0.15**	0	0	0.7	0.69	0.71	**0.04**		
	CHE	0.01	-0.01	0	0	**0.07**	0	0.71	0.69	0.71	0.7	**0.06**	
	EST	0	0	0	0	0	-	0	0	0	0	0	**-**

CZE = Czech Republic, DFS = Denmark, Finland and Sweden, IRL = Ireland, DEU = Germany, CHE = Switzerland. Heritabilities of the trait for each organisation is shown in bold on the diagonals.

Table 8. Variance components for direct genetic effect (d), maternal genetic effect (m), maternal permanent environmental effect (em) and residual (e) for each participating organisation, Limousin and Aberdeen Angus.

		LIM					AAN		
Country	σ^2_d	σ^2_m	σ^2_{em}	σ^2_e	Country	σ^2_d	σ^2_m	σ^2_{em}	σ^2_e
AUS	125	71	81	546	CHE	380	94	76	587
CHE	381	96.9	76	587	CZE	686	197	208	377
CZE	689	203	208	377	DEU	383	326	-	719
DEU	390	331	-	719	DFS	128	99.1	81	302
DFS	278	127	90	547	EST	351	-	-	412
ESP	138	70.6	43	294	IRL	450	194	45	647
EST	372	-	-	412					
FRA	245	67.2	63	354					
GBR	273	60.8	63	421					
IRL	452	199	45	647					
LVA	194	34.5	-	590					
SVN	944	531	-	626					

CZE = Czech Republic, DFS = Denmark, Finland and Sweden, ESP = Spain, GBR = Great Britain, IRL = Ireland, FRA = France, DEU = Germany, CHE = Switzerland; AUS= Australia; SVN = Slovenia, LAT = Latvia, EST= Estonia.

4. Results and Discussion

4.1. Descriptive statistics of performances in all participating organisations

Descriptive statistics for LIM and AAN populations of the participant organisations are presented in Table 9. The average aww for Estonian LIM was 260 kg (± 43kg) while the average aww of Estonian AAN was 253 kg (± 48kg).

Table 9. Descriptive analysis of aww for Limousin and Aberdeen Angus per country.

Breed	Country	No. animals	Mean	SD	Minimum	Maximum
LIM	CZE	15,547	277.88	40.88	81	454
	DFS	97,654	227.16	41.72	43	408
	ESP	33,191	257.00	42.59	147	376
	GBR	134,987	272.11	43.98	69	496
	IRL	170,090	289.45	53.75	110	535
	FRA	2,982,700	264.71	40.57	130	466
	DEU	117,947	255.98	43.60	101	499
	CHE	39,117	221.37	39.36	61	471
	AUS	68,762	246.71	42.93	56	468
	SVN	2,547	255.04	41.23	137	410
	LAV	6,142	247.74	41.15	122	379
	EST	4,565	260.33	43.47	108	450
AAN	CZE	35,848	274.27	44.29	77	454
	DEU	117,683	249.08	42.22	97	490
	DFS	56,593	226.90	45.23	44	424
	IRL	18,126	267.05	53.88	108	505
	CHE	57,869	218.06	39.67	60	456
	EST	4,798	253.63	48.34	100	470

CZE = Czech Republic, DFS = Denmark, Finland and Sweden, ESP = Spain, GBR = Great Britain, IRL = Ireland, FRA = France, DEU = Germany, CHE = Switzerland; AUS= Australia; SVN = Slovenia, LVA = Latvia, EST= Estonia.

Participating organisations with relatively small populations have been previously reported to be those that benefited the most from joining the international genetic evaluation because of the addition of international information. These organisations obtained a larger panel of international breeding animals to choose from, as well as access to the best ranked international bulls ordered according to the local scale (Bonifiazi *et al.*, 2020a; Venot *et al.*, 2014). This was expected to also be the case for EST, considering the amount of submitted performances compared to other organisations.

In previous studies for LIM, FRA was reported to be the organisation with the highest impact in the international evaluation; in these studies, this fact was related to its number of performances (Bonifazi *et al.*, 2020a, Venot *et al.*, 2008). Therefore, French animals were expected to represent important genetic links between organisations in the present evaluation.

Following the mentioned trend of FRA, in the case of AAN, DEU was expected to have an important impact in the evaluation.

4.2. Analysis of variance in Estonian performances.

4.2.1. All effects

All effects fitted in Estonian model showed to have levels with a similarly significant effect over aww in both breeds (Table 10). The linear models showed an R^2 for Estonian LIM and AAN of 0.39 and 0.53, respectively.

Table 10. Summary of multi-factor ANOVA test for all simultaneous effects in Estonian Limousin and Aberdeen Angus.

Breed	Effect	Df	F value	P value
LIM	ASEXTWIN	3	181.28	< 0.001
	HYS	159	12.61	< 0.001
	YEAR	19	13.04	< 0.001
	AACA	3	114.78	< 0.001
	Residuals	4,380		
AAN	ASEXTWIN	3	269.28	< 0.001
	HYS	154	28.97	< 0.001
	YEAR	18	8.91	< 0.001
	AACA	3	67.08	< 0.001
	Residuals	4,619		

In the case of Estonian LIM, the inclusion of YEAR effect did not contribute to the R^2 of the model. HYS and YEAR effects were found to overlap, resulting in YEAR being confounded with HYS (data not shown). This can explain why the observed R^2 for Estonian LIM was lower than the one for Estonian AAN, and also suggested that YEAR could be excluded from Estonian LIM model.

4.2.2. Sex of Animal and presence of twins (ASEXTWIN)

The trend shown by the effect's levels according to each one's average aww for Estonian LIM and ANN are presented in Figure 3 and Figure 4, respectively.

In Estonian LIM the level with the highest average aww was: "single males" (2519 individuals) with 258kg (± 43kg) while the level with the lowest average aww was "females with twins" (40 individuals) with 207kg (± 38kg) (Figure 3). In Estonian AAN the levels were: "single males" (2460 individuals) with 252kg (± 48kg), and "females with twins" (117 individuals) with 206kg (± 40kg) (Figure 4).

In beef cattle rearing, female calves generally reach a lower weaning weight than male calves (Szabó *et al.*, 2006), this is true even in the presence of twins. In addition, calves from twin pregnancies also generally reach a lower weaning weight than calves from non-twin pregnancies (Suzuki *et al.*, 1998).

However, the size of the sample can have an effect on the estimates. If it is too small this could add variability or bias (Fosgate, 2009). The effect of the group size could explain why in the average aww of males with twin siblings did not show a significant difference to that of females with no twin siblings.

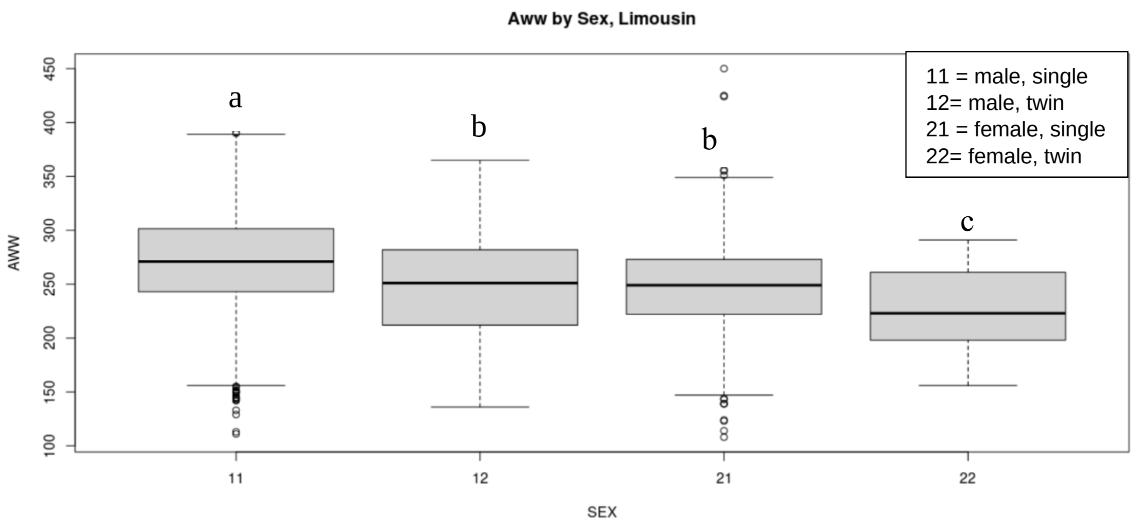

Figure 3. Adjusted weaning weight by Sex, Estonian Limousin. Least square means of the levels sharing a letter are not significantly different (Tukey- adjusted comparisons).

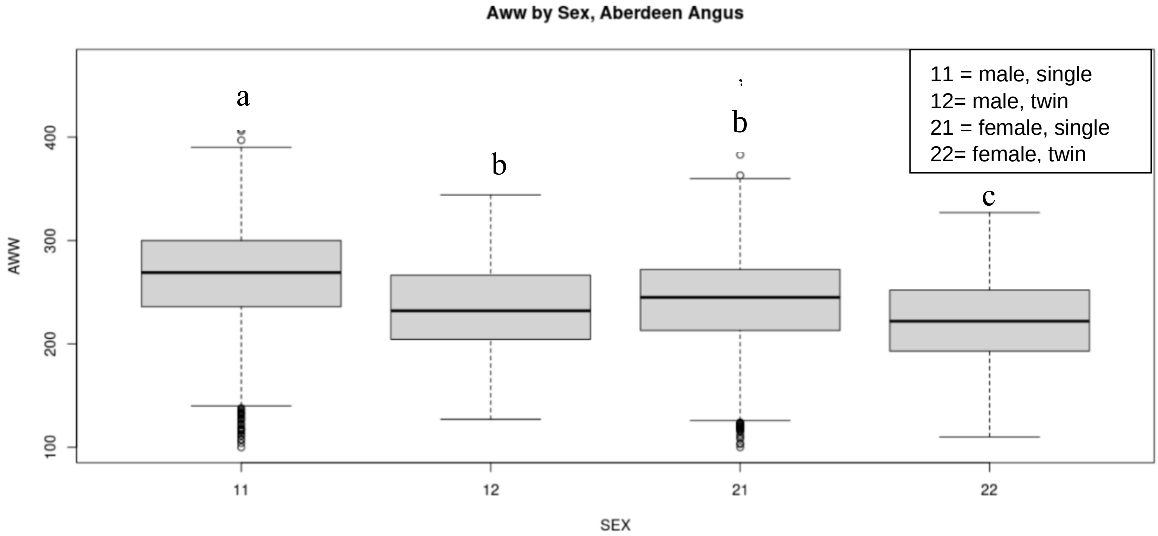

Figure 4. Adjusted weaning weight by Sex, Estonian Aberdeen Angus. Least square means of the levels sharing a letter are not significantly different (Tukey- adjusted comparisons).

4.2.3. Age at calving (AACA)

The effect of age at calving on aww for Estonian LIM and ANN are presented in Figure 5 and Figure 6, respectively.

In Estonian LIM the level with the highest average aww was “oldest dams” group (3610 individuals) with 253kg (± 43kg) while the level with the lowest average aww was “youngest dams” (152 individuals) with 219kg (± 41kg) (Figure 5). In the case of Estonian AAN, the levels were: “oldest dams” (3811 individuals) with 242kg (± 47kg), and “youngest dams” (324 individuals) with 219kg (± 48kg) (Figure 6).

Figure 5. Adjusted weaning weight by Age at calving, Estonian Limousin. Least square means of the levels sharing a letter are not significantly different (Tukey- adjusted comparisons).

Figure 6. Adjusted weaning weight by Age at calving, Estonian Aberdeen Angus. Least square means of the levels sharing a letter are not significantly different (Tukey- adjusted comparisons).

In previous studies primiparous cows have been reported to produce less milk than multiparous cows, this has an impact on the growth of the calf which results in achieving a lower weaning weight. As the dam grows older, the milk production improves, and consequently, calves achieve a higher weaning weight (Swali & Wathes, 2007). This tendency is followed by Estonian LIM (Figure 5).

Environmental factors have been reported to have an effect over the volume of milk produced by the dam that can result in differences between the expected milk production and the observed one (M'hamdi *et al.*, 2012), therefore, decreased milk production of the dam could result in a lower weaning weight of the offspring. This could explain why there was no significant difference between the average aww of cows in group 2 and group 3 of Estonian AAN.

4.2.4. Year of Birth (YEAR)

Figure 7 and Figure 8 show the distribution of aww within each year of birth for Estonian LIM and AAN, respectively.

For Estonian individuals of both breeds, there was no clear behaviour of average aww for the considered period.

Birth years are generally considered as environmental fixed effects in genetic evaluations (Swali & Wathes, 2007; Venot *et al.*, 2009a; Lopez *et al.*, 2020). This is because there are different environmental conditions every year, and these conditions could have an effect over the individuals. For example, droughts and rainfalls affect the pastures and their availability, this in turn has a repercussion on the dam´s nutrition. In consequence, there is an effect on the offspring's birth weight related to the uterine environment present during the gestation (Assan, 2013).

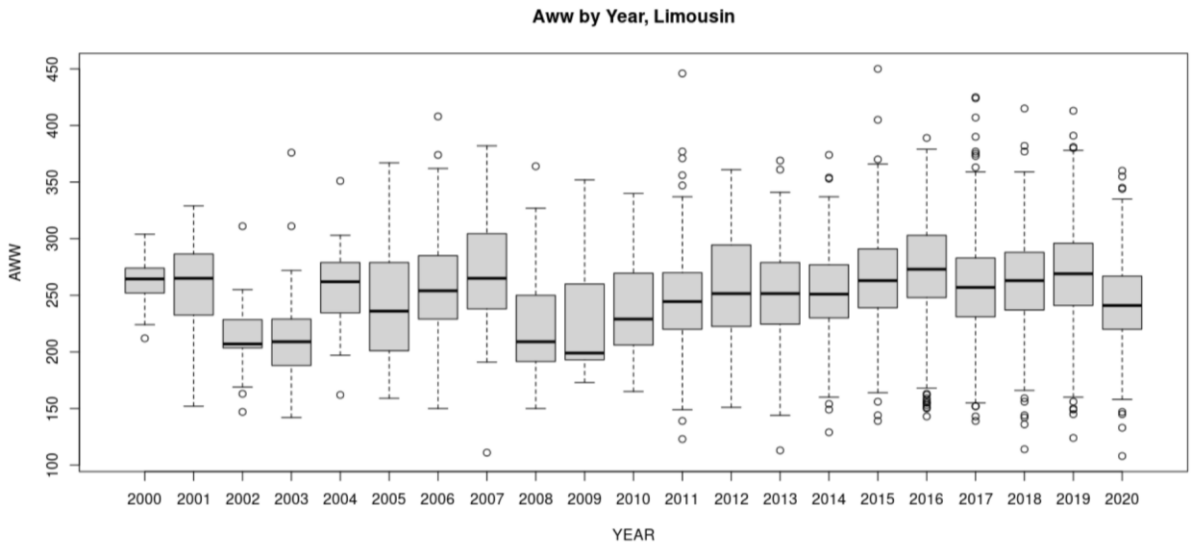

Figure 7. Adjusted weaning weight by year of birth, Estonian Limousin.

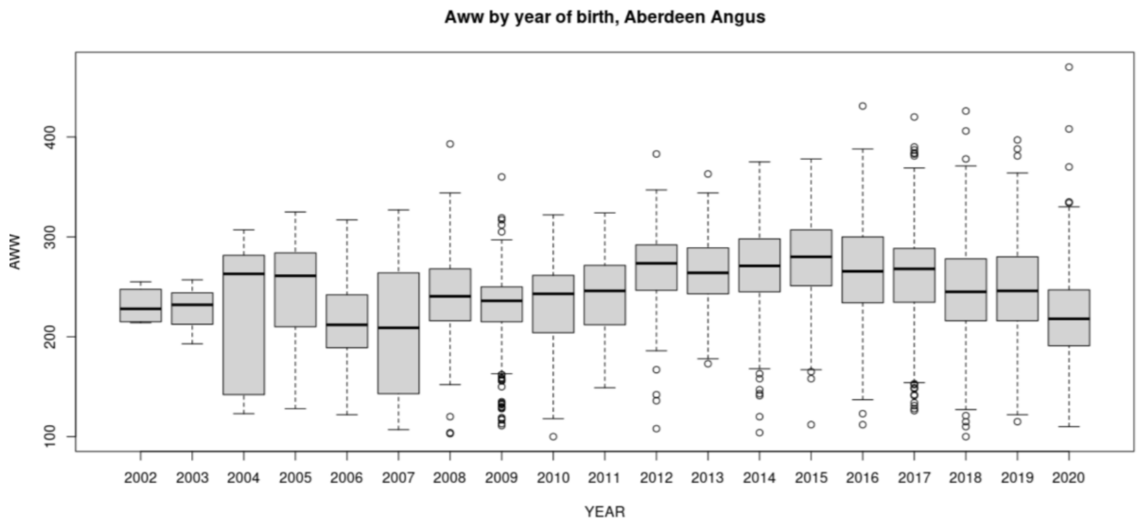

Figure 8. Adjusted weaning weight by year of birth, Estonian Aberdeen Angus.

4.3. International and pseudo-national EBVs on Estonian Scale

In the international evaluation, EST obtained EBVs on its own scale for all animals in the international pedigree for both breeds. As the international pedigree for LIM was larger, a greater amount of EBVs were obtained for LIM than for AAN (Table 11).

The correlation between international and pseudo-national EBVs was 0.67 ($p < 0.001$) for the 11,618 Estonian LIM animals and 0.79 ($p < 0.001$) for the 11,751 Estonian AAN.

The level of the correlations showed a good consistency between the international and the pseudo-national EBVs, with some expected variation considering the different approaches used in the evaluations.

The higher correlation found for AAN suggested a lower impact of international information over Estonian EBVs as it was expected to observe a lower variation of EBVs thanks to the international evaluation. This could be related to a smaller number of international performance records related to Estonian AAN, that in turn would have less effect over international EBVs and, therefore, the resulting correlation between pseudo-national and international EBVs would be higher.

Table 11. Number of International and pseudo-national EBVs in Estonian scale for Limousin and Aberdeen Angus.

LIM		AAN	
Evaluation	No. EBVs	Evaluation	No. EBVs
International	4,292,204	International	376,347
Pseudo-national	11,618	Pseudo-national	11,751

In the international evaluation, pedigree information of each participating organisation is merged into a common pedigree. Therefore, when an organisation participates in an international genetic evaluation, a larger spectrum of breeding animals in the domestic scale is provided (Venot *et al.*,2014). Upon joining the international evaluation, EST received a substantial amount of international EBVs for foreign animals for both LIM and AAN breeds (Table 11), from which breeding animals could be selected.

4.4. Descriptive analysis of EBVs and Reliabilities.

Descriptive statistics for Estonian LIM and AAN EBVs and reliabilities are presented in Table 12 and 13, respectively. In Estonian LIM, an increase of 8 kg in the average international EBV was observed along with a 0.12 increase in the average international reliability (Table 12) while Estonian AAN showed an EBV average increase of 4 kg and of 0.09 in reliability (Table 13).

Table 12. Descriptive statistics of Pseudo-national and International EBVs and Reliabilities in Estonian Limousin (No. Animals 11,618).

Evaluation	Estimates	Mean	SD	Min.	1st Quartile	Median	3rd Quartile	Max.
Pseudo-national	EBVs	-1.39	12	-66.51	-6.27	-1.58	3.66	72.8
	Reliability	0.28	0.23	0	0.02	0.3	0.51	0.96
Int.	EBVs	6.72	13.64	-62.22	-1.83	6.26	15.17	80.83
	Reliability	0.4	0.15	0	0.29	0.41	0.53	0.96

Table 13. Descriptive statistics of Pseudo-national and International EBVs and Reliabilities in Estonian Aberdeen Angus (No. Animals 11,751).

Evaluation	Estimates	Mean	SD	Min.	1st Quartile	Median	3rd Quartile	Max.
Pseudo-national	EBVs	-1.81	11.64	-70.96	-6.91	-0.4	3.38	64.84
	Reliability	0.27	0.23	0	0.02	0.27	0.51	0.94
Int.	EBVs	2.67	13.2	-65.28	-5.14	2.34	10.79	69.61
	Reliability	0.36	0.18	0	0.22	0.39	0.52	0.94

These results confirmed the expected variation of EBVs and reliabilities comparing pseudo-national and international genetic evaluations. The change in EBVs and reliabilities depend on the data and the pedigree associated to each individual and its relatives; considering the performance of foreign progeny, for example, in the case of AI (Venot *et al.*, 2008; 2009b). Increase in reliabilities of Estonian individuals was expected to come from the inclusion of foreign progeny performance, affecting directly the reliability of the sires, or improving the individual's reliability by having a sire with improved reliability due to its progeny abroad.

4.5. Reliabilities

Reliability is an important parameter in animal breeding. It measures the precision of EBVs (Gorjanc *et al.*, 2015). This precision is related to the amount of information used for the estimation of breeding values (Harris & Johnson, 1998). For example, a sire with numerous progenies, will have a highly reliable EBV (DairyNZ, 2021). Therefore, with the addition of international information, the increase in reliability of Estonian individuals with genetic links abroad was expected.

With an increase of reliabilities, the increase of the number of bulls suitable for international use could take place, and thus, offer an economic incentive to Estonian breeders through the commercialization of semen doses.

4.5.1. Distribution of Pseudo-national and International reliabilities in Estonian individuals.

The distribution of Estonian LIM and AAN reliabilities in pseudo-national and international evaluations are presented in Figures 9 and 10, respectively. As expected, marked differences were found between the reliabilities of EBVs in both breeds.

In Estonian LIM almost 40% of pseudo-national EBVs had a reliability between 0 and 0.10. In the international evaluation, a marked decrease of more than 30% of this category of EBVs was observed. Also, the EBVs with a reliability between 0.20 and 0.30 showed the largest proportion increase, going from almost 10% of the total EBVs in the pseudo-national evaluation to 20% in the international evaluation (Figure 9).

The largest proportion of Estonian LIM EBVs (30%) showed a reliability between 0.40 to 0.50 owing to the international evaluation, while more than 60% of the EBVs showed a reliability between 0.10 to 0.50. More than 10% of the international EBVs had a reliability over 0.50 (Figure 9).

In Estonian AAN, the proportion of EBVs with 0 to 0.10 reliability dropped more than 30% in the international evaluation, while EBVs with 0.20 to 0.30 reliability were doubled. 70% of Estonian AAN's EBVs showed a reliability between 0.20 to 0.50 in the international evaluation (Figure 10).

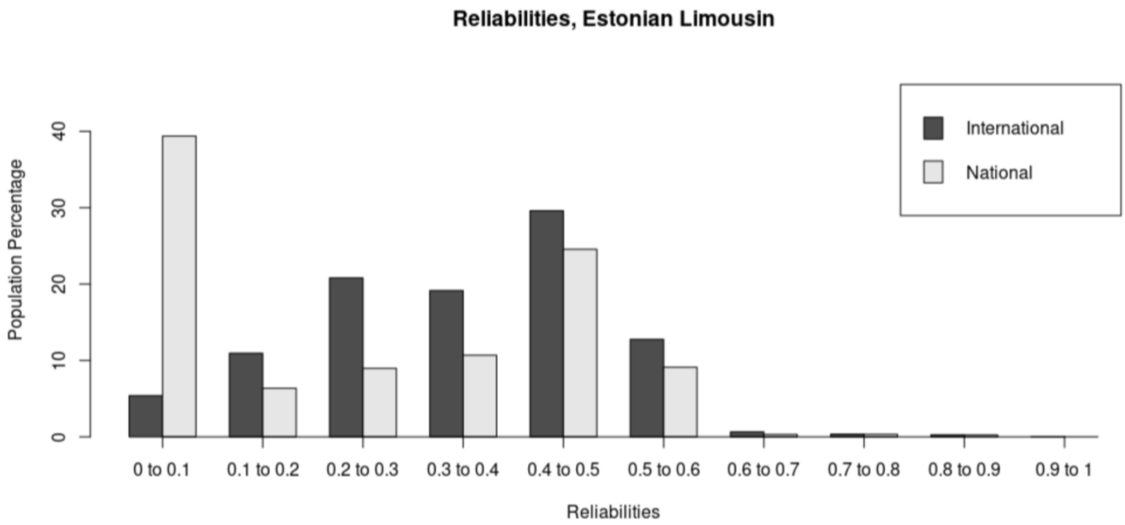

Figure 9. Pseudo-national and International reliability distribution, Estonian Limousin

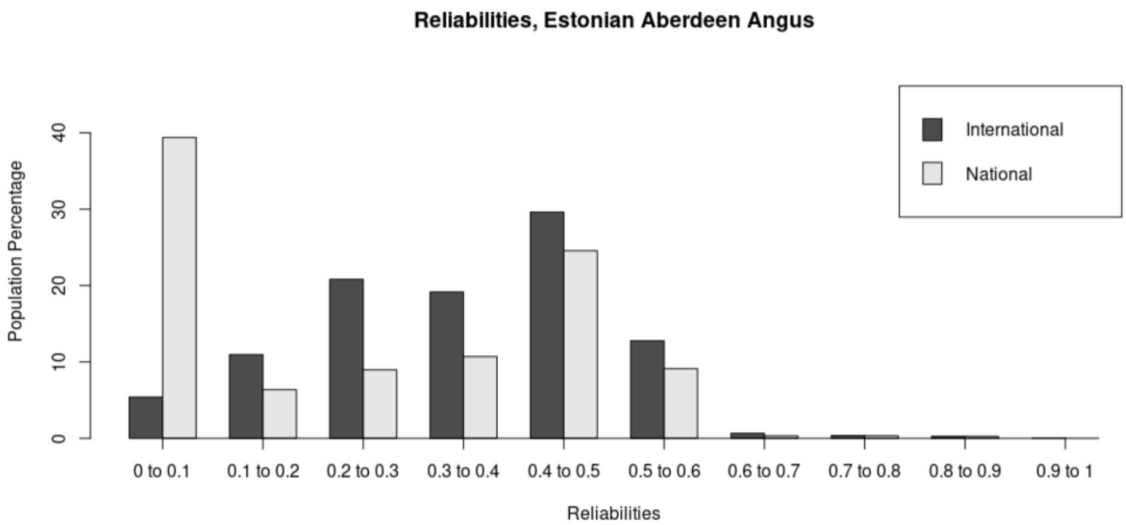

Figure 10. Pseudo-national and International reliability distribution, Estonian Aberdeen Angus.

The marked reduction in the proportion of EBVs with low reliabilities in international evaluation is consistent with previous studies. There, organisations with a small proportion of entries in the international evaluation had substantial benefits for individuals with low reliability. These organisations went from having individuals in the first quartile with a reliability of 0 to having the same individuals with a 0.40 reliability (Bonifazi et al., 2020; Venot et al., 2009b). According to Venot et al. (2014) this is due mainly to bulls with progeny abroad. However, with a good direct genetic correlation between countries, the domestic bulls' reliabilities can also benefit (Venot et al., 2009b).

4.5.2. Reliability differences between International and pseudo-national EBVs in Estonian individuals.

The distribution of the proportion of Estonian LIM and AAN that showed reliability differences between 0.01 and 0.70 are presented in Figure 11 and 12. A total of 5633 Estonian LIM (48%) and 6028 Estonian AAN (51%) showed no difference between pseudo-national and International reliabilities. These individuals were primary animals without any connection to foreign animals.

For the individuals that showed reliability improvement, Estonian AAN had a larger proportion of EBVs with a reliability differences between 0.01 and 0.10 (Figure 12) than EBVs showing the same improvement in Estonian LIM (Figure 11). Similarly, the proportion of EBVs with a difference between 0.10 and 0.20 was larger in Estonian AAN (Figure 12). However, proportions of EBVs with a reliability improvement over 0.20 were larger in Estonian LIM (Figure 11). Estonian LIM had an average difference of 12%, while Estonian AAN's was 9%.

For the individuals showing reliability differences in Estonian LIM, 767 were individuals with performance records in Estonia; 763 of them benefited from sires with performances and progeny abroad, while 4 individuals had progeny abroad. The remaining 5218 were individuals that had performance records abroad. In addition, 1501 foreign individuals were sired by the latter.

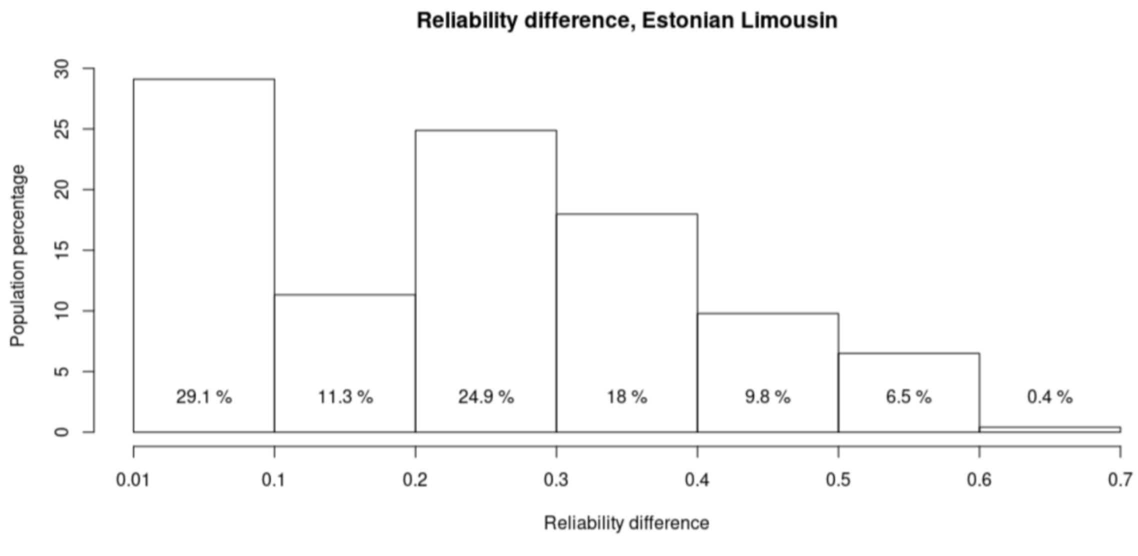

Figure 11. Reliability differences between International and Pseudo-national EBVs for Estonian Limousin. The total percentage of the population represented by each bin is written in text in the Figure.

Comparably, in Estonian AAN 737 individuals had performance records in Estonia; 5 had progeny abroad while the rest benefited from sires with foreign performances and progeny. The remaining 4986 individuals had performances abroad and 1393 foreign individuals were sired by these.

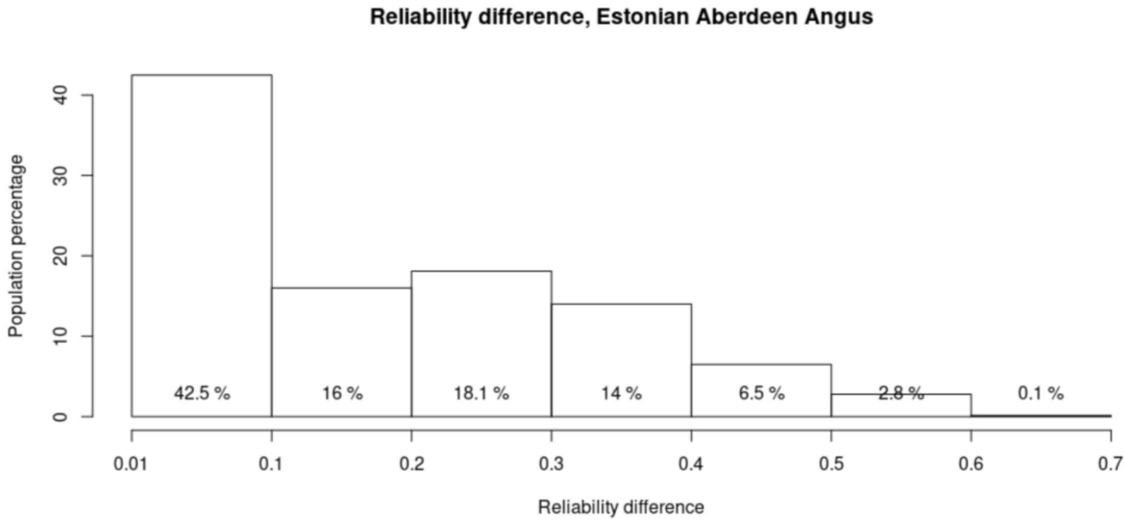

Figure 12. Reliability differences between International and Pseudo-national EBVs for Estonian Aberdeen Angus. The total percentage of the population represented by each bin id written in text in the Figure.

The observed distributions of reliability differences in Figure 11 and Figure 12 resemble those found by Bonifazi *et al.* (2020a), where the largest proportion of EBVs in all evaluated organisations showed a reliability difference between 0 and 0.10. Also, the average reliability estimated for Estonian LIM ranged between those found by Bonifazi *et al.* (2020a) where the highest direct EBVs average reliability difference was 0.24 and the lowest 0.02.

In an international evaluation, across-country estimated correlations are necessary for the calculation of international EBVs (Phocas *et al.*, 2005). The correlations are calculated from the genetic links between countries, which are generally sires with progeny in different countries (Bonifazi *et al.*, 2020b; Venot *et al.*, 2009b). Good genetic correlations between countries is expected to result in the increase in reliability (Bonifazi *et al.*, 2020a; Venot *et al.*, 2014).

The overall larger proportion of improved reliabilities and higher reliability differences of Estonian LIM can be explained by the correlations set in the matrix used for the evaluation, as well as the larger number of populations and performances within each population. This is because the larger the population size, the higher the number of possible genetic links; additionally, the assumed correlation guarantees a good connection between EST and the other participating organisations.

Furthermore, in agreement with previous published results (Venot *et al.*, 2008; Venot *et al.*, 2014), it was observed that the individuals on both breeds which benefited the most from the international evaluation were foreign animals used as sires or dams, along with bulls which had foreign progeny. In the previous studies average increase in reliabilities ranged between 0.12 to 0.46 for individuals with no local progeny (Venot *et al.*, 2008; Venot *et al.*, 2014)

However, it must be mentioned that the pseudo-national EBVs and reliabilities obtained in the present study, were estimated using the full international Interbeef pedigree, which has more information compared to the one used for EBVs estimation in Estonia during real national evaluations (Bonifazi *et al.*, 2020a; Interbull Centre, 2019b). This could result in pseudo-national EBVs with higher reliability than national EBVs.

The possible difference between real and pseudo-national EBVs' reliability, due to the use of the international pedigree, could also influence the proportion of EBVs found with no improvement, reducing the number of individuals achieving a 0.01 reliability difference.

4.5.3. Comparison of pseudo-national and international EBVs by different levels of reliability in Estonian individuals.

As the reliability threshold level increased, the correlation between pseudo-national and international EBVs within each threshold level also increased. This was the case in both Estonian LIM and AAN (Table 14).

Table 14. Number of EBVs of both evaluations in both breed after a joint reliability (REL) threshold filter

	LIM		AAN	
Threshold	No.Animals	Correlation	No.Animals	Correlation
5% REL	8,057	0.79	7,897	0.88
10% REL	7,412	0.89	7,257	0.93
30% REL	5,809	0.98	5,638	0.99
50% REL	3,062	0.99	3,056	0.99

High correlations among international and pseudo-national EBVs have been reported previously as the low possibility of sires being re-ranked when moving to the international evaluation (Phocas *et al.*, 2004; Venot *et al.*, 2008). This can be explained by the sires' EBVs being less affected by the inclusion of international information.

Similarly, in the case of Estonian animals, as the reliability level increased, the individuals within those levels had EBVs which were less affected by international data, and therefore the correlation between pseudo-national and international EBVs increased.

As the reliability level increased, the individuals whose reliabilities benefited the most from the international evaluation were progressively left out. The remaining individuals, (those with already high reliabilities) were expected to be individuals with local progeny and no links abroad, whose reliability was not expected to increase with the introduction of international information (Venot *et al.*, 2008), along with individuals with local progeny but also links abroad. This last group was expected to show some differences in reliability in the international evaluation.

4.5.4. Reliability differences for different levels of reliability

As expected, as the reliability threshold level increased, the proportion of individuals that showed no reliability differences also increased. On the other hand, as the reliability thresholds increased, the reliability differences showed by the EBVs were smaller. This occurred in both Estonian LIM and AAN.

In the case of Estonian LIM, 67% of the individuals within the at least 0.05 reliability level showed no reliability improvement (data not shown). The remaining 32% showed reliability differences between 0.01 and 0.60, the distribution of differences in reliabilities between EBVs of these individuals are presented in Figure 11A.

In the group of at least 0.10 reliability Estonian LIM, 27% of the group showed reliability differences between 0.01 and 0.50 (Figure 11B). A larger proportion of EBVs with reliability differences between 0.01 and 0.10 was observed in this group. The remaining 72% of the individuals showed no reliability improvement (Not shown in the graph).

The at least 0.30 reliability Estonian LIM had a proportion 81% of individuals with no improvements (data not shown). The reliability differences of the remaining 19% of the individuals are shown in Figure 11C; most of these individuals had a reliability difference between 0.01 and 0.10.

Finally, 86% of Estonian LIM with at least 0.50 reliability had no reliability improvement in the international evaluation. The differences of the remaining 14% are shown in Figure 11D, nevertheless, almost 100% of these had an improvement between 0.01 and 0.10.

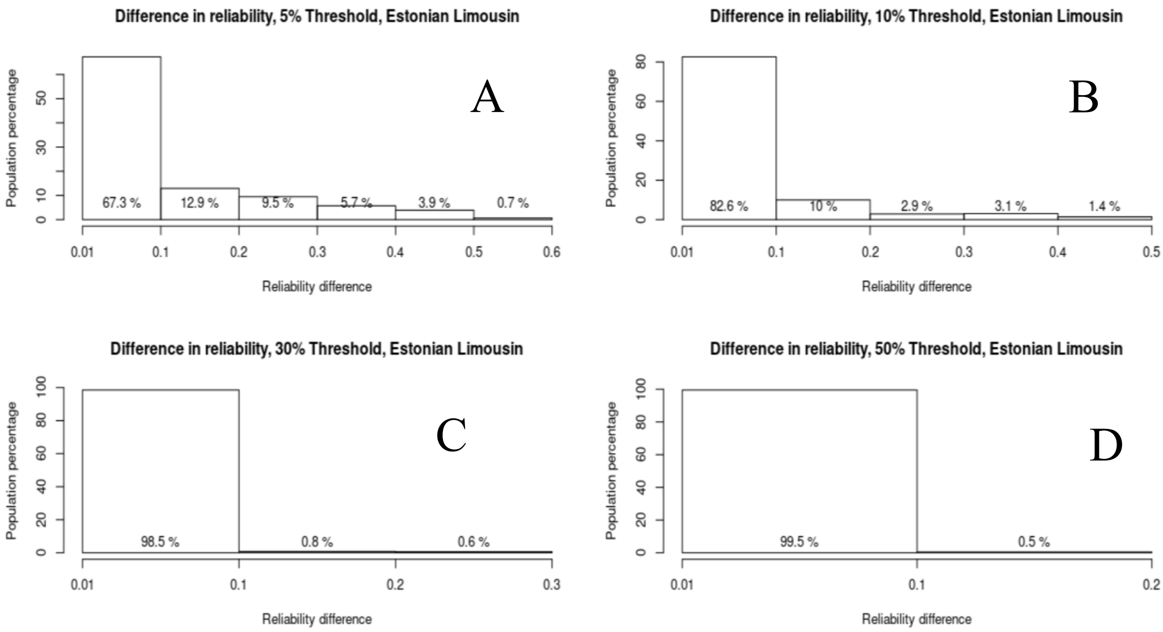

Figure 13.Reliability differences between International and Pseudo-national EBVs for Estonian Limousin in different reliability levels (A-D). The total percentage of the population represented by each bin is written in text in the Figure. The reliability is expressed from 0 to 1.

A similar trend was followed by Estonian AAN. In the group of at least 0.05 reliability (Figure 12A), 30% of individual showed reliability differences between 0.01 to 0.60. The remaining 70% of the individuals did not show improvements in reliabilities (data not shown).

73% of the at least 0.10 reliability Estonian AAN showed no reliability improvements. The rest had differences between 0.01 and 0.60. This group achieved a higher range of reliability differences than the 0.10 Estonian LIM group. Also, there was a larger proportion of EBVs with differences between 0.01 to 0.10 compared to Estonian AAN with 0.05 reliability (Figure 12B).

In the 0.30 Estonian AAN group, 80% of the individuals did not show improvement (data not shown). Reliability differences ranged between 0.01 and 0.30 (Figure 12C).

In the last group (0.50 reliability), 84% of the individuals showed no improvement (data not shown) while the remaining individuals showed reliability differences between 0.01 and 0.20 (Figure 12D). Almost 100% of the individuals with reliability differences had an improvement between 0.01 and 0.10.

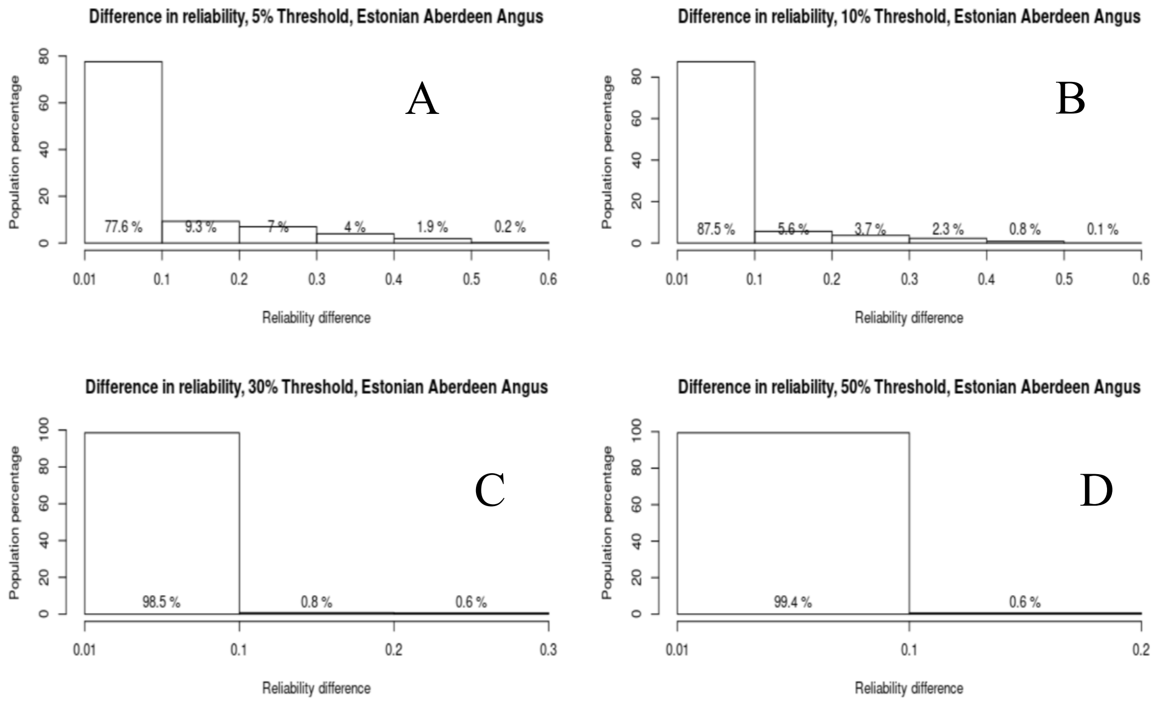

Figure 14. Reliability differences between International and Pseudo-national EBVs for Estonian Aberdeen Angus in different reliability levels (A-D). The total percentage of the population represented by each bin is written in text in the Figure. The reliability is expressed from 0 to 1.

Lower correlations between EBVs suggest that re-ranking of individuals within a data set can occur and as the correlation increases, the possibility of re-ranking decreases (Phocas *et al.*, 2004; Venot *et al.*, 2008). This also suggests that with a lower correlation, a larger impact of the international evaluation on the EBVs can be seen and therefore a larger difference in reliability could occur.

As it was seen in Figure 11A and 12A, with a lower correlation between EBVs a wider range of reliability differences was achieved. This range decreased as the reliability level increased. The latter could be related to the decreased impact of the international evaluation on EBVs with already high reliability, such reduced impact is suggested by the increased correlations between EBVs within high reliability levels.

In previous studies, FRA was the least affected organisation in regards of reliability increase when moving to an international evaluation in LIM. This was associated to the already large national French data which was not highly affected with the introduction of international data (Bonifazi *et al.*, 2020a; Venot *et al.*, 2008). A similar behaviour was observed by Estonian individuals with already high reliabilities in the pseudo-national evaluation. These individuals showed however some increase in reliability when moving to the international evaluation.

Also, as the reliability level increased, so did the proportion of animals with no improvement. This could also be related to the lower impact that international data have over animals with higher reliabilities. Additionally, individuals with local progeny and no links abroad can also be included in this propotion.

4.6. Sires used in Estonia

4.6.1. Country of origin of the sires used in Estonia

According to IDEA´s pedigree, Estonian LIM that had local performances were sired by 195 different bulls from 10 different countries of origin. Local Estonian AAN had 206 different sires from 11 different countries of origin. The siring countries of individuals along with the number of sires original from each country and the number of sired offspring in both breeds are presented in Tables 15 and 16, respectively.

In Estonian LIM 2297 individuals (50% of total) were sired by 95 Estonian bulls (48% of total). The second most common siring country was DNK with 691 sired calves and the third most common siring country was FRA with 503 sired calves (Table 15). However, if FIN, DNK and SWE are considered as one (as it is done in Interbeef), DFS would have sired 1112 calves with 48 bulls, placing DFS as the second most common siring country.

Slight differences in average reliabilities of individuals grouped according to their siring country were found for Estonian LIM. The difference between the lowest pseudo-national average reliability and the highest was 0.07 while it was 0.08 in the case of average international reliability (Table 15).

Nevertheless, Estonian LIM with the highest average pseudo-national and international reliability were sired by bulls from FIN (Table 15). However, if FIN is considered as part of DFS, then, the individuals sired by LTU bulls would have had the highest average pseudo-national and international reliabilities.

During the pseudo-national evaluation, the siring countries with the three highest average reliabilities in Estonian LIM were: LTU, DFS, FRA, DEU and CAN. There was a difference of 0.03 between the reliability of CAN and LUT. The siring country with the lowest average pseudo-national reliability were: LAV and EST (Table 15).

In the international evaluation the second and third highest average reliabilities changed. In this case the order was: LTU, DFS, FRA, DEU, CAN and HUN (Table 15). DEU, DFS, FRA and CAN gained 0.01 average reliability in the international evaluation. EST and LAV showed the lowest average international reliabilities, however, EST also gained 0.01 average reliability in the international evaluation.

Table 15. Siring Countries with average reliabilities in both evaluations, Estonian Limousin

Country	No. Sires	No. Calves	Average Reliability	
			Pseudo-national	International
EST*	95	2297	0.48	0.49
DFS*	48	1112	0.52	0.53
DNK*	30	691	0.51	0.51
FRA*	27	503	0.52	0.53
DEU*	17	301	0.52	0.53
SWE*	14	312	0.52	0.53
FIN*	4	109	0.54	0.55
LTU	3	255	0.54	0.54
CAN	2	3	0.51	0.53
LVA*	2	42	0.47	0.47
HUN	1	52	0.5	0.5

*CAN= Canada; DEU = Germany; DNK = Denmark; EST= Estonia; FIN= Finland; FRA = France; HUN= Hungary; LTU= Lithuania; LVA = Latvia; SWE= Sweden- * Participating organisations in aww evaluation.*

In the case of Estonian AAN, 103 Estonian bulls (63% of total) sired 2952 individuals (61% of total), the second most common siring country was GBR with 687 sired calves and the third was DNK with 356 sired calves (Table 16). However, DFS sired 771 individuals with 30 bulls, turning into the second most common siring country.

A difference of 0.28 between the lowest and highest average reliabilities in both evaluations was observed for Estonian AAN (Table 16). The individuals with the highest pseudo-national and international average reliability were sired by bulls from GBR. The siring country with the lowest average reliabilities was CZE.

However, also in Estonian AAN, slight differences among the top average reliabilities were observed. A difference of 0.02 was observed between the average reliabilities of the siring countries in the case of pseudo-national evaluation. In this case, the order of siring countries was: GBR, DEU and a tie between IRL and USA.

In the international evaluation IRL and DEU had the second highest average reliability followed by USA. A 0.01 difference in average reliability was observed between the latter siring countries while a difference of 0.02 between IRL, DEU and GBR was observed.

Table 16. Siring Countries with average reliabilities in both evaluations, Estonian Aberdeen Angus.

Country	No. Sires	No. Calves	Average Reliability	
			Pseudo-national	International
EST*	130	2952	0.49	0.49
DFS*	30	771	0.48	0.48
GBR	25	687	0.55	0.56
DNK*	17	356	0.5	0.51
DEU*	10	324	0.53	0.54
SWE*	10	257	0.47	0.47
CAN	4	14	0.48	0.48
USA	4	28	0.51	0.53
FIN*	3	158	0.46	0.46
AUS	1	1	0.49	0.51
CZE*	1	2	0.27	0.3
IRL*	1	5	0.51	0.54

*AUS= Australia; CAN= Canada; CZE= Czech Republic; DEU = Germany; DNK = Denmark; EST= Estonia; FIN= Finland; GBR = Great Britain; IRL=Ireland; SWE= Sweden, USA= United States of America. * Participating organisations in aww evaluation.*

Insemination doses of sires with at least 0.50 reliability could be offered in the international market if they have at least 25 offspring (Venot *et al.*, 2014). The number of eligible local Estonian sires according to these regulations were 11 for Estonian LIM and 29 for Estonian AAN (data not shown). The export of semen from these bulls could represent an extra income for EST.

It has been thoroughly mentioned in the literature that for international evaluations the connectedness between countries is very important, as the quality of the joint genetic evaluation depends greatly on the joint genetic link (Vesela *et al.*, 2013; Venot *et al.*, 2009a; 2009b). These connections are generally given by sires with progeny in different countries (Bonifazi *et al.*, 2020b; Venot *et al.*, 2009b). In view of the number of bulls from the most common siring countries in Estonian individuals of both breeds and the increase of the average reliabilities achieved when moving to the international evaluation, the hypothesis of a good genetic connection between EST and the participating organisations FRA and DFS in the evaluation for LIM and between EST and the organisations DFS and DEU in AAN arose.

4.6.2. Common and non-common sires between Estonia and other countries.

The highest number of common sires for Estonian LIM was with DEU (24 bulls) (Table 17). The bulls shared with LVA (12 bulls) sired the highest percentage of Estonian LIM (8%) (Table 17). A total of 1043 Estonian LIM (23% of the total) were sired by common bulls. Moreover, 152 sires were not shared among EST and any other participating organisation. These bulls sired 3522 individuals (77% of Estonian LIM).

Table 17. Common bulls among Estonia and other participating organisations for Limousin.

Country	No. sires	No. Calves	Calves Percentage
DEU	24	86	2%
FRA	17	263	6%
DFS	17	129	3%
LVA	12	375	8%
GBR	9	28	1%
CHE	8	49	1%
CZE	8	40	1%
AUS	6	29	1%
ESP	6	22	0%
IRL	6	21	0%
SVN	1	1	0%

CZE = Czech Republic, DFS = Denmark, Finland and Sweden, ESP = Spain, GBR = Great Britain, IRL = Ireland, FRA = France, DEU = Germany, CHE = Switzerland; AUS= Australia; SVN = Slovenia, LVA = Latvia.

The highest number of shared sires for Estonian AAN were from DEU (19 bulls) (Table 18). The highest percentage of individuals sired by common bulls in Estonian AAN was 2%, achieved by DEU and DFS (12 common bulls) (Table 18). A total of 326 Estonian AAN (7% of the total) were sired by common bulls, while 4458 individuals (93% of the total) were sired by 143 bulls which were not shared among EST and any other participating country.

Table 18. Common bulls among Estonia and other participating organisations for Aberdeen Angus.

Country	No. sires	No. Calves	Calves Percentage
DEU	19	97	2%
DFS	14	73	2%
CZE	12	55	1%
CHE	10	64	1%
IRL	8	37	1%

CZE = Czech Republic, DFS = Denmark, Finland and Sweden, IRL = Ireland, DEU = Germany, CHE = Switzerland.

In previous international evaluations, the number of common bulls between participating organisations were reported to be between 9 and 300 for breeds like CHA and LIM (Venot *et al.*, 2009a) or even over 1000 in LIM (Bonifazi *et al.*, 2020a). Nevertheless, in beef cattle low genetic connections between populations have frequently been reported as an issue during international evaluations due to the infrequent use of AI (Venot *et al.*, 2008, Bonifazi *et al.*, 2020b; Renand *et al.*, 2003), resulting in trouble when calculating the genetic correlation across countries (Phocas *et al.*, 2005; Bonifazi *et al.*, 2020b; Venot *et al.*, 2006; Fouilloux *et al.*, 2006).

In this study, it was shown that EST and the other participating organisations shared a limited number of sires. This aspect should be taken into account during the estimation of genetic correlations in case of further participation of Estonia in Interbeef test runs.

4.6.3. Country of origin of common sires

There was a total of 43 common bulls that were used as sires for Estonian LIM (Table 19), these bulls were simultaneously shared among the organisations: AUS, BEL, CHE, CZE, DEU, DNK, ESP, EST, FIN, FRA, GBR, IRL ,ITA, LTU, LUX, LVA, NLD, SVN and SWE. These 43 common bulls sired over 40,000 individuals among all mentioned organisations. The country of origin of the common sires are shown in Table 19, the main country of origin for LIM bulls was FRA (16 sires), followed by DEU (10 sires).

There was a total of 21 common sires used in Estonian AAN (Table 19), these bulls were simultaneously shared among the organisations: AUS, AUT, BEL, BGR, CAN, CHE, CZE, DEU, DNK, EST, FIN, FRA, GBR, HUN, IRL, ITA, LTU, LUX, LVA, NLD, NOR, NZL, POL, SWE, URY and USA. Over 50,000 individuals among all organisations were recorded as offspring of these 21 common sires. The main country of origin for the mentioned common bulls in AAN was GBR (12 sires) (Table 19).

Table 19. Country of origin for common sires in both breeds.

LIM		AAN	
Country	No. Sires	Country	No. Sires
FRA*	16	GBR	12
DEU*	10	USA	3
DNK*	8	CAN	3
EST	4	DNK*	1
CAN	2	IRL*	1
FIN*	1	SWE*	1
LVA	1		
SWE*	1		

*CAN= Canada; DEU = Germany; DNK = Denmark; EST= Estonia; FIN= Finland; FRA = France; GBR = Great Britain; IRL=Ireland; LVA = Latvia; SWE= Sweden, USA= United States of America. * Participating organisations in aww evaluation.*

The genetic links between EST and other participating organisations were less than 50 bulls in both breeds, and some of these bulls were shared by several organisations simultaneously. FRA was the country of origin for the largest proportion of common sires in LIM, which was expected due the large size of French LIM population along with the international renown of French sires (Bonifazi *et al.*, 2020a; Venot *et al.*, 2008). The most frequent country of origin for the common sires in Estonian AAN was GBR, which was not part of the evaluation. Nevertheless, FRA and GBR seemed to be key links for Estonian LIM and Estonian AAN, respectively.

FRA has shown to be the main genetic link in previous studies for international beef cattle genetic evaluations (Phocas & Lalöe, 2003; Venot *et al.*, 2014; Venot *et al.*, 2008), however, these studies were performed using CHA or LIM, which are breeds of French origin and have larger populations.

Regarding AAN, this breed was included in the Interbeef genetic evaluation recently (Interbull, 2019), which is a reason why scientific literature lack of studies regarding international evaluations of AAN aww.

5. Conclusion

The pilot run performed using performances from Estonia confirmed the expected benefits of the international beef evaluation from Interbeef for the participating country. Both the increase of EBV reliability on the local scale and the access to EBVs of large number of foreign animals had been observed.

Estonia received international EBVs for more than 4 million LIM and 300,000 AAN animals. Additionally, there was an average increase in EBV reliabilities, compared to the pseudo-national ones, of 12% and 9%, for LIM and AAN respectively. Also, the animals' reliabilities that were shown to have improved the most from the international evaluation were those related to animals reared in foreign countries.

Thanks to the international EBVs expressed on the local scale, foreign sires could be ranked according to Estonian specificities, facilitating the selection of the best bulls according to Estonian objectives. Furthermore, local Estonian sires could be found to be of interest for international market representing a possible economic incentive for Estonian breeders.

Although the benefit previously reported, limited genetic links were found between Estonian breeds and other populations, especially in AAN. It would be advisable to create additional connections exchanging semen of internationally used bulls to increase the value of international genetic evaluation results.

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