Intensive livestock recording for sustainable breeding programs and adaptation strategy to climate change

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Abstract

The hypothesis that, intensive recording is needed for sustainable breeding programs in developing countries in the face of climate change was tested.Using stochastic simulation, genetic gain realised by breeding strategies using local and imported genetic materials under limited and intensive recording in the local population was compared. Local breeding strategy (LBS) was within breed selection based on local breeding goal. Imported strategies were admixture conventional (ACS) and organic (AOS). They involved importationof semen from conventional (ACS) and organic (AOS) breeding programs in developed countries to inseminate local sows. All candidates in ACS and AOS were recorded for all traits in the index. Only 0.25% of the candidates in LBS were recorded under limited recording. Thereafter, intensity of recording in LBS was increased from 0.25-100%. With limited recording, LBS realised genetic gain of €13.87 compared to €44.89 and 55.59 for ACS and AOS, respectively. The LBS, however, outperformed ACS and AOS as intensity of recording increased. At 20% recording LBS realised 49 and 37%more genetic gain than ACS and AOS, respectively. The LBS realised genetic gain of €142.09, compared to €56.55 and 70.75 for ACS and AOS, respectively, when all candidates were recorded.These findings confirm that intensive recording would be required to sustain the local breeding programs and make the within breed selection attractive as an intervention strategy to climate change. Intensive recording could be realised by creating awareness among farmers on importance of records in farm management and adoption of new technologies likegenomic selection.

Keywords: *livestockrecording, breeding goal, climate change*

Introduction

The world's climate is changing at unprecedented rates and the risks are greatest in the developing countries in the tropics where people rely mainly on natural resources (Rege et al., 2011). The direct effects of climate change include high temperatures and unpredictable rainfall patterns. These effects are likely to have a major impact on livestock and smallholder farmers in developing countries as forage and crop yields are expected to drop by 10-20% by 2050 (Jones and Thornton 2003). To overcome these challenges livestock producers may be forced to change their production system by keeping animals that can survive on less feed, water and are adapted to tropical heat stress and diseases but still remain productive. Although, many local breeds are already adapted to harsh living conditions in the tropics, most developing countries still relyon importation of unadaptable high producing breeds which may not be sustainable in the face of climate change for severalreasons (Thornton 2010). First, the breeding goals for the temperate countries are not similar to those in the developing countries. This could result in weak genetic correlations and therefore low performance of imported breeds. Second, there is existence of genotype by environment interaction. This result in re-ranking of genotypes and therefore the best animals in the exporting countries may not necessarily be the best for the importing country. Third, poor planned breeding strategies such as unplanned random crossbreeding and breed substitution. This poses threat to adaptable indigenous livestock genotypes. There is therefore need for intervention strategies that would account for climate change and promote conservation by utilization of adaptable local genetic resources. Such strategies should not only address tolerance of the animals to changing climatic conditions but also improve productivity per animal.

Within breed selection and crossbreeding of adapted breeds and high producing breeds have been suggested as some of the adaptation strategies to climate change (Rege et al., 2011). Such strategies would require sound local nucleus breeding programs. Although, nucleus breeding programs have been utilized in the developed countries to improve animals from low multi-purpose breeds to high specialized line producers, their sustainability in the developing countries has been a challenge due to poor and inconsistent recording, poor infrastructure, dysfunctional institutions, lack of human capital and finances (Kosgey et al., 2011). The current study will focus on performance recording and devise mitigation measures.

The goal of livestock recording schemes is usually to provide farmers with information about individual animals for management and breeding purposes (Kosgey et al., 2011). Although, livestock identification, pedigree and performance recording is an important ingredient in adaptation to climate change, it has been given little attention by both the farmers and policy makers in developing countries. This could be due to lack of scientific information to demonstrate to farmers and policy makers the potential benefits of livestock recording in relation to increased productivity and adaptation to climate change.It is believed that with intensive pedigree and performance recording the local breeds could realize higher response to selection for both productive and adaptability traits than imported breeds. Using simulation based on breeding scheme similar to those used in pigs, the hypothesis that intensive performance recording is needed for sustainable breeding programs in the face of climate change in the developing countrieswas tested.

Materials and methods

Procedure: Stochastic simulation was used to predict genetic gain realised in breeding programs using local and imported genetic materials based on intensity of performance recording in the local population. Pig breeding program was used as a model example to test the hypothesis, but the findings could be applied to other livestock breeding programs. The use of a new technology, genomic selection was also compared with conventional pedigree method in the local population.

Breeding Schemes and strategies: Two breeding schemes namely local and admixture were considered. The local scheme was a single tier breeding system consisting 10 males randomly mated to 40 sows with each sow furrowing 10 piglets resulting to 400 piglets per generation. The breeding strategy considered in this scheme was:
Local breeding strategy (LBS): This strategy assumed there was a local breeding program involving within breed selection. It mimics a scenario where the locally adapted pig breeds are selected to improve their performance under the local production conditions based on the local farmers breeding goal. It considers selection based on limited and intensive trait recording. Limited trait recording is synonymous with the current farmers breeding practices in the developing countries.

The admixture scheme was a two tier nucleus breeding system. The upper tier was assumed to be that of the exporting country. It was assumed to have a larger pig population with intensive pedigree and performance recording than the lower tier. This makes sense because the exporting countries have large and better managed herds than importing tropical countries. It consisted of 10 boars randomly mated to 100 sows resulting to 1000 piglets per generation. All the candidates in this tier were recorded for all the traits in the breeding index. Semen from highest ranking candidates in this tier was used for inseminations in this tier while the second highest rankings were exported for use in the lower tier. The lower tier is for the importing country and was similar to LBS in population and management structure as described above. Limited recording of 0.25% was assumed in the lower tier. All the male candidates were culled, before sexual maturity, so that only the imported semen from the upper tier was used to inseminate randomly selected sows in the lower tier. Two breeding strategies were considered under this scheme:

Admixture conventional strategy (ACS): This strategy assumes that there is no selection in the local population. Semen from boars selected on conventional breeding goal was therefore imported to inseminate local sows.

*Admixture organicstrategy (AOS):*This strategy is similar to ACS but semen from boars selected on organic breeding goal was imported to inseminate local sows.

Breeding goals, genetic and economic parameters

Two breeding goals were considered in the current study. The first breeding goal was that of the local smallholder pig producers as defined by Mbuthia et al. (2015). The second breeding goal was that of exporting country. The Danish conventional and organic breeding goals as defined by Danbred were adopted in this study (DPRC 2015; Sorensen 2015). The conventional and organic breeding goals are market oriented and aims at producing pigs with high productivity under intensive and outdoor production systems, respectively. The local, conventional and organic breeding goals were defined objectively, as the economic values of traits in the breeding goal were estimated as change in profitability of the production system due to a unit change in one trait holding other traits constant (DPRC 2015; Sorensen 2015;Mbuthia et al., 2015).Only traits which are in both local and imported country breeding goals were considered. They included early growth rate (EGR), late growth rate (LGR), lean meat percentage (LMP), feed efficiency (FE), live piglets (LP), sow longevity (LG) and piglet mortality (PM). Their genetic and phenotypic parameters and economic values are presented in Table 1. These parameters were obtained from studies carried out in the Danish (Do et al., 2013; Sorensen 2015) and Kenyan (Ilatsia et al., 2006; Mbuthia et al., 2015) pig populations.

Sampling procedure

Each breeding scheme was initiated by sampling unrelated base populations. Ten boars and 100 sows in exporting country and 10 boars and 40 sows in the importing country were sampled.

For each animal i in the base population, a vector of true breeding values (**tbv$_i$**) was calculated for all simulated traits using the following equation:

$$\mathbf{tbv_i} = \mathbf{L}' \times \mathbf{r_1} \qquad 1$$

where $\mathbf{L}'$ is the Cholesky decomposition of the genetic (co)variance matrix **G**,and $\mathbf{r_1}$ is a vector of random numbers from a standardized normal distribution. In later generations **tbv$_i$** was simulated as:

$$\mathbf{tbv_i} = 0.5 \times (\mathbf{tbv_{i(sire)}} + \mathbf{tbv_{i(dam)}}) + \sqrt{0.5 \times (1 - (F_{i(sire)} + F_{i(dam)})/2)} \times (\mathbf{L}' \times \mathbf{r_1}) \qquad 2$$

where $F_{i(sire)}$ and $F_{i(dam)}$ are the inbreeding coefficients of the sire and the dam. The phenotypes of the traits for the i^{th} base animal were calculated as:

$$\mathbf{obs_i} = \mathbf{tbv_i} + \mathbf{C}' \times \mathbf{r_2} \qquad 3$$

where $\mathbf{C}'$ is the Cholesky decomposition of the environmental (co)variance matrix **R**,and $\mathbf{r_2}$ is a vector of random numbers from a standardized normal distribution.

Table 1. Heritability (along diagonal), genetic (above diagonal) and residual (below diagonal) correlations, genetic (σ_a^2) and residual (σ_e^2) variances and economic values (€) for traits in the index in local, conventional and organic breeding goals

Traits[1]	EGR	LGR	LMP	FE	LP	LG	PM
Biological parameters							
EGR (g/day)	0.29	0.46	-0.04	-0.20	-0.05	0.00	0.00
LGR (g/day)	0.06	0.33	-0.20	-0.30	-0.15	-0.25	0.05
LMP (%)	0.05	0.04	0.44	-0.34	0.05	-0.11	0.05
FE (FE/kg gain)	-0.04	-0.53	-0.07	0.32	0.00	0.00	0.00
LP (N/litter)	0.00	0.00	0.00	0.00	0.06	0.26	0.40
LG (%)	0.00	0.09	0.00	0.00	0.00	0.17	0.00
PM (%)	0.00	0.00	0.00	0.00	0.20	0.00	0.04
Variances							
σ_a^2	185.000	1536.000	0.275	0.006	0.9000	0.028	0.120
σ_e^2	452.931	3118.545	0.350	0.013	14.100	0.137	2.880
Economic parameters (€)							
Breeding goals							
Local	17.026	0.088	17.821	-1.198	6.781	0.527	-8.241
Conventional	0.0140	0.0147	1.3000	-19.7050	2.6270	11.3940	0.0000
Organic	0.0120	0.0290	1.5420	-29.4910	0.6970	11.3940	0.0000

[1]See description in the text

Prediction of breeding values

Traditional breeding values: All the breeding values were predicted using best linear unbiased prediction (BLUP) by fitting a multivariate animal model to the phenotypes. The model was computed as:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Za} + \mathbf{e} \qquad 4$$

Where **Y** was the vector of phenotypes,**b** a vector of fixed effects, **a** a vector of random animal effects, **e**, a vector of residual errors, and **X** and **Z** were incidence matrices. The following (co)variance structure was used to predict breeding values:

$$\begin{pmatrix} \mathbf{a} \\ \mathbf{e} \end{pmatrix} \sim \mathrm{N}\left(0; \begin{bmatrix} \mathrm{G} \otimes \mathrm{A} & 0 \\ 0 & \mathrm{R} \otimes \mathrm{I} \end{bmatrix}\right) \qquad 5$$

Where **A** was the numerator relationship matrix among all animals, **G** was the additive genetic (co)variance matrix of traits, as defined in Table 1. **R** is the (co)variance matrix for residual effects, as defined in Table 1 and **I** is an identity matrix. The variance components used to predict breeding values were the same as those used to simulate the data. The breeding value prediction was carried out using the DMU package (Madsen & Jensen 2008).

Genomic breeding values: To estimate genomic breeding values the pig genome was in the founder population. The genetic architecture of the founder population was generated to reflect the linkage disequilibrium in pigs. The founder population consisted of 25 boars and 25 sows. Random mating was applied in this population for 1000 generations. The genome was assumed to consist of 18 chromosomes of 167 cM each. Each chromosome contained $3.0\text{x}10^{8}$ loci evenly distributed across the genome. The allelic mutation rate was assumed to $4.0\text{x}10^{-6}$ and every 8^{th} locus was a potential QTL. After 1000 generations, a total of 55,937 markers and 7,944 QTL were segregating. The effects of QTL alleles were sampled from a normal distribution. Haplotypes from the last founder generation were sampled to initiate the genomic breeding schemes.

The genomic breeding values were estimated using single-step genomic-BLUP (GBLUP) procedures as described by Gao et al. (2012). The GBLUP model was:

$$y = Xb + Zg + e \qquad (6)$$

Where *y, b, g,* and *e* were the vectors of trait phenotype, fixed effects, random effects and random residual errors, while *X* and *Z* are incidence matrices. The fixed effects included generational effects and overall mean. The genomic breeding values were computed using the (co)variance structure similar to that equation 5, but the *a* and *A* were replaced with *g* and *H*, respectively. The *g*is the vector of genomic breeding values of the traits in the breeding goal and *H*, the (co)variance matrix of genomic breeding values of the traits in the index.

Estimation of genetic correlation between the breeding goals

The genetic correlations between local, conventional and organic were estimated to determine their effects on response to selection in the local pig population. The genetic correlation (r_g) between the breeding goals was estimated as:

$$r_g = \frac{\mathbf{w}_{\mathbf{BGk}}^{'} \times \mathbf{G} \times \mathbf{w}_{\mathbf{BGl}}}{\sqrt{\left(\mathbf{w}_{\mathbf{BGk}}^{'} \times \mathbf{G} \times \mathbf{w}_{\mathbf{BGk}}\right) \times \left(\mathbf{w}_{\mathbf{BGl}}^{'} \times \mathbf{G} \times \mathbf{w}_{\mathbf{BGl}}\right)}}$$

where $\mathbf{w}_{BGk}^{'}$ and $\mathbf{w}_{\mathbf{BGl}}$ were the vectors of economic values for traits in the breeding goal *k* and *l* in Table 1, respectively, **G** was a 7 x 7 genetic variance-covariance asymmetric matrix of traits in the breeding goal in Table 1.

Data Analysis

Annual rate of genetic gain expressed in Euros realised in the local production system with limited recording were plotted. The effect of increased intensity of recording at different proportions 0.25 -100% in the local population on response to selection in LBS, ACS and AOS were also plotted. The genetic gain realised by the scheme using new technology, genomic information in comparison with conventional one, using pedigree in the local population at different proportions of recording intensities is also presented.Each scheme was run for 10 years with overlapping generations and replicated 20 times. The rates of genetic gain were calculated for candidates born between year 5 and 10. This was to allow the population to attain equilibrium with respect to Bulmer effect and age distribution in the first 5 years. The rate of genetic gain for each animal was predicted as linear regression of true breeding values for each trait in the breeding goal weighted by their corresponding economic values. The results are presented as means (± s.d.) of 20 replicates in all the schemes. A stochastic simulation program, ADAM (Pedersen et al., 2009) was used to model theschemes.

Results and discussion

Annual genetic gain assuming limited recording in the local population

The annual rate of genetic gain in the three breeding strategies assuming limited performance trait recording in the local pig population is presented in Figure 1. The LBS realised the least response to selection compared to the two admixture strategies (ACS and AOS). The LBS realised a genetic gain of €13.87 compared to €44.89 and 55.59, for ACS and AOS, respectively. This demonstrates that it would be more beneficial to import semen from any breeding program to inseminate local sows as long as the local farmers do not invest in recording. The superiority of the imported strategies over local strategy with limited registration could be attributed to large registered herds in the exporting countries. This implies that such boars have higher intensity of selection and could also be ranked more reliably compared to local boars which were not only from small herds but also had fewer records. The intensity of selection and amount of information used to estimate the breeding value of selection candidates has direct impact on response to selection (van Arendonk 2011).The comparison between the two admixture strategies, indicate that importing semen from boars selected on organic index (AOS) would realise 25% more genetic gain per year compared to those from conventional males (ACS). This makes sense because in the current study the genetic correlation between local and conventional breeding goal was found to be r_g=0.20 while that between local and organic breeding goals was r_g =0.32. This demonstrates that although the two genetic correlations are weak, the relationship between organic and local breeding goalswere stronger than that between conventional and local. From these findings, it is evident that with limited recording, within breed selection may not be attractive and therefore most farmers may continue to rely on imported genetic materials to increase productivity. This may not promote conservation by utilization of the locally adapted breeds in the face of climate change.

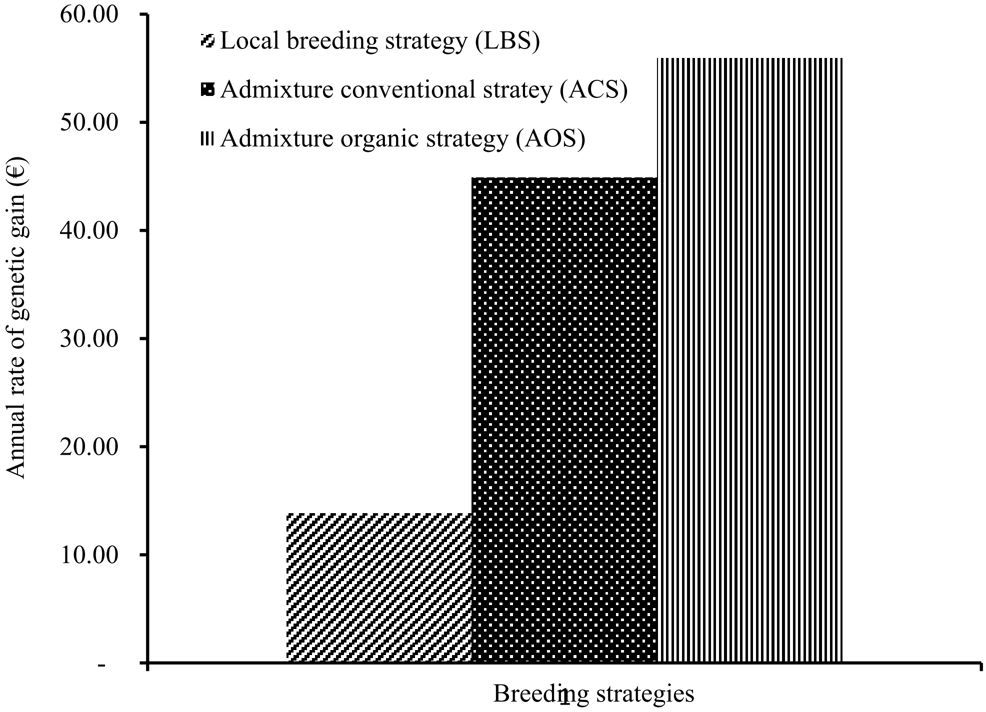

Figure 1.Annual rate of genetic gain (€) realised in breeding strategies based on local, admixture conventional and organic assuming limited trait performance registration in the local population

The impact of intensive performance recording was investigated by increasing the level of recording at different proportions in the local population and the findings are presented in Figure 2. The findings showthat, with only 20% increased recording in the local population; the LBS outperform ACS and AOS by 49 and 37%, respectively. At 100% registration in the local population, the LBS realised €142.09, compared to €56.55 and 70.75 for ACS and AOS, respectively, at the same recording level. This implies that, with intensive recording the local breeding program would realize 60.20 and 50.21% more response to selection compared to ACS and AOS, respectively. This change in performance in the LBScould be attributed three reasons. First, the increasedrecording level increased the information needed to predict the breeding values of the selection candidates. These information increases the accuracy of selection hence reliable ranking of the selection candidates. Second, selection was based on the breeding goal not the index. Selection on index is always affected by genetic correlation between the index and breeding goal as observed early in the current study. Third,information from both sexes is important in estimation of breeding values. This could explain the low response to selection realised in ACS and AOS compared to LBS even though the level of recording in the local population was being increased. In LBS, information from both males and females were used to estimate breeding values, while in ACS and AOS all the males in the local population were culled and therefore only information on females were available. This concurs with previous studies on phenotyping strategies in genomic selection where Okeno et al. (2014) reported that response to selection could be maximized by phenotyping both males and females. This makes sense because there are some traits which are sex limited and therefore cannot be recorded in both sexes.

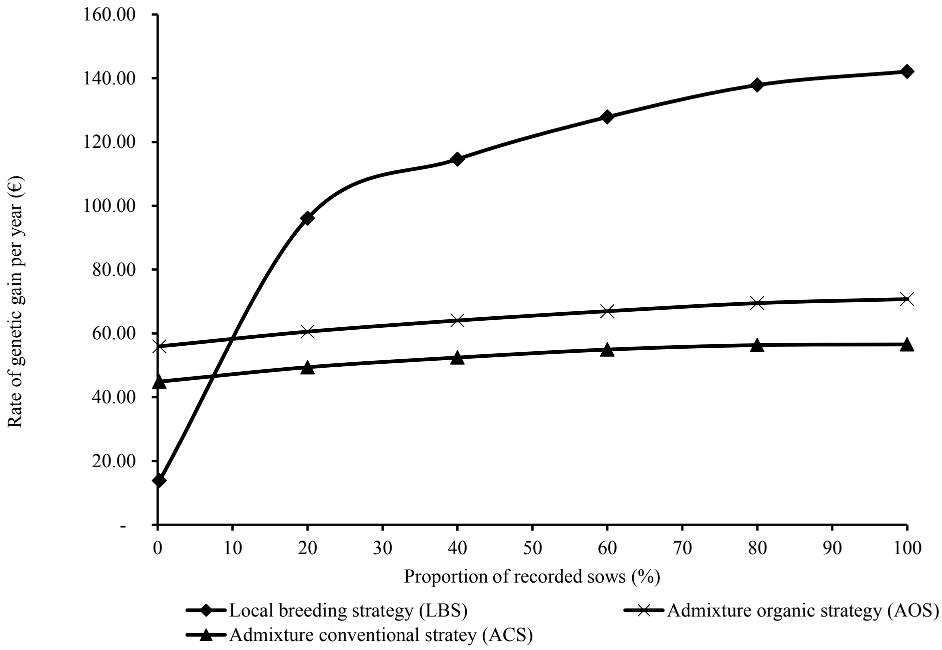

Figure 2.Annual rate of genetic gain (€) for breeding strategies based on local, admixture conventional and organic as a function of proportion of registered candidates in the local population

Although performance recording may be carried out by farmers, maintaining pedigree records could be a challenge. There is therefore need for new technologies to establish kinships in the population. Response to selection realised when genomic rather than pedigree information was used to establishing relationships between candidates was therefore investigated. This was carried out in such a way that, only performance recorded candidates were genotyped. The rate of genetic gain realised as intensity of performance recording and genotyping increased from 0.25-100% is presented in Figure 3. The results indicate that, the breeding scheme that uses genomic information to establish kinships (LBS-GS) was superior to one using pedigree information (LBS-PI) in annual genetic gain by 23.18 and 16.88% when recording and genotyping were limited (0.25%) and intensive (100%), respectively. This impliesthat, adoption of genomic selection could be worthwhile considering in the local population even with limited registration. The superiority a scheme with genomic selection relies in the fact that, with genomic information the inheritance of chromosomal segments of selection candidates can be traced for several generations. This enables accurate estimation of relationship between candidates which in turn increase accuracy of Mendelian sampling terms and therefore accuracy of genomic estimated breeding values (Henryon et al., 2014). The findings in this study concur with those obtained by Akanno et al. (2013) in pig breeding programs in the tropics. Although, that study considered only single trait selections, the response to selection was higher in genomic scheme than in pedigree scheme. The superiority of genomic selection under limited phenotyping and genotyping schemes has also been reported in pig breeding programs (Henryon et al., 2012; Okeno et al., 2014).

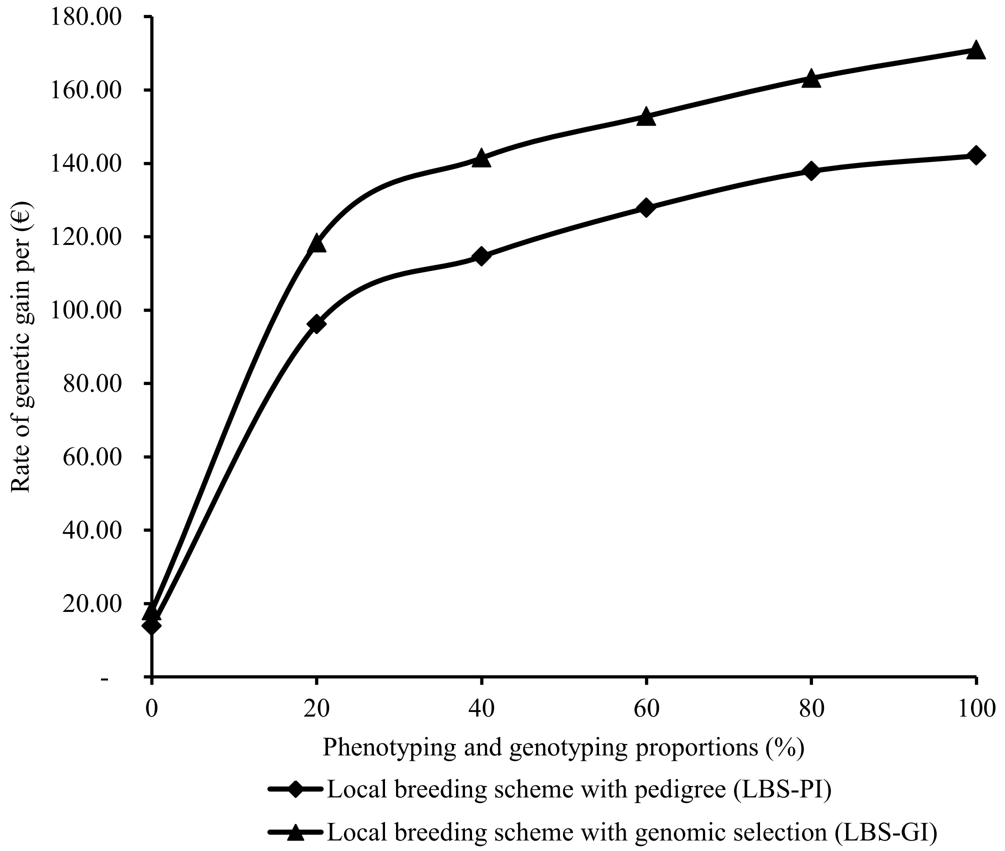

Figure 3.Annual rate of genetic gain (€) realised in local breeding scheme with pedigree (LBS-PI) and genomic (LBS-GI) assuming different phenotyping and genotyping proportions

Implication

This study provides the evidence that, as long as the recording in the local population remain limited, faster response to selection may not be realised by establishing local breeding program. This means that the importing strategies especially those from organic breeding programs will remain attractive to local producers. This could posse danger on animal genetic resource conservation as most farmers will always go for high producing breeds to meet the ever increasing demand for animal products. Such strategies might not be suitable in long run in the face of climate change. This is because the imported breeds are poorly adaptable to tropical conditions and the breeding goals between the exporting and importing countries are incompatible as demonstrated in this study. On the other hand, the study confirms hypothesis that intensive performance recording is needed for sustainable breeding program in the face of climate change. This is because intensive recoding would enable informed decisions making in selecting locally adapted breeds for genetic improvement. This would result to faster response to selection hence making within breed selection more attractive than imported genetic materials. The challenge would be how to motivate the farmers to intensify the pedigree and performance recording bearing in mind that poor recording has contributed enormously in unsustainability of local breeding programs (Kosgey et al., 2011).

Poor or lack of recording could be mitigated through innovative approaches and technologies. The first approach could be to change recording narrative. The narratives have been packaged for decades to insinuate that, recording is only for breeding purposes and therefore are more important to geneticists than the farmers themselves. This has made most farmers not to participate in recording as they do not feel the value or potential benefits of recording their animals. This should change to demonstrate to farmers that recording would enable them make informed decisions on day to day management of their herds and therefore have direct link toprofitability of the farm. This could be done in such a way that, the farmers are organized into groups and trained on the basic agribusiness skills to enable them appreciate that livestock production is a business enterprise. In a business enterprise, the simplest way to monitor the progress towards the business goal is through well-kept records. For instance performance records would help the farmer make better decisions on culling, feeding and breeding and replacement policies. This would help the farmer to invest more on productive animals and cull unproductive ones.

In the wake of food safety concerns and need for traceability of livestock products to their farms of origin, recording institutions can liaise with product processors in ensuring recording is achieved. The processors would enforce compliance to recording standards by attaching market incentives to products from animals with records. Such incentives could be for instance subsidized extension services, easier access to financial services e.t.c, as currently done by some dairy processors in Kenya. This will, however, require reorganization of the industry since most of livestock products are sold through informal market channels in the developing countries.

New technologies that utilize genomic technologies such as genomic selection and parentage testing to determine genetic relationships between individuals in population could be adopted. This would overcome the challenge pedigree recording by the farmers. This technology would require genotyping candidates at the farm level and comparing them with reference population. The reference population could be set in some of the already existing farms which provide genetic materials. The responsibility of genotyping could be vested on recording institution for smooth management. This would make it easy to establish relationships and with records from farmers, establishment of local selection strategy would be feasible.Although genomic selection would result to additional costs associated with genotyping, the genetic gain realised from such a scheme has been demonstrated to overcome the costs. The fact that the price for genotyping per candidate is also reducing should make genomic selection attractive to local breeding programs. The cost could be reduced further by using prior information to select the most appropriate individuals to genotype.

Conclusion

The findings of the current study have confirmed hypothesis that, intensive performance recording would be needed for sustainability of local breeding programs to mitigate climate change. The high response to selection realised in local breeding program with intensive registration compared to those based on importation affirm that within breed selection would be feasible. Since such genotypes are adapted to the local production conditions, improving their productivity would make them attractive to farmers. In cases where importation of genetic materials is to be done, it would be worth considering genetic materials from organic breeding programs.

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