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Multiple criteria decision-making process to derive consensus desired genetic gains for a dairy cattle breeding objective for diverse production systems

C. M. Kariuki,*†[1] J. A. M. van Arendonk,‡ A. K. Kahi,§ and H. Komen†
*Department of Animal Sciences, Chuka University, PO Box 109-60400, Chuka, Kenya
†Animal Breeding and Genomics Centre, Wageningen University, PO Box 338, 6700 AH Wageningen, the Netherlands
‡Hendrix Genetics Research, Technology and Services, PO Box 114, 5830 AC Boxmeer, the Netherlands
§Animal Breeding and Genomics Group, Department of Animal Sciences, Egerton University, PO Box 536-20115, Egerton, Kenya

ABSTRACT

Dairy cattle industries contribute to food and nutrition security and are a source of income for numerous households in many developing countries. Selective breeding can enhance efficiency in these industries. Developing dairy industries are characterized by diverse production and marketing systems. In this paper, we use weighted goal aggregating procedure to derive consensus trait preferences for different producer categories and processors. We based the study on the dairy industry in Kenya. The analytic hierarchy process was used to derive individual preferences for milk yield (MY), calving interval (CIN), production lifetime (PLT), mature body weight (MBW), and fat yield (FY). Results show that classical classification of production systems into large-scale and smallholder systems does not capture all differences in trait preferences. These differences became apparent when classification was based on productivity at the individual animal level, with high and low intensity producers and processors as the most important groups. High intensity producers had highest preferences for PLT and MY, whereas low intensity producers had highest preference for CIN and PLT; processors preferred MY and FY the most. The highest disagreements between the groups were observed for FY, PLT, and MY. Individual and group preferences were aggregated into consensus preferences using weighted goal programming. Desired gains were obtained as a product of consensus preferences and percentage genetic gains (G%). These were 2.42, 0.22, 2.51, 0.15, and 0.87 for MY, CIN, PLT, MBW, and FY, respectively. Consensus preferences can be used to derive a single compromise breeding objective for situations where the same genetic resources are used in diverse production and marketing circumstances.

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[1]Corresponding author: charles.kariuki@wur.nl

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INTRODUCTION

Locally based dairy cattle breeding programs in developing countries are an alternative to continuous semen importation for situations where significant genotype by environment interaction exist (Vargas and van Arendonk, 2004). However, developing dairy industries are faced with challenges in establishment of breeding programs. These challenges include poorly developed pricing systems, diverse production and marketing systems, small flock sizes, and lack of systematic pedigree and performance recording, particularly within the smallholder production system (Rangnekar and Thorpe, 2001). To overcome these challenges, it has been suggested to use large-scale farms as a nucleus to create genetic gains for both large- and small-scale producers (Kahi et al., 2004; Kariuki et al., 2014). However, establishment of a breeding program requires the definition of a breeding objective and a structure for genetic evaluation and selection that satisfies both large- and small-scale producers.

Breeding objective weights specify the rate and direction of genetic change in traits identified for improvement based on the production and marketing situations (Hazel, 1943). Conventionally, breeding objectives aim at economic optimization, which is achieved through the use of economic weights for breeding objective traits. Economic weights for breeding objective traits can be derived using profit functions or bio-economic modeling (Amer, 2006). In these approaches, weights are derived as partial derivatives for a unit change of each trait in the breeding objective holding other traits constant (Ponzoni and Newton, 1989). This procedure requires clear specification of production (costs/inputs) and marketing (incomes/revenues) systems [e.g., van Arendonk (1991) and Kahi et al. (2004)]. Implicitly, with economic weights, homogeneity of costs and revenues are assumed among commercial producers (i.e., economic weights relate to a specific production system).

Multiple production systems in developing countries reflect differences in costs and revenues (FAO, 2011). In Kenya, for instance, 2 distinct production systems have been identified corresponding to large-scale and smallholder producers. Differences in costs between these systems emanate from scale of production and investment. Smallholder systems, even under intensification, are characterized by less than 5 milking cows reared on approximately 1 acre of land on average, whereas large-scale systems have an average of 33 milking cows reared on an average of 160 acres (Bebe et al., 2003a; Karanja, 2003). Large-scale systems generally have a higher scale of mechanization and labor input, and have less tendency to be risk averse. However, due to low production levels, it is estimated that smallholder production systems have the highest relative production costs (Karanja, 2003).

On the other hand, differences in revenues emanate from the existence of multiple milk outlets. Markets determine not only the prices per kilogram of milk but also the level of production. Marketing systems in Kenya have been classified into informal and formal markets. Informal markets, which are composed of direct sales to individuals, hotels, and institutions such as schools and hospitals, account for 80% of the total milk sold (Omore et al., 1999). Formal markets include sales to cooperative or private owner milk processing factories. Large-scale producers rely mainly on the formal markets as the main outlets, whereas the informal market is the major outlet for smallholder producers (Omore et al., 1999). Payment for milk by both formal and informal markets is currently based on volume. Differences in milk prices have been reported among these outlets (Thorpe et al., 2000; Karanja, 2003). Furthermore, fluctuations in milk prices are common in the Kenya dairy sector. Such fluctuations are due to instability in levels of production resulting from seasonality in feed quality and quantity. These factors complicate the derivation of economic values.

The implementation of separate breeding programs for each production system is unfeasible in the near future for 2 reasons. First, intricate dependence at the genetic level exist between the 2 production systems. Smallholder farmers are not self-reliant in production of replacement heifers but largely rely on large-scale farms (Bebe et al., 2003a). Moreover, the large-scale system is a source of genetic material for smallholder farmers through provision of semen. Second, smallholder farmers hardly practice any pedigree and performance recording, making it impossible to rely on them when implementing a selective program. To account for these factors, Kahi et al. (2004) defined a breeding objective for the dairy sector in Kenya based entirely on the smallholder production system. However, an approach that compels large-scale producers to adopt a smallholder breeding objective is not likely to optimize production for the former system. An alternative approach would be to breed the best compromise genotype for the 2 systems.

Goal aggregating procedures are used in creating consensus in the decision-making process. The procedures have been used to derive consensus desired genetic gains for a single breeding scheme serving diverse production systems (Sae-Lim et al., 2012; Omasaki et al., 2016). The procedure involves 2 steps. First, the multiple decision making procedure analytic hierarchy process (**AHP**) is used to compute individual weights for activities (traits; Saaty, 1977). These weights indicate the preferences given by an individual to each trait and are defined by scaling ratios using the principal eigenvector of a positive pair-wise comparison matrix. Second, individual preferences are aggregated into group and consensus preferences using weighted goal programming (**WGP**; Linares and Romero, 2002). Consensus desired gains are then defined as the product of consensus preferences and percentage genetic gains (**G%**).

The objectives of this paper were (1) to determine trait preferences among different categories of dairy cattle producers and processors, (2) aggregate individual preferences to consensus preferences, and (3) derive consensus desired gains for breeding objective traits. We used the dairy cattle industry in Kenya as a working example.

MATERIALS AND METHODS

Data on the Holstein-Friesian and its crosses within large-scale and smallholder production systems were used for the study. The Holstein-Friesian breed and its crosses form the predominant genotype accounting for more than 50% of the dairy cattle in Kenya (Bebe et al., 2003b; Ojango et al., 2012). The popularity of this breed is driven by semen importation by large-scale producers and the flow of genes (through sale of heifers and AI) from large-scale farmers to small-scale farmers (Bebe et al., 2003b).

Data Collection

The AHP was used to determine individual preferences based on importance (strengths) given to the different traits in dairy cattle production. Data were obtained using a field survey. The survey was conduct-

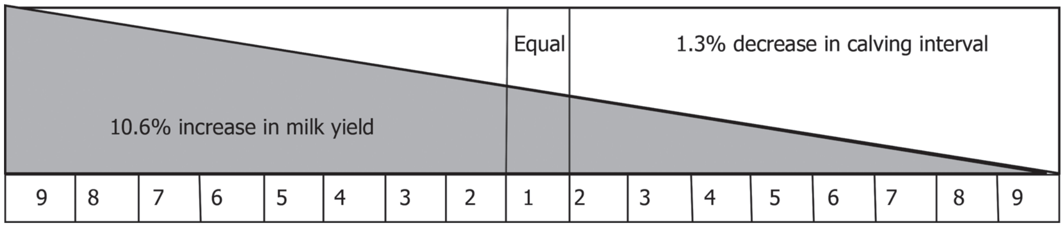

Figure 1. The Saaty scale for pair-wise comparison. Percentage possible genetic improvement is expressed within the upper row and intensity of importance is on the lower row. Scale of intensity is from 1 to 9. One = equal, 3 = weak, 5 = strong, 7 = demonstrate, and 9 = absolute importance of one trait over the other. 2, 4, 6, and 8 are intermediate values between 2 adjacent judgements.

ed in Nakuru, Naivasha, Nyeri, Embu, and Tharaka Nithi counties in Kenya. We conducted an initial survey in which respondents were asked to rank 19 traits according to their perceived order of importance. Table 1 lists the 19 traits and their definitions. Out of 64 respondents visited, we obtained 47 responses from 18 large-scale producers, 24 small-scale producers, and 5 processors. Ranking was on a scale of 1 to 19, where the most important trait was given rank 1 and the least important trait was given rank 19. For situations where respondents had difficulties ranking all the 19 traits, they were asked to rank the first 5 most important traits. To ensure uniformity in trait descriptions, definitions were provided in the questionnaire. Efforts were also made during the survey to ensure proper understanding of each trait description. In addition, general information on the farm economy was also collected.

The second survey involved a total of 78 respondents who were classified into smallholder farmers (40), large-scale farmers (24), and milk processors (14). This survey focused on the 5 highest valued traits for inclusion in the pair-wise comparison. Saaty's scale of intensity of importance (Saaty, 1977; Figure 1) was used to compare pairs of traits. A total of 10 {i.e., [5 × (5 − 1)/2]} pairs of comparisons were done. The scale of intensity of importance was in a range of 1 to 9. The value 1 indicated equal importance (i.e., meaning equal rate of genetic improvement for a pair of traits), whereas the value 9 indicated that the chosen trait is absolutely important over the other (i.e., only the important trait in a pair should be subjected to selection pressure). The intermediate values were as described in Figure 1.

To avoid unrealistic expectations and, by extension, unrealistic choices between traits, we approximated possible genetic gains (as a percentage of the trait mean) after one generation of phenotypic selection for each trait. Response to selection was calculated using the formula

$$G = ih^2CV\mu p, \quad [1]$$

Table 1. Traits in the preliminary survey and their descriptions

Trait	Description
Milk yield	Amount of milk a cow produces per lactation
Protein yield	Amount of milk protein a cow produces per lactation
Fat yield	Amount of milk fat a cow produces per lactation
Production persistence	Ability to maintain the level of milk production through the lactation
Production lifetime	The number of lactations a cow will have before voluntary or involuntary culling
Lactation length	The number of days a cow continues producing milk after calving
Calving interval	The period between 2 consecutive calvings
Calving ease	A measure of difficulty in dropping a calf
Survival to 3 mo	The ability of a calf to survive the first 3 mo of life
Mastitis	A measure of a cow's inherent resistance to mastitis
Backbone strength	A measure of the strength of a cow's backbone. Measured as straight, curved, or arched
Legs strength	A measure of how strong the legs of a cow are
Udder attachment	A measure of how firmly the udder is attached. Affects walking-related problems, ease of milking, and susceptibility to mastitis
Teat length	A measure of the length of teats. Affects ease of milking
Docility	A measure of nonaggressiveness to other cows and handlers (during milking and when not being milked)
Intake of low-quality roughages	Ability to ingest and convert low-quality roughages
Resistance to heat	Ability to perform well under high-temperature conditions
Resistance to East Coast fever (ECF)	A measure of inherent resistance to ECF
Mature BW	A measure of feed requirements for maintenance. Large animals have high maintenance requirements.

Table 2. Heritability, phenotypic standard deviations, phenotypic means, and expected genetic gains for 5 highest ranked traits[1]

Trait	h^2	σ_P	μ_P	G%	Reference
MY (kg)	0.29	1,110.00	4,557.0	10.6	Ojango and Pollot (2001)
CIN (d)	0.047	75.34	406.0	1.3	Ojango and Pollot (2002)
PLT (mo)	0.18	1,781.25	47.5	10.1	Abou-Bakr (2009)
MBW (kg)	0.17	73.48	606.0	3.1	Abdallah and McDaniel (2000)
FY (kg)	0.24	49.35	276.9	6.4	Campos et al. (2015)

[1]Intensity of selection was fixed at 1.501 for all traits. MY = lactation milk yield; CIN = calving interval; PLT = production lifetime; MBW = mature body weight; FY = lactation fat yield; σ_P = phenotypic standard deviation; μ_P = phenotypic mean; G% = genetic gain expressed as a percentage of the phenotypic mean.

where G = genetic gain; i = intensity of selection; h^2 = heritability; CV = coefficient of variation (calculated as CV = σ_P/μ_P), where σ_P = phenotypic standard deviation, and μ_P = phenotypic mean. The CV was used rather than σ_P to account for scale differences of means and variances of traits reported in the literature (Falconer and Mackay, 1996). In addition, we attempted to use parameter estimates from studies conducted in the tropics. Percentage genetic gains were computed as

$$G\% = ih^2CV \cdot 100\%. \quad [2]$$

Estimates for the above parameter estimates and the resulting possible genetic gains (as a %) for the 5 traits are presented in Table 2.

Determination of Traits for Inclusion in Pair-Wise Comparisons

The 5 traits for inclusion in the pair-wise comparisons were determined using percentages. To determine the percentage for each trait, we tabulated all traits ranked between 1 and 5 in the preliminary survey. We then calculated the percentage of times a trait was ranked within a given rank category. In addition, we calculated the percentage of times each trait was ranked among the 5 most important traits. Table 3 presents a summary of the percentages. The decision on the traits to include in the pair-wise comparisons was based on the 2 percentages. The traits with the highest percentages at the individual trait and combined levels were chosen as the most preferred. As an example, fat yield (FY) did not have the highest percentage in any of the 5 trait levels but was the fifth highest at the combined level, and was included in the most preferred traits. The 5 highest ranked traits were milk yield (**MY**), production lifetime (**PLT**), calving interval (**CIN**), FY, and mature body weight (**MBW**).

Calculation of Individual Preferences

The AHP is a ratio scaling method for weights in hierarchical structures using the principal eigenvector of a positive pairwise comparison matrix. For a comprehensive description of the method, the reader is referred to Saaty (1977). Briefly, for each respondent, we wish to recover the vector **w** of weights for n = 5 traits in the breeding objective from a matrix **A**. The matrix **A** is constructed using intensities indicated in the pair-wise comparisons in the Saaty scale. **A** was constructed such that it fulfilled the reciprocal property $a_{ji} = 1/a_{ij}$. where a_{ij} are entries in the matrix **A** and are computed as w_i/w_j, where w_i and w_j are weights for the ith and jth traits. The solution for vector **w** of weights was obtained by solving the system $(\mathbf{A} - n\mathbf{I})\mathbf{w} = 0$, where n = 5 and **I** is an identity matrix. (Saaty, 1977). Individual preferences were attained by normalizing the eigenvector.

Large inconsistencies in responses from the respondents indicate randomness rather than logic; thus, results cannot be expected to yield a reliable solution (Saaty, 1977). All responses were checked for consistency to ensure they had a consistency ratio less than 0.1. In a few cases where the consistency ratio was greater, the interview was redone. All calculations were done using the Super Decisions software (Saaty, 2003).

Calculating Consensus Preferences and Desired Gains

Group Preferences. A 2-step WGP procedure described by (Linares and Romero, 2002) was used to define the consensus weights. In the first step, group preferences were obtained by minimizing the sum of disagreements between the individual preferences. This was achieved by solving the following WGP model Achievement function:

$$\text{Min}\sum_{i=1}^{q}\sum_{k=1}^{N_j}\left(n_{ik}+p_{ik}\right)^{\pi}$$

subject to [3]

Goals:

$$W_i^j + n_{ik} - p_{ik} = a_i^{kj},$$

where $i = 1, 2, ..., q$ = number of traits in the breeding objective ($q = 5$ traits), $j = 1, 2, ..., m$ social groups, N_j = number of respondents in the jth group, a_i^{kj} = preference weight attached to the ith trait by the kth member of the jth group, W_i^j = preference weight attached to the ith trait by the jth social group, and n_{ik} and p_{ik} are the negative and positive deviations of a_i^{kj} from W_i^j, respectively. π acts is a metric attached to the sum of deviation variables indicating the weight given the outlier group. Our objective was to minimize the sum of individual disagreements; we therefore set π =1 (Gonzalez-Pichon and Romero, 1999; Linares and Romero, 2002). How social groups were defined is explained in a later section.

Consensus Preferences. The second step was to derive consensus preferences from group preferences obtained earlier by solving the following extended WGP model (Linares and Romero, 2002) Achievement function:

$$\text{Min}(1-\lambda)D + \sum_{i=1}^{q}\sum_{j=1}^{m}\left(\overline{n}_{ij}+\overline{p}_{ij}\right)$$

subject to

Goals: [4]

$$\sum_{i=1}^{q}\left(\overline{n}_{i1}+\overline{p}_{i1}\right) - D \le 0,$$

$$\vdots$$

$$\sum_{i=1}^{q}\left(\overline{n}_{im}+\overline{p}_{im}\right) - D \le 0,$$

$$W_i^S + \overline{n}_{ij} - \overline{p}_{ij} = W_i^j,$$

where q = number of traits, m = number of social groups, W_i^j = the jth group preference value for the ith trait, W_i^S = consensus weight attached to the ith trait, and $\overline{n}_{i1} + \overline{p}_{i1}$ = the sum of the negative and positive deviations of the jth social group preference value from the consensus preference value. D represents the disagreement in each social group with respect to the consensus obtained, and λ represents the emphasis put on the minority group. We varied the values of λ between 0 and 1 to obtain compromises between a model

Table 3. Importance of traits expressed as a percentage at individual rank level and for the 5 highest ranks combined

	Ranking (% of respondents placing traits in respective ranks)					
	Individual rank[2]					
Trait[1]	1	2	3	4	5	Combined[3]
Backbone strength	2	3	2	2	11	4
Calving ease	2	6	2	4	2	3
Calving interval	6	9	**19**	9	**14**	**11**
Docility	2	9	0	0	2	2
Fat yield	0	6	14	4	9	**7**
Intake of low quality roughages	0	0	0	0	0	1
Lactation length	0	0	2	7	2	2
Leg strength	0	0	2	9	0	2
Mastitis	0	6	0	11	11	6
Mature BW	3	6	17	**18**	5	**10**
Milk yield	**66**	0	7	4	7	**19**
Production lifetime	3	**38**	14	**18**	7	**15**
Protein yield	0	13	5	2	0	3
Resistance to East Coast fever	0	0	7	0	5	2
Survival to 3 mo	1	0	2	0	6	2
Teat length	0	0	2	4	5	2
Udder attachment	3	3	2	7	9	6

[1]Bolded traits had the highest rankings.

[2]Number of times (as a %) each trait was ranked within each rank. Ranks are from 1 (highest level of importance) to 5 (lowest level).

[3]Importance (as a %) considering the 5 highest ranked traits together.

that defines the consensus by minimizing the disagreement of the most displaced social group and a model which defines the consensus by maximizing the average agreement, thus avoiding the ensuing associated biases (Linares and Romero, 2002).

Desired Genetic Gains. Desired genetic gains were obtained by multiplying the genetic gain with the consensus preferences for each trait.

Definition of Social Groupings

In the present study, we investigated 4 criteria for definition of intensification. First, groups were defined based on the land size, number of cows, and level of investment in machinery (group A). Under these criteria, farms that had $\leq$10 cows, $\leq$4 ha of land, and did not own a tractor were classified as smallholder and the rest were classified as large scale. Other social groupings were based on source of semen (imported vs. local; group B), average MY per cow per day (<10 kg vs. 10 to 15 kg vs. >15 kg; group C), and amount of concentrate provided per cow per day ($\leq$5 kg vs. >5 kg; group D). Processors were included in each grouping as a separate unique group.

RESULTS

Breeding Goal Traits

Table 3 presents the traits included in the breeding goal. A wide range in choice of importance was observed with 17 of the 19 traits presented in the first questionnaire appearing among the 5 highest ranked. Traits with the highest proportions were MY, PLT, CIN, MBW, and FY. These were chosen as the breeding objective traits.

Individual Preferences

Figure 2 presents the median and interquartile ranges for individual preferences (ignoring social groupings) for the breeding objective traits. Medians were 0.219, 0.350, 0.214, 0.093, and 0.048 for MY, PLT, CIN, MBW, and FY, respectively. The large interquartile ranges observed indicate differences in preferences for these traits among respondents.

Social Preferences

Second, we investigated the presence of social groupings by calculating social (group) preferences. The traditional classification of production systems into small-scale and large-scale producers (group A) and grouping based on semen source (group B) did not capture substantial differences in preference values (Figure 3). However, differences were observed for the other grouping criteria. Producers with lower milk production and lower use of concentrates (low intensity producers; **LIP**) had systematic lower preference values for MBW, MY, and PLT compared with producers with high production and more concentrate use (high intensity producers; **HIP**). On the other hand, LIP had higher preference values for CIN and FY. Large differences were observed between producers in general and processors. The largest disparities were observed for MY and FY, which had highest preferences among processors. For the other traits, the order of importance for processors was PLT, CIN, and MBW, in descending order.

Consensus Preferences

Third, we calculated consensus preferences for the social groupings with the largest disparities (groups C and D). Table 4 presents the consensus preferences. How to deal with outlier groups when determining consensus is defined by the metric λ. When $\lambda = 0$, the consensus is defined by minimizing the disagreement of the most displaced social group, whereas for $\lambda = 1$, the consensus is defined by maximizing the average agreements among social groups. The λ values above 0.26

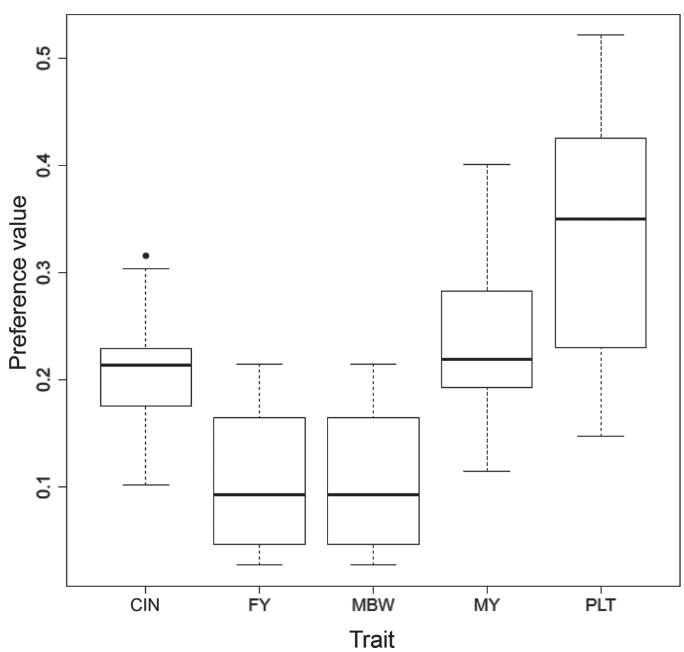

Figure 2. Box plots showing the median (thick horizontal line within boxes), interquartile range, extreme values (bar at end of dotted lines extending from boxes), and outlier (circular dot) for trait individual preferences. CIN = calving interval; FY = fat yield; MBW = mature body weight; MY = milk yield; PLT = production lifetime.

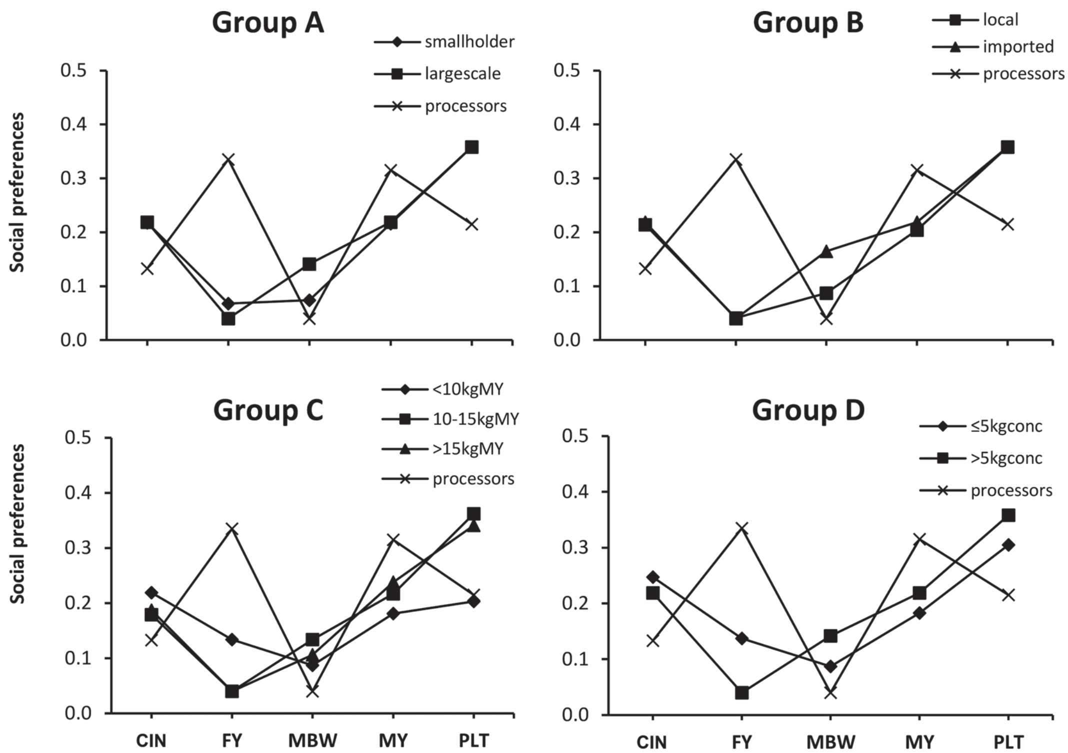

Figure 3. Social preference values. Social groups were defined based on the traditional criteria, milk yield per cow per day, amount of concentrate fed per cow per day, or the source of semen. Group A: based on traditional criteria; group B: based on source of semen, imported = imported semen, local = locally produced semen; group C: based on average milk yield per cow per day, <10 kgMY = less than 10 kg, 10–15 kgMY = between 10 and 15 kg, >15 kgMY = above 15 kg of milk yield per cow per day; group D: based on amount of concentrate (conc) fed per cow per day; ≤5 kg = 5 kg and below, and >5 kg = more than 5 kg of concentrates per cow per day. Processors were only one group. MY = milk yield; CIN = calving interval; PLT = production lifetime; MBW = mature body weight; FY = fat yield.

and 0.50 had the highest average agreement consensus for groups C and D, respectively. However, these solutions were highly biased against the processors group, which had maximum disagreement equal to 0.465 and 0.570 units, which are equivalent to 45 and 73% of the total disagreements, respectively. The most balanced solution was when the parameter λ was ≤ 0.25 and >0 for group C and ≤ 0.50 and >0 for group D. The corresponding consensus values were 0.238, 0.179, 0.215, 0.056, and 0.134 for group C, and 0.219, 0.153, 0.228, 0.040, and 0.173, for group D, for MY, CIN, PLT, MBW, and FY, respectively. Compared with average individual preferences (presented earlier), MY, MBW, and FY had higher whereas CIN and PLT had lower consensus preference values.

Desired Gains

Last, desired gains were computed as the product of G% and the average of the best consensus values for groups C and D (Table 5). Derived desired gains were 2.42, −0.22, 2.51, 0.15, and 0.87% for MY, CIN, PLT, MBW, and FY, respectively.

DISCUSSION

Definition of a breeding objective is paramount when designing a breeding scheme. Breeding goal weights define the direction and level of genetic change required for specific traits. Developing dairy cattle industries are characterized by diverse production and marketing systems, reflecting differences in costs and revenues. In this study, we employed a multi-criteria decision-making process to determine trait preferences among different groups and aggregate differences to obtain consensus preferences among the groups.

Choice of Criteria for Determination of Trait Preferences

Various participatory approaches have been proposed for derivation of trait preferences for breeding and conservation of livestock species. Such approaches are an alternative to the formal economic weighting approach for situations with under-developed market channels or where animals have nonmonetary values (or both), and for situations with multiple production

Table 4. Estimates of consensus preferences and social disagreements

	Consensus preferences[2]					Social group disagreements[3]					
λ[1]	MY	CIN	PLT	MBW	FY	D	D_1	D_2	D_3	D_4	Z
Group C											
[1, 0.26)	0.238	0.179	0.215	0.087	0.040	0.465	0.203	0.215	0.153	0.465	1.036
(0.25, 0.01)	**0.238**	**0.179**	**0.215**	**0.056**	**0.134**	0.340	0.109	0.309	0.247	0.371	1.036
[0]	0.217	0.179	0.215	0.040	0.139	0.340	0.340	0.340	0.340	0.340	1.360
Group D											
[1, 0.51)	0.219	0.219	0.358	0.087	0.137	0.570	0.064	0.152	0.570		0.786
(0.50, 0.01)	**0.219**	**0.153**	**0.282**	**0.040**	**0.137**	0.361	0.273	0.361	0.361		0.995
[0]	0.219	0.133	0.215	0.063	0.093	0.361	0.361	0.361	0.361		1.083

[1]λ = range of λ producing equal solutions, where [and] indicate "equal to" and (and) indicate "higher than" and "lower than" boundary values, respectively.

[2]MY = milk yield; CIN = calving interval; PLT = production lifetime; MBW = mature body weight; FY = fat yield. Bolded values are the most balanced solutions.

[3]D_i indicates the disagreements between the consensus preference and the social preference, where i = 1, 2, 3, 4, and 5. For group C (consensus based on amount of concentrate fed per cow per day), 1 = ≤5 kg, 2 = >5 kg, and 3 = processors; for group D (consensus based on farm milk yield per cow per day), 1 = ≤10 kg, 2 = 10 to 15 kg, 3 = >15 kg, 4 = processors. Z = average overall disagreements.

and marketing systems. Some participatory approaches used in deriving trait preferences in livestock systems in the literature are conjoint analysis (Tano et al., 2003), choice experiments (Scarpa et al., 2003; Byrne et al., 2012), weighted indices (Bett et al., 2009; Mbuthia et al., 2015), Wilcoxon signed rank (Gizaw et al., 2010) and AHP (Sae-Lim et al., 2012; Omasaki et al., 2016).

With index ranking, preferences are expressed as weighted averages of all the rankings for a particular trait (Bett et al., 2009), whereas with Wilcoxon ranks, preferences are based on computed ranks (Gizaw et al., 2010). With conjoint analysis and choice experiments, preferences are defined as marginal changes in prices resulting from variation in the trait of interest (Scarpa et al., 2003). Conjoint analysis and choice experiments have been shown to identify differences in preferences among producers (social groups) when ranking traits (Tano et al., 2003; Byrne et al., 2012). However, the above approaches are not amenable to aggregation with consensus preferences.

Multiple criteria decision-making procedures are preferred for aggregation of preferences as they allow participation of the decision makers, are flexible and transparent (Mirasgedis and Diakoulaki, 1997). One such multiple criteria decision-making procedure is WGP (Linares and Romero, 2002). The initial step in constructing consensus preferences is derivation of individual preference values for objective traits in the context of compromise programming [i.e., pairwise comparison of alternatives (Linares and Romero, 2002)]. The AHP is a compromise programming approach, where individual preferences are expressed as normalized weights (Saaty, 1977). The AHP therefore offers a suitable approach for a situation where the core objective is derivation of consensus preferences.

Use of AHP in derivation of consensus weights is limited by the number of traits that can be included in the objective. With more than 7 traits, the AHP computations become unworkable. However, in our case, where the objective is to investigate the possibility of establishment of a breeding scheme for a developing industry, a breeding objective with few traits is probably more suitable as a starting point.

Breeding Goal Traits

A main challenge to the implementation of a genetic improvement initiative in developing countries is the

Table 5. Most optimal consensus preferences and the corresponding desired genetic gains[1]

Trait	MY	CIN	PLT	MBW	FY
Pref[2]	0.229	0.166	0.249	0.048	0.136
G%[3]	10.6	−1.3	10.1	3.1	6.4
DesiredG%[4]	2.42	−0.22	2.51	0.15	0.87

[1]MY = milk yield; CIN = calving interval; PLT = production lifetime; MBW = mature body weight; FY = fat yield.

[2]Pref = consensus preferences.

[3]G% = genetic gains expressed as a percentage.

[4]DesiredG% = desired genetic gains expressed as a percentage.

limited and erratic participation of producers in routine pedigree and performance recording (Wasike et al., 2011; Zonabend et al., 2013). A breeding goal with a few key traits can offer a realistic starting point. Therefore, we fixed the number of traits in the breeding goal to 5. The key traits were determined to be MY, CIN, PLT, MBW, and FY. Previous studies have shown that sale of milk and culls are the main income sources for dairy producers in Kenya (Bebe et al., 2003b). Consequently, MY and MBW were highly ranked traits. Further, reproductive traits and fat content of the milk have been reported to be highly valued among smallholder producers (Bebe et al., 2003a). However, Bebe et al. (2003a) did not include longevity in their study. In the present study PLT was highly ranked, which may indicate the desire to keep cows in production for longer, to reduce replacement costs, or both. Disease resistance is an important trait in tropical countries (Bebe et al., 2003b; Tano et al., 2003). However, in the present study most of the respondents in the survey viewed resistance to East Coast fever (used as a measure of disease resistance) as not being very important as they could easily prevent the disease through regular dipping. In addition, selection for disease resistance would be hampered by lack of genetic parameters within a developing industry scenario.

Definition of Social Groups and Derivation of Social Preference Values

The first step in the definition of a breeding objective is specification of the production and marketing systems as this plays an important role in the identification of costs and revenues (Ponzoni and Newton, 1989). Whereas desired gain breeding goals are not based on formal economic weighting, level of intensification (input and output levels) is to a large extent a major indicator of desired genetic change by dairy producers. Dairy cattle production systems in developing countries are generally classified into smallholder and large-scale systems based on multiple criteria including land size, level of mechanization, labor input and output, level of feeding, and household income (Okwenye, 1994; Bebe et al., 2003a; Kasirye, 2003). In developing countries where the level of specialization is low, the definition of intensification should be directly related to the product in consideration among the multiple products produced at the farm. As an example, the number of cows owned is likely to be highly confounded with the amount of land owned and may not indicate the desired level of productivity per cow. In this study, we adopt more targeted classification criteria based on the animal level (i.e., MY and feeding per cow per day). Such an approach is more indicative of intensification at the product level rather than at farm level, and more likely to explain the producer's desired gains. This is supported by the study of Mubiru et al. (2007) who showed that MY is positively correlated with level of feeding and amount of expenses in terms of veterinary costs, and negatively correlated with the number of cows owned, labor input, and land size.

Our results show that when intensification is described from an animal level, substantial differences exist between HIP (>10 kg of MY and >5 kg of concentrate per cow per day) and LIP (<10 kg of MY and <5 kg of concentrate per cow per day). High intensity producers had higher preferences for MY, MBW, and PLT (groups C and D). Increases in productivity directly indicate an increase in feed requirement. Increased provision of high-quality feeds can therefore be interpreted as a direct consequence of the need for intensive production. Maximization of milk production to generate more cash through the sale of milk and for family consumption are key driving factors for producers (Bebe et al., 2003a). In addition, MBW determines the market value of culls as they are mainly slaughtered for meat. On the other hand, an increase in MY will require better feed of high quality. High costs for concentrate feeds coupled with seasonal fluctuations in quality and quantity of fodder pose the greatest challenge to dairy production in Kenya (Omore et al., 1999). The comparatively lower preference values for MY by LIP may be indicative of a conscious knowledge between what they desire and what is practically profitable. However, the differences between LIP and HIP in their preference for MY were minimal.

Market outlets form an important group and need to be considered in the derivation of weights as they determine the demand for products and prices. Two market outlets exist in Kenya (i.e., formal markets where milk is sold to processors and informal markets where milk is sold directly to consumers). Processors had MY and FY as the highest preferred traits. Apparently, these are the traits that are likely to have the most direct effect on their profitability. Approximately 20% of the milk produced in Kenya is sold through the formal market (Omore et al., 1999). Future demand for pasteurized milk in Kenya will depend on household incomes (SDP, 2004; FAO, WFP, and IFAD, 2012). Recent increases in demand for animal products in developing countries have been attributed to increasing incomes and population sizes (FAO, WFP, and IFAD, 2012). High preference for MY by processors may indicate high market demand for milk, whereas FY indicates a conscious need to maintain milk quality. In Kenya, milk is priced in terms of quantity. However, milk quality is important (SDP, 2004).

In the present study, we did not directly consider the informal market. However, it is assumed that producers target the needs of the market, and therefore, some aspects of the informal market needs are reflected in the LIP choices because this forms their main outlet (Omore et al., 1999). The LIP had higher preferences for FY (groups C and D). This fully agrees with the fact that the informal market has a consumer preference for low-priced, high-butterfat-content raw milk (Omore et al., 1999; SDP, 2004). Therefore, the higher preference values for FY by LIP can be construed to indicate the need to maintain the quality of the milk consumed at the household level while at the same time satisfying the requirement of the informal market.

Consensus Preferences and Desired Genetic Gains

Complexity in design and implementation of breeding programs, especially for dairy cattle that largely rely on producer participation, may explain the absence of such programs in developing countries. However, implementation of local breeding programs for dairy cattle provides a means to optimize developing dairy cattle industries (Vargas and van Arendonk, 2004; Okeno et al., 2010). A viable starting point may be the establishment of a single small-sized breeding program (Kariuki et al., 2014). The acceptance of such a breeding program by producers is likely to be determined by the breeding goal. Consensus in the definition of the breeding goal is therefore prudent.

Economic values-based breeding objectives tend to overemphasize selection for marketable production traits, mostly to the detriment of nonmarketable functional and health traits (Groen et al., 1997; Rauw et al., 1998). As an example, for the Kenyan dairy cattle industry, challenges in the practical implementation of economic values-based breeding objectives are apparent from the studies by Kahi and Nitter (2004) and Kahi et al. (2004). The first problem relates to the structure of marketing system where the value of milk is not broken down to constituent parts. Consequently, market value for milk components such as fat and protein is lacking. However, this does not imply that these components have no market value, but it could be argued that their value is inclusive in the volume price. This has led to economic values calculated based on this marketing system resulting in a negative value for FY (Kahi and Nitter, 2004). Other studies have shown consumers prefer milk with high fat content (Omore et al., 1999; SDP, 2004). This presents a special situation where consumer preferences are not reflected in commodity prices. The processors seem to have adjusted for this anomaly by setting a minimal fat percentage level when purchasing milk from producers, though these levels are not adequately communicated to producers (personal observation). A breeding objective with negative selection for FY is likely to be detrimental in the long term.

Sale of culls is one of the main revenue sources for dairy producers (Bebe et al., 2003b). Kahi and Nitter (2004) estimated an economic value of Kenya shillings 7.95 for MBW, indicating a strong positive selection for heavier animals. Heavier animals require more in terms of food quantity for maintenance and production. The positive selection for heavier animals, particularly among smallholder producers, contradicts the expectations. A major challenge for dairy production is poor quality and insufficient quantities of feed and high prices for concentrates (Rege et al., 2011). Although BW of culls is an important trait contributing directly to revenues, our results show a conscious judgment among producers between expectations and the realities of production. The LIP had the lowest preference for MBW, which may be indicative of the challenges this group of producers face in cost of feeding. Overall, in our results MBW had the least preference of 0.048.

Beside economic value estimation, definition of a national breeding objective for the dairy industry in developing countries is complicated by the diversity among the key players. To overcome this challenge, Kahi et al. (2004) derived a breeding objective based on the smallholder system for the current (volume-based) and future (volume- and fat-based) marketing systems. Because response to selection will always be expressed in the future, a breeding goal that considers a future marketing situation is desirable. However, failure to account for differences within the production systems is not likely to optimize production in these systems, and consequently, may be rejected. On the other hand, desired gains reflect the stakeholders' expectations with respect to production and market circumstances. Desired gains, therefore, can be used to incorporate stakeholders' views and wishes in the derivation of breeding objectives (Martin-Collado et al., 2015).

Derivation of breeding objectives has traditionally been geared toward an economic optimum, which cannot be achieved with desired gains. Economic optimum can be achieved through use of economic farm models to derive economic values for traits in the breeding goal. However, a purely economic view in the derivation breeding objectives has also been shown to result in undesired responses in functional and welfare traits (Groen et al., 1997; Rauw et al., 1998). Effects of such undesired responses on the overall economic performance of low-input developing dairy systems is expected to be severe (Rege et al., 2011). Breeding objectives that incorporate both market and nonmarket values of traits have been proposed (Nielsen et al., 2006). Derivation of such objectives incorporate economic and desired gains values. In addition, a consensus desired gains objective that aims to determine the best compromise for all production systems means a compromise in performance for all systems. However, we expect such a compromise to have a positive effect on the overall performance, compared with a situation where production is optimized for only one production system. A future prospect is that low-input producers will be able to produce replacement heifers on their farms, allowing the derivation of a sub-index for them.

For the current situation, a single breeding objective for both high and low producers can provide a means for genetic improvement of dairy cattle in Kenya in the short term. Using consensus preferences, pedigree and performance records from large-scale producers can be optimally used to improve the entire value chain. Initiation of a fully functional locally run breeding scheme can provide an impetus for more participation of producers in recording of pedigrees and performances. We have used WGP to define consensus weights by minimizing disparities between different groups. The premise of our thinking is that the preference values for individual respondents are a measure of the utility they derive from the traits. Our results also suggest that such utility has a monetary basis as social preferences indicate conscious efforts within groups to maximize profitability within the constraints they face. In a descending order, desired genetic gains were 2.51, 2.42, −0.22, 0.87, and 0.15% for PLT, MY, CIN, FY, and MBW, respectively. These desired gains can form a basis for the design of an optimal multi-trait breeding program that accounts for the diversity in the industry (Brascamp, 1978; Gizaw et al., 2010).

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