INTRODUCTION

Kermani is a meat and wool type, fat-tailed, medium-sized and white-wool sheep breed, indigenous to the southeastern areas of Iran and appropriately adapted to the unfavorable climatic conditions and pastures of low quantity and quality which is prevalent in the region (Mohammadbadi et al. 2017). The wool of Kermani sheep is fairly thick with a carpet grade. Mutton is the main source of red meat in Iran and now meat production from the sheep does not sufficient for increasing consumer demand.

The primary objective of a breeding program for any livestock species is to maximize the rate of genetic progress for economically important traits (Rashidi et al. 2008) such as body weight and reproductive performance. Increasing the profitability of any sheep production system is of great importance (Harris, 1970).

Hossein-Zadeh and Ardalan (2008) pointed out that meat production is one of the primary goals in sheep breeding of Iran. Ghiasi et al. (2016) reported that the number of lambs produced by each ewe constitutes the main part of income while milk production is of secondary importance and wool has no income or is little.
Falconer and Mackay (1996) recommended the application of selection indices for multi-trait selection in animal populations. Selection indices incorporate data on biological and also economic aspects of production simultaneously into a single value known as aggregate genotype (Parish et al. 2011; Paswan et al. 2016). Various breeding objectives and selection indices have been proposed in several livestock species such as indigenous chickens in Kenya (Okeno et al. 2012), Rayeni Cashmere goat (Kargar Borzì et al. 2017), wormsilk (Seidavi et al. 2008), buffalo (Aguadelo-Gómez et al. 2016) and Aberdeen Angus cattle (Campos et al. 2014).

In Iran, under rural production systems, most sheep breeding enterprises may be unfavorably affected by the factors such as limited numbers of breeding males which increase the level of inbreeding in the flock.

In order to increase the genetic progress and decrease the rate of inbreeding, the establishment of a suitable selection index considering factors such as flock size, ram ratio and traits of interest is necessary. As Kermani sheep breed mainly reared under the rural system, there is no information on the suitable selection indices for improving the performance of flocks under such systems. Up to our knowledge, there is no information on such selection indices. Therefore, the present study was performed for comparing different selection indices in Kermani sheep under rural production systems.

**MATERIALS AND METHODS**

**Breeding objective and selection criteria**

Different areas of the Kerman province, which located in the south-eastern part of Iran, were chosen for gathering the required information. Five farmers were considered finally to take part in the present investigation. All farmers expected to increase their economic profit from their sheep flocks through higher meat and wool output and also reduced costs. Therefore, higher reproduction rate, higher growth rate and higher wool weight of the sheep are of primary interest. To select animals for the increased quantity of meat and wool produced, ewe body weight, annual wool weight and total weaning weights of lambs per exposed ewe, were used as selection criteria. The breeding objectives of rural production systems in Kermani sheep were acquired from economic analysis and the conversation with flock holders. So, breeding goals (meat production and wool production) and selection criteria (body weight (kg), total weaning weight for each exposed ewe (kg) and wool production (kg)) for Kermani sheep were considered.

**Structure of (co)variance matrix**

The phenotypic and genetic (co)variance matrix (Table 1) was derived from the data of experimental breeding station of Kermani sheep, located in Shahrbak, southeast of Iran, which collected over a period of 18 years (1993-2011). (co)variance components for the traits were estimated by the Average Information Restricted Maximum Likelihood (AI-REML) method fitting an animal model. For this purpose, the WOMBAT computer program was used (Meyer, 2006). The required information which was accessible from those records also was reported in some research (Bahreini Behzadi et al. 2007; Mokhtari et al. 2008; Mokhtari et al. 2010).

**Economic analysis**

Microsoft excel spreadsheets were used to estimate productive and reproductive efficiency as well as of the costs and incomes. The systems, production costs and revenues, and profit equation were estimated as explained by Kosgey et al. (2003). In the present study, a deterministic static model was used for calculating the economic values (EVs) of decisive traits of Kermani sheep. The total annual profit of the flock was derived as the difference between costs and revenues of the system.

The average prices in 2011 were used and all costs and prices were expressed in Dollar. The productive and time units were the ewe and year, respectively. The inputs for the production system were feed, management, and fixed costs. The outputs were revenues from the sale of cull ewes and rams, excess lambs and wool. The input parameters were taken from the five Kermani sheep flocks with a total size of 635 heads. The economic value of each trait (Vi) was obtained by Eq. (1)

\[ V_i = P_i - P \]  

(1)

Where:

P and Pi: profits before an increase and after increase of the trait by 1%, keeping all other traits at their mean value simultaneously (Lobo et al. 2011).

**Data simulation and flock structure**

To determine the appropriate selection index for Kermani sheep, the productive population was simulated. For this purpose, the base population was randomly established based on genetic and phenotypic (co)variance matrices (Table 1) of Kermani sheep and the means of the studied flocks (Table 2) by applying the Visual Basic 6.0 programming language. The assumptions and the statistical distribution of the simulated parameters are presented in Table 3.

After simulating the phenotypic records of the base population, for obtaining the phenotypic records of the offspring random mating was done between top adult rams and ewes (the best parents) as follows:

\[ y_0 = \mu + 0.5g_b + 0.5g_d + m + e \]
m = 0.5 (2-Fb-Fd) 0.5ZLG

Where:
y0: vector of offspring phenotypic records.
µ: vector of mean of the trait considered.
gb and gd: vectors of breeding values for rams and ewes respectively.
m: vector of Mendelian sampling.
e: vector of residuals.
Z: vector of random numbers normally distributed with a mean of zero and variance equal to one.
LG: lower triangular matrix obtained from Chalsky analysis G.
Fb and Fd: inbreeding coefficients for rams and ewes, respectively.

Top adult rams and ewes were selected based on economic selection index. To choose the best parents, the selection index for each animal was established. Flock size, ram ratio, numbers of generations, numbers of traits, litter size, percentage of ram and ewe in the flock, longevity of rams and ewes in the flock, age of the animal at maturity and mortality rate were defined similarly to the considered Kermani sheep flocks (Table 2).

The overlap between generations was considered. Selection indices were derived by changing the ram ratio from 2 to 8 percent.

Economic analysis
The absolute and relative economic values of studied traits are shown in Table 1. Relative economic values of EBW, AWW, and TWWEE traits were - 1.95, 1.00 and 14.48, respectively. The calculated economic values, except EBW, were positive. Positive economic value for a trait indicated that genetic progress in that trait would positively influence on the profitability of the breeding system. Negative economic values for body weight traits were also reported in literature (Bett et al. 2011; Kargar Borzi et al. 2017). Economic increase comes from higher meat and wool output as well as reduction of costs in sheep flocks. Hence, higher reproduction and growth rate and wool weight are economically important. The economic value for total weaning weight of lambs per exposed ewe was larger than the other traits (Table 1), implied that TWWEE has higher influence on the costs of production system than other studied traits.

The comparison of selection indices
The values of inbreeding under the considered selection indices (I1 to I4), different flock size and ram ratio are shown in Table 4. The obtained results showed that inbreeding was reduced by increased flock size and ram ratio, accordingly. The lowest value of inbreeding was obtained under I4 which included TWWEE in flock size of 300 and ram ratio of 0.08. Kosgey et al. (2003) reported that the increase in flock size would be associated with decreased genetic gain and inbreeding. Therefore, for preventing the increase of inbreeding in small-sized flocks, the ram ratio should be increased (Kosgey et al. 2003).

As shown in Table 4, the maximum value for selection index (183.54) was obtained under the first index, I1, with flock size of 200 and ram ration of 0.02 while the minimum one (135.10) was obtained under I3, flock size of 100 and ram ratio of 0.08. Inbreeding ranged from 0.052 (under I4, flock size of 300 and ram ratio of 0.08) to 0.288 (under I1, flock size of 100 and ram ratio of 0.02).

The values of aggregate genotype and economic gain under different flock size and ram ratio across four selection indices (I1 to I4) are shown in Table 5.

Aggregate genotype (H) was defined as:

\[ H = \sum vi \times gi \] (3)

Where:
vi: relative economic value of the i\textsuperscript{th} trait in the aggregate genotype.
gi: breeding value of the i\textsuperscript{th} trait in the aggregate genotype.

RESULTS AND DISCUSSION

Developing the selection indices
Four selection indices with different herd size and ram ratio were proposed (I1–I4) to compare genetic and economic gain and inbreeding rate with computer simulation after selected 10 years. The traits included in indices were: ewe body weight (EBW), annual wool weight (AWW) and total weaning weight of lambs per exposed ewe (TWWEE). The first index (I1) was considered as a full selection index that included all the considered traits. To decrease the cost of trait measurement, other selection indices were proposed to detect the appropriate selection index. The traits contained in each index were as follows: EBW, AWW, and TWWEE (I1); AWW and TWWEE (I2); EBW and TWWEE (I3) and TWWEE (I4).

Economic gain under each index was defined as:

\[ E = \sum (EVi \times BVi) \] (2)

Where:
EVi: absolute economic value of the i\textsuperscript{th} trait involved in the index.
BVi: breeding value for the i\textsuperscript{th} trait included in the index.

Economic analysis
The absolute and relative economic values of studied traits are shown in Table 1. Relative economic values of EBW, AWW, and TWWEE traits were - 1.95, 1.00 and 14.48, respectively. The calculated economic values, except EBW, were positive. Positive economic value for a trait indicated that genetic progress in that trait would positively influence on the profitability of the breeding system. Negative economic values for body weight traits were also reported in literature (Bett et al. 2011; Kargar Borzi et al. 2017). Economic increase comes from higher meat and wool output as well as reduction of costs in sheep flocks. Hence, higher reproduction and growth rate and wool weight are economically important. The economic value for total weaning weight of lambs per exposed ewe was larger than the other traits (Table 1), implied that TWWEE has higher influence on the costs of production system than other studied traits.
Table 1
Estimates of mean, economic values and structure of (co)variance matrix for Kermani sheep

<table>
<thead>
<tr>
<th>Trait (kg)</th>
<th>Mean (SD)</th>
<th>Absolute economic values ($)</th>
<th>Relative economic values</th>
<th>EBW</th>
<th>AWW</th>
<th>TWWEE</th>
<th>I1</th>
<th>I2</th>
<th>I3</th>
<th>I4</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBW</td>
<td>38 (5.62)</td>
<td>-4.5 (-1.95)</td>
<td>1.25 (0.11)</td>
<td>0.11</td>
<td>0.14</td>
<td>0.12</td>
<td>0.08</td>
<td>0.05</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>AWW</td>
<td>0.65 (0.10)</td>
<td>2.3 (0.73)</td>
<td>0.08 (0.04)</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>TWWEE</td>
<td>18 (2.31)</td>
<td>33.30 (14.48)</td>
<td>3.89 (1.34)</td>
<td>0.13</td>
<td>0.12</td>
<td>0.11</td>
<td>0.09</td>
<td>0.08</td>
<td>0.07</td>
<td>0.06</td>
</tr>
</tbody>
</table>

1 Genetic variance in diagonal and residual variance in diagonal (in parentheses); residual (below diagonal) and genetic (above diagonal) covariances.

EBW: ewe body weight; AWW: annual wool weight and TWWEE: total weaning weight for each exposed ewe.

SD: standard deviation.

Table 2
Overview of the assumed values for the input variables of the study

<table>
<thead>
<tr>
<th>Variables</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flock structure</td>
<td>Birth weight (kg)</td>
</tr>
<tr>
<td>Number of the ewe in flocks</td>
<td>600</td>
</tr>
<tr>
<td>Number of ram in flocks</td>
<td>35</td>
</tr>
<tr>
<td>Conception rate (%)</td>
<td>93</td>
</tr>
<tr>
<td>Number of lamb in year</td>
<td>1.38</td>
</tr>
<tr>
<td>Number of lamb per birth</td>
<td>1.1</td>
</tr>
<tr>
<td>Ewe survival (%)</td>
<td>94</td>
</tr>
<tr>
<td>Replacement survival (%)</td>
<td>93</td>
</tr>
<tr>
<td>Pre-weaning survival (%)</td>
<td>81</td>
</tr>
<tr>
<td>Post-weaning survival (%)</td>
<td>92</td>
</tr>
<tr>
<td>Replacement rate (%)</td>
<td>29</td>
</tr>
<tr>
<td>Culling rate of ewes (%)</td>
<td>21</td>
</tr>
<tr>
<td>Culling rate of rams (%)</td>
<td>1.7</td>
</tr>
<tr>
<td>Production variables</td>
<td>The proportion of rams in flock (%)</td>
</tr>
</tbody>
</table>

Table 3
The assumptions and statistical distribution of the simulated parameters

\[ y = \mu + g + e = N (\mu, \sigma^2) \]
\[ g = LG'Z_1 \]
\[ e = LRZ_2 \]

\[ \sigma^2 = G + R \]
\[ G = LGL' \]
\[ R = LRL' \]

y: vector of phenotypic records; \( \mu \): vector of mean of traits; g: vectors of additive genetic value for traits; e: vector of residuals; G: matrix of additive genetic (co)variance; R: residuals (co)variance; LG and LR: lower triangular matrix obtained from Chalsk analysis G and R respectively and Z_1 and Z_2: vectors of random numbers normally distributed with a mean of zero and variance equal to one.

Table 4
The values of inbreeding and selection index under different flock size and ram ratios of Kermani sheep

<table>
<thead>
<tr>
<th>Ram ratio</th>
<th>0.02</th>
<th>0.04</th>
<th>0.06</th>
<th>0.08</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>I_1</td>
<td>0.288</td>
<td>154.36</td>
<td>0.197</td>
</tr>
<tr>
<td></td>
<td>I_2</td>
<td>0.258</td>
<td>152.41</td>
<td>0.189</td>
</tr>
<tr>
<td>200</td>
<td>I_1</td>
<td>0.262</td>
<td>152.6</td>
<td>0.188</td>
</tr>
<tr>
<td></td>
<td>I_2</td>
<td>0.275</td>
<td>161.28</td>
<td>0.179</td>
</tr>
<tr>
<td>300</td>
<td>I_1</td>
<td>0.262</td>
<td>152.6</td>
<td>0.188</td>
</tr>
<tr>
<td></td>
<td>I_2</td>
<td>0.205</td>
<td>161.25</td>
<td>0.119</td>
</tr>
</tbody>
</table>

I_1: included ewe body weight (EBW), annual wool weight (AWW), and total weaning weight of lambs per exposed ewe (TWWEE); I_2: included annual wool weight (AWW) and total weaning weight of lambs per exposed ewe (TWWEE); I_3: included ewe body weight (EBW) and total weaning weight of lambs per exposed ewe (TWWEE); I_4: included total weaning weight of lambs per exposed ewe (TWWEE).
Under the first selection index (I₁), the highest amount of aggregate genotype value (183.64) and economic gain (123.65 $) was obtained. By considering the second selection index (I₂), aggregate genotype value and economic gain were varied between 136.10 to 169.12 and 93.79 to 115.57 $, respectively.

Under the third selection index (I₃), a minimum amount of aggregate genotype value (136.04), and economic gain (86.39 $) was obtained. Under the fourth selection index (I₄), aggregate genotype value and economic gain were varied between 145.45 to 175.20 and 79.78 to 114.73 $, respectively. Under all developed selection indices, in flock size of 300 and ram ratio of 0.02 the highest amount of aggregate genotype value and economic gain was achieved. A reduction in ram percent will precipitate genetic progress because of the high selection intensity (Falconer and Mackay, 1996).

Economic values were positive for AWW and TWWEE but not for EBW, implying that by increasing body weight of ewes, the profit would be reduced. Obtained negative economic values for ewe body weight were in agreement with the result obtained by Bett et al. (2011). Also, Conington et al. (2004) reported a negative economic value for mature body weight. The highest economic value was obtained for TWWEE.

Likewise, Gallivan (1996) pointed out that reproductive traits have high economic value in Canadian sheep. The main influencing factors to be considered in genetic selection strategies are the accuracy of selection, selection intensity, effective population size and mating system (Falconer and Mackay, 1996).

Therefore, optimum response to selection may be achieved by maximizing the accuracy of selection, selection intensity and additive genetic variance or effective population size (Falconer and Mackay, 1996). But, all of these factors cannot be maximized, with limited resources. For example, increasing selection intensity decreases effective population size, which consequently resulted in a reduction in response to selection.

Likewise, increasing the accuracy of selection by use of selection indices also reduces effective population sizes, which lead to a quicker increase in the rate of inbreeding (Quinton and Smith, 1995). Inbreeding rates are speed up in livestock, and inbreeding causes economic losses through depression in production, growth, health, and fertility (Weigel, 2001). To increase genetic progress and limit the rate of inbreeding, establishment of appropriate selection index based on different herd size and ram ratio were the purpose of this research. The obtained results (Table 4) showed that the mean of inbreeding during 10 generations of selection was reduced with an increase in flock size and ram ratio. The increase in inbreeding negatively influences on genetic variance and decrease the genetic gain, accordingly (Falconer and Mackay, 1996).

Therefore, for reducing the mean of inbreeding, large flock size and the adequate number of rams for mating are required. It is obvious that adequate number of rams for mating can reduce effectively the rate of inbreeding over generations with a minimal decrease of selection response. Therefore, the results of the present study will guide Kermani sheep breeders focus on a scheme to decide the starting numbers of basis animals to create a breeding herd.

### Table 5: The values of aggregate genotype and economic gain ($) under different flock size and ram ratios of Kermani sheep

<table>
<thead>
<tr>
<th>Flock size Index</th>
<th>Ram ratio 0.02</th>
<th>Aggregate genotype gain ($)</th>
<th>Economic gain ($)</th>
<th>Ram ratio 0.04</th>
<th>Aggregate genotype gain ($)</th>
<th>Economic gain ($)</th>
<th>Ram ratio 0.06</th>
<th>Aggregate genotype gain ($)</th>
<th>Economic gain ($)</th>
<th>Ram ratio 0.08</th>
<th>Aggregate genotype gain ($)</th>
<th>Economic gain ($)</th>
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<tbody>
<tr>
<td>100</td>
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<tr>
<td>1</td>
<td>155.36</td>
<td>114.171</td>
<td>152.32</td>
<td>111.397</td>
<td>147.92</td>
<td>99.495</td>
<td>137.97</td>
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<td>2</td>
<td>152.42</td>
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<td>141.80</td>
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<td>153.6</td>
<td>105.794</td>
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<td>86.390</td>
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<tr>
<td>4</td>
<td>163.28</td>
<td>99.114</td>
<td>157.11</td>
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<td>6</td>
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<td>159.56</td>
<td>102.386</td>
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</table>

I: included ewe body weight (EBW), annual wool weight (AWW), and total weaning weight of lambs per exposed ewe (TWWEE); I₂: included annual wool weight (AWW) and total weaning weight of lambs per exposed ewe (TWWEE); I₃: included ewe body weight (EBW) and total weaning weight of lambs per exposed ewe (TWWEE); I₄: included total weaning weight of lambs per exposed ewe (TWWEE).
To prevent excessive inbreeding in the flock, small-sized flocks may be combined. The increase of flock size will cause a reduction of inbreeding, and increase of genetic and economic gain, accordingly. Then, decrease of ram up to 2% and increase of flock size up to 300 may be suggested as the most suitable breeding program for Kermani sheep under extensive production system.

The annual response to selection applying a multi-trait selection index will be smaller in each component trait than the selection accomplished for that trait individually. However, it is important to evaluate all traits with economic value, to improve genetic progress and the greatest rate of change in overall economic merit. Selection for reproductive traits should be based on a criterion that is highly similar to the breeding goals; for example, if the selection is based on the number of lambs, the frequency of genes affecting the total weight of the lamb is not sufficiently affected.

Snyman et al. (1996) indicated that the selection for the number of lambs born per ewe is only significant for the number of lambs and will not increase the weight of lambs; while the selection for total weaning weight per ewe will also increase individual weight gain of lambs. Therefore, traits that were considered in the full selection index included EBW, AWW, and TWWEE. Response to selection increased with an increase in herd size. However, with an increase in ram ratio, response to selection decreased (Tables 4 and 5). The highest genetic and economic responses were obtained under the first index (I1). Under the second selection index (I2), the least genetic and economic responses to selection were obtained. Among the developed selection indices in the present study, the first one, which included all the three considered traits into account, may be taken as the best one for flock holders of Kermani sheep. Anyhow, if meat quantity to be the first interest of the flock holders of Kermani sheep, the third index (I3) which combines ewe body weight and total weaning weight of lambs per exposed ewe may be an appropriate alternative.

CONCLUSION

Results of the present study indicated that, for the genetic improvement of Kermani sheep populations, Index 1, with all traits including (ewe body weight, annual wool weight and total weaning weight for each exposed ewe), may be used appropriately. The choice and use of the index depending on the definition of objectives. The results of the study can be used to design local sheep breeding programs in Iran, and in other countries in low-input production systems with low technological progress, such that those found in the tropics.

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