

**GENETIC AND PHENOTYPIC EVALUATION OF  
CROSSBRED DAIRY CATTLE FOR PERFORMANCE  
TRAITS WITH ASSOCIATED METEOROLOGICAL  
FACTORS**

**Dissertation**

**Submitted to the Guru Angad Dev Veterinary and Animal Sciences University in  
partial fulfillment of the requirements for the degree of**

**DOCTOR OF PHILOSOPHY  
in  
ANIMAL GENETICS AND BREEDING  
(Minor Subject: Animal Biotechnology)**

**By**

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## CERTIFICATE – I

This is to certify that the dissertation entitled, “**Genetic and Phenotypic Evaluation of Crossbred Dairy Cattle for Performance Traits with Associated Meteorological Factors**” submitted for the degree of **Ph.D.**, in the subject of **Animal Genetics & Breeding** (Minor Subject: **Animal Biotechnology**) of the Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, is a bonafide research work carried out by **Tassew Mohammed Ali (L-2017-V-02-D)** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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### **ABSTRACT**

The studies were undertaken to assess the effect of genetic and non-genetic factors on different production and reproduction traits, to analyze the growth and lactation curves across fixed factors, to estimate the genetic and phenotypic parameters for performance traits and to establish the relationship of THI with different production and reproduction traits in crossbred cattle. The performance data on crossbred cattle pertaining to growth, reproduction and milk production traits were collected from Dairy Livestock Farm (DLF), Guru Angad Dev Veterinary and Animal Sciences University whereas the meteorological data were obtained from School of Climate Change and Agricultural Meteorology, Punjab Agricultural University. Phenotypic data of both first and pooled lactation performance traits were analyzed using SAS version 9.3 to estimate all the parameters considered under the study. The overall least square means for BW0, BW365, BW450, BW540, AFS, AFC, WFC, FLNSPC, FLPP, FLSP, FCI, FL305\_DMY, FLMY, FLL, FLDP, FLPY and FLDPY were 29.40±0.18 kg, 195.49±1.44 kg, 243.88±1.49 kg, 291.57±1.57 kg, 712.05±9.24 days, 1008.01±9.52 days, 404.55±2.09 kg, 2.34±0.06 no., 276.96±0.27 days, 177.52±5.18 days, 454.21±5.22 days, 4323.53±73.83 kg, 3646.92±48.38 kg, 370.74±4.41 days, 93.32±1.53 days, 20.70±0.29 kg and 47.49±1.15 days, respectively, whilst ALNSPC, ALPP, ALSP, ALCI, AL305\_DMY, ALMY, ALL, ALDP, ALPY and ALDPY were averaged as 2.37±0.04 no., 276.98±0.18 days, 173.91±3.17 days, 451.44±3.24 days, 4478.64±47.99 kg, 3813.69±32.43 kg, 370.12±2.91 days, 91.36±0.97 days, 21.72±0.20 kg and 47.48±0.74 days, in that order. Season of birth significantly influenced all growth traits except BW180. The influences of period of birth on all growth traits and on AFS, AFC, FLPP, FLDP, ALSP, ALCI, AL305\_DMY, ALMY and ALPY were found to be significant. Period of calving had significant influences on FLNSPC, FLSP, FCI, FLMY, FL305\_DMY, FLL, ALNSPC, ALSP and ALDPY whereas genetic group exerted significant influences on BW180, FLNSPC, FLPP, FL305\_DMY, FLMY, FLPY, AL305\_DMY, ALMY and ALPY. The heritability estimates for growth traits were intermediate to high whereas the heritability estimates of first lactation reproduction and milk production traits ranged from low to intermediate. The heritability estimates for reproduction traits from all lactation were low whereas low to intermediate for all lactation milk production traits. REML and MIVQUE0 are considered to be the good methods with no genetic variation among between them and good precision estimates for ranking sires based on FL305\_DMY, AL305\_DMY, WFC and AFC. The Quadratic and Gompertz models followed by Cubic and Logistic models gave best fit and reliable description to the growth curve whereas PRM and IPM models followed by MLF and GTF showed best fit average lactation curve characteristics of crossbred dairy cattle. The effects of Temp, THI and THIadj on all performance traits except NSPC, PP, DMY and PY were insignificant. The herd management should consider the significant genetic and non-genetic factors. The selection criteria and suitable breeding approach may be considered to improve the herd. Moreover, new germplasm should be introduced in the herd to increase genetic variability. Meteorological variables are one of the important factors for the productive and reproduction efficiency of crossbred dairy cattle. Mitigation of heat stress due to meteorological factors should be considered as an integral component of the cattle management system.

**Key Words:** Genetic factors, non-genetic factors, performance traits, genetic parameters, growth curve, lactation curve, meteorological factors and crossbred dairy cattle

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Signature of Major Advisor

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Signature of the Student

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## LIST OF ABBREVIATIONS

1. $\Delta E$	:	Environmental trend
2. $\Delta G$	:	Genetic trend
3. $\Delta P$	:	Phenotypic trend
4. °C	:	Degree Celsius
5. 305_DMV	:	305 days lactation milk yield
6. AAC	:	Age at calving
7. AFC	:	Age at first calving
8. AFS	:	Age at first service
9. AI	:	Artificial Insemination
10. AICRP	:	All India coordinated research project
11. AL	:	All available Lactation
12. ANLNO.	:	Animal number
13. ANOVA	:	Analysis of variance
14. Avg.	:	Average
15. BLUP-AM	:	Best Linear Unbiased Prediction under Animal Model
16. BLUP-SM	:	Best Linear Unbiased Prediction under sire Model
17. BS×S	:	Brown Swiss cross with Sahiwal
18. BV	:	Breeding value
19. BW0	:	Birth weight
20. BW180	:	Body weight at 180 days of age
21. BW270	:	Body weight at 270 days of age
22. BW365	:	Body weight at 365 days of age
23. BW450	:	Body weight at 450 days of age
24. BW540	:	Body weight at 540 days of age
25. BW90	:	Body weight at 90 days of age
26. C(P)	:	Conceptual predictive criterion
27. CI	:	Calving interval
28. CV	:	Coefficient variation
29. DF	:	Degree freedom
30. DFREML	:	Derivative free Restricted Maximum Likelihood
31. DIMP	:	Days in milk at peak production
32. DLF	:	Directorate of Livestock Farm
33. DMV	:	Daily milk yield
34. DO	:	Day open
35. DOC	:	Date of calving
36. DP	:	Dry period
37. DPY	:	Days to attend peak yield
38. E	:	Environment
39. EDF	:	Exponential decline function
40. F×T	:	Friesian cross with Tharparkar
41. FAO	:	Food and Agriculture Organization

1. FC	:	Friesian cross
2. FL	:	First lactation
3. ft	:	feet
4. g	:	gram
5. GG	:	Genetic group
6. GTF	:	Gamma-Type Function
7. $h^2$	:	Heritability
8. HF	:	Holstein Friesian
9. HF×T	:	Holstein Friesian cross with Tharparkar
10. HHS	:	Holstein Holstein and Sahiwal
11. HRS	:	Holstein Red Dane and Sahiwal
12. HS	:	Holstein and Sahiwal
13. ICMR	:	Indian Council of Medical Research
14. IPCC	:	Intergovernmental Panel on Climate Change
15. IPM	:	Inverse polynomial model
16. K	:	Maturation rate
17. Kg	:	Kilo gram
18. LL	:	Lactation length
19. LMY	:	Lactation milk yield
20. LO	:	Lactation order
21. LRM	:	Linear regression model
22. LSM	:	Least square method
23. LWSI	:	Livestock Weather Safety Index
24. m	:	Meter
25. M	:	Inflection point
26. m.a.s.l :	:	Meter above sea level
27. Max	:	Maximum
28. Min	:	Minimum
29. MIVQUE0	:	Minimum Variance Quadratic Unbiased Estimator zero
30. MLF	:	Mixed Log Function
31. MOB	:	Month of birth
32. MOC	:	Month of calving
33. MPPA	:	Most Probable Producing Ability
34. MSE	:	Mean square error
35. MSS	:	Mean sum of squares
36. N	:	Number
37. NID	:	Normally and independently distributed
38. NSPC	:	Number of service per conception
39. OABW	:	Observed average body weight
40. P	:	Phenotype
41. PABW	:	Predicted average body weight
42. Pe	:	Persistency
43. PEM	:	Parabolic Exponential Model

1. POB	:	Period of birth
2. POC	:	Period of calving
3. PP	:	Pregnancy period
4. PRM	:	Polynomial regression model
5. PY	:	Peak Yield
6. r	:	Repeatability
7. $r^2$	:	Coefficient of determination
8. $R^2_{adj}$	:	Adjusted coefficient of determination
9. RE	:	Residual error
10. REML	:	Restricted Maximum Likelihood
11. RH	:	Relative humidity
12. RS	:	Red Dane and Sahiwal
13. S	:	Sahiwal
14. SE	:	Standard error
15. SD	:	Standard deviation
16. SOB	:	Season of birth
17. SOC	:	Season of calving
18. SP	:	Service period
19. SR	:	Solar radiation
20. SRLS	:	Simplified Regressed Least-Square
21. SSE	:	Sum square error
22. TDN	:	Total digestible nutrient
23. Temp	:	Temperature
24. THI	:	Temperature Humidity Index
25. $THI_{adj}$	:	Adjusted Temperature and Humidity Index
26. TNZ	:	Thermo-neutral zone
27. W	:	Watt
28. WAC	:	Weight at calving
29. WFC	:	Weight at first calving
30. WS	:	Wind speed



## CHAPTER I

### INTRODUCTION

India is home to huge cattle genetic resources with an estimated population of 193.46 million, out of which exotic/crossbred cattle populations was 50.42 million (20<sup>th</sup> Livestock Census, 2019). The importance of exotic/crossbred cattle in the country's economy has been significantly growing up. Crossbreeding work was started in the country as early as 1875, near Patna using Shorthorn bull on local cows and the “Taylor” breed of cattle was formed (Sinha, 1951). Nowadays, it has been a proven fact that extensive crossbreeding of native cows with exotic breeds like Jersey and Holstein Friesian has resulted in the white revolution (20th Livestock Census, 2019).

The Sahiwal is one of the most important dairy breeds of India. They are capable of producing an average of 7.76 kg of milk a day (Parveen, 2017). Sahiwal breed has been maintained and improved at Guru Angad Dev Veterinary and Animal Science University (GADVASU) Directorate Livestock Farm (DLF). DLF was established in 1968 aimed to improve the performances of Sahiwal cattle via a crossbreeding program under the Dairy Cattle Breeding Project. The genetic improvement of the breed was begun with crossbreeding of Sahiwal cows with Red Dane bulls at the Punjab Agricultural University, Ludhiana (now GADVASU, Ludhiana). Later on, the breeding programme was modified to concentrate on Holstein-Friesian crossbreds and the use of the Red Dane breed was discontinued in the mating plan. Two-breed crosses possessing 50% Holstein-Friesian and 50% Sahiwal inheritance (HS) were also produced which were again inseminated with the semen of Holstein-Friesian bulls to produce crossbreds with 75% Holstein-Friesian and 25% Sahiwal germplasm (HHS). Interse mating with selection has been followed in the subsequent generations until now.

Performance traits of cattle are influenced by the individual direct genetics and the environment under which the animal is raised, as well as by the maternal genetics and the maternal environment effects (Matika *et al.*, 2003). The non-genetic factors (age, season of birth/calving, year of birth/calving, parity, breed, farm etc.) affect milk production, reproduction, and growth traits by direct obscuring the expression of their actual genetic worth (Grahlot *et al.*, 1989; Ray *et al.*, 1992; Demeke *et al.*, 2003).

Typically, genetic parameters were estimated by partitioning phenotypic covariance between relatives into causal components such as variances due to additive effects, and temporary and permanent environmental effects (Falconer and Mackay, 1996). Moreover, the performance records of an animal should be corrected for classifiable non-genetic sources of variation, which is essential for obtaining precise estimates of genetic parameters. Estimation of genetic parameters for economic traits using animal models is essential for planning breeding strategies under specific production environments, genetic evaluation of animals and prediction of response to selection. It is also relevant for conservation and defining optimum breeding objectives.

The understanding of trends in genetic progress will help future genetic direction to be established by the definition of specific goals for breeding a profitable and sustainable dairy herd (Missanjo *et al.*, 2012). Genetic trend study is also important to assess genetic improvement program progress, to make adjustments aiming to optimize genetic gain, and to increase farm profitability in the future (Silva *et al.*, 2001). The precision of genetic trend estimates is enhanced greatly as the number of years studied increases (Burnside and Legates, 1967).

The concept of Most Probable Producing Ability (MPPA) was first introduced by Lush (1945) as a means of estimating the producing ability of each cow under standard conditions within a herd. MPPA measures both genetic and permanent environmental effects. It is used to predict the future performance of animals and helps to rank the animals especially dams in a herd for selection whereas sire evaluation is one of the most important aspects of dairy breed improvement programme as the contribution of sire path is higher than the dam path for overall genetic improvement of a trait. The success of a breeding programme depends on how early and how accurately bulls can be proved.

Growth curves are used for formulating breeding programme and investigating optimum feeding programmes, determining optimum slaughtering age and the effects of selection on live weight at a certain age. Previous studies have suggested that calf growth measurements could be used to predict productivity later in life, but the information in the scientific literature is limited (Ghoraishy and Rokouei, 2013). Moreover, the breeding of heifers is decided based on their body sizes rather than their ages which means that they are bred when they attained 60% of their mature body weight. The growth curve study in cattle has mainly used non-linear models that

relate the animal weights and ages (Garnero *et al.*, 2006; Forni *et al.*, 2009; Souza *et al.*, 2010). Whilst typical lactation curves for dairy cows show a peak or maximum daily output between 4 and 8 weeks after calving, followed by a daily decrease in the amount of milk (persistence) until drying, where the lactation will be naturally terminated (Macciotta *et al.*, 2005). At the cow level, lactation curve modeling is of help for monitoring individual yields for diet planning, early detection of diseases before the appearance of clinical signs and for selecting animals to be culled (Nicolò *et al.*, 2016). Several non-linear models (Grossman and Koops, 1988; Guo and Swalve, 1995; Gengler, 1996) have been proposed recently to describe the lactation curve.

Climate change is one of the major challenges that largely affect the ability of livestock to grow, lactate, and reproduce to their maximal genetic potential. IPCC (2007) reported that the temperature of the earth has been increased by 0.2°C per decade and also predicted that the global average surface temperature would be increased to 1.4-5.8°C by 2100. The impact of climate change can be direct or indirect. Direct effects involve heat exchanges between the animal and the surrounding environment that are related to radiation, temperature, humidity and wind speed (Houghton *et al.*, 2001) while the indirect effects of climate-driven changes in animal performance result mainly from alterations in the nutritional environment (Calvosa *et al.*, 2009; Sejian, 2013). Heat stress (HS) occurs when any combination of environmental factors cause the effective temperature of the environment to be higher than the animal's thermo-neutral zone (Armstrong, 1994). The effects of heat stress are devastating in the dairy industry unless managed well. It is considered to be one of the primary factors which reduce growth, milk production and fertility in dairy cows, which ultimately culminates in severe economic loss to livestock farmers around the world ((Kazdere *et al.*, 2002; West, 2003; Verwoerd *et al.* 2006; Hansen, 2007). It is more adverse in warmer and humid climatic areas. Reduced milk yield under heat stress is caused by associated effects on thermal regulation, energy balance and endocrine changes (Yousef, 1985; Ominski *et al.*, 2002). Bouraoui *et al.* (2002) reported that for every degree above the Temperature Humidity Index (THI) of 69 in dairy cattle, there may be a 0.4 kg decrease in milk production. Milk yield reductions of up to 50% have been reported for Holstein cows due to heat stress during the summer as compared to the winter (Baumgard and Rhoads, 2013). High yielding

breeds are more susceptible than low yielding breeds (Sunil *et al.*, 2011; Prathap *et al.*, 2017).

Air temperature, relative humidity, wind speed and solar radiation are meteorological variables that affect the livestock. They all can be applied for measuring the status of HS. However the common predictor of heat-stress is Temperature Humidity Index (THI) which combines air temperature and relative humidity, developed initially for humans by Thom (1958) and extended to dairy cattle by Berry *et al.* (1964). Other meteorological variables such as wind speed and solar radiation are also important measures of the level of heat stress (Buffington *et al.*, 1981; Shioya *et al.*, 1997; Da Silva *et al.*, 2010). The THI is a single value depicting the integrated effect of air temperature and humidity associated with the level of heat stress. When THI is less than 72 corresponding to air temperature between 5 to 25 °C, within which they maintained a physiological body temperature of 38.4-39.1°C, the animal exhibits optimum performance (Armstrong, 1994). The thermo-neutral zone (TNZ) for various mammals has been described by Bianca (1962), Johnson (1965), and Yousef (1965). Armstrong (1994) used THI <72 as a thermal comfort zone, 72 to 78 as mild heat stress, 79-88 as moderate heat stress, 89-98 as severe heat stress and >98 as danger heat stress; but according to Zimbelman *et al.* (2009) and De Rensis *et al.* (2015) mild signs of heat stress were observed at THI of 68 to 74, and a THI  $\geq$ 75 will cause drastic decreases in production performance. Changes in wind speed influence the convection cooling whereas solar radiation greatly influences heat load and in combination, has a very significant impact on the regulation of thermal balance in dairy cows (Davis and Mader, 2003). The effective wind speed recommended for dairy cattle in the USA during heat stress is from 1.8 to 2.8 m s<sup>-1</sup> (Bailey *et al.*, 2016). Wind speed and solar radiation would also greatly improve the applicability of the Livestock Weather Safety Index (LWSI) under varying environmental conditions (Herbut *et al.*, 2018). However basic THI does not take into account the effects of wind speed and solar radiation. Mader *et al.* (2006) studied on adjustment of basic THI for wind speed (WS) and solar radiation (SR) based on daily average and reported that THI would be reduced by 3.14 units for each 1 m/s increase in WS and 1.49 units for each 100 W/m<sup>2</sup> decrease in SR. LWSI has considered wind speed and solar radiation since 1970 and it was first used by the US National Weather Service. Adjusted THI (THI<sub>adj</sub>) assumes a lower limit for the occurrence of heat stress as 74, while values from 75 to 78 indicate the alert stage, from 79 to 83 danger conditions

and >84 emergency conditions (Mader *et al.*, 2006; Hahn *et al.*, 2009; Arias and Mader, 2010).

Ludhiana district is one of the hot and humid subtropical climate areas, where it is characterized by extreme hotter summer and extreme colder winter seasons. The summer season is also accompanied by high humidity and radiation and low air movement. Because of seasonal differences, the crossbred dairy cattle have often experienced both heat and cold stresses; thereby their growth, reproduction, and lactation may highly be impaired.

However, few reports on the genetic and phenotypic evaluation of performance traits and lactation curve pattern, whereas no previous studies on growth curve modeling and individual and combined meteorological factors influences on performance traits are available for crossbred cattle population maintained in DLF of GADVASU, which has been under genetic improvement through crossbreeding with phenotypic selection for several years. Undertaking such type of study is, therefore, useful as it will aid to evaluate the on-going breeding practice and suggest future breeding strategies, considering the findings of meteorological variables and their combinations in the selection program, recommend the optimum Temperature, Humidity, THI and THIadj values for optimum milk production. It may also develop good heat stress management practices and fill the gaps in knowledge. Thus, the present study was carried out with the following objectives:

- **To assess the effect of genetic and non-genetic factors on different production and reproduction traits in crossbred cattle**
- **To analyze the growth and lactation curves across fixed factors in crossbred cattle**
- **To estimate the genetic and phenotypic parameters for performance traits in crossbred cattle**
- **To establish the relationship of THI with different production and reproduction traits**

## CHAPTER II

### REVIEW OF LITERATURE

The scientific literature collected was reviewed as per the objectives of the study under the following headings and sub-headings.

#### **2.1. Crossbreeding Experiences in India**

India is home to huge cattle genetic resources with an estimated population of 193.46 million, out of which exotic/crossbred cattle populations were 51.36 million (20<sup>th</sup> Livestock Census, 2019). The importance of exotic/crossbred cattle in the country's economy has been significantly growing up. The good indicators, in this regards, were the population of the total exotic/crossbred cattle has increased by 26.9 % in 2019 as compared to the previous census (39.73 million (13<sup>th</sup> Livestock Census, 2012) and crossbred cows contributed more than 26% of the total milk production (20th Livestock Census, 2019). Crossbreeding work was started in the country as early as 1875, near Patna using Shorthorn bull on local cows and the “Taylor” breed of cattle was formed (Sinha, 1951). Nowadays, it has been a proven fact that extensive crossbreeding of native cows with exotic breeds like Jersey and Holstein Friesian has resulted in the white revolution (Wakchaure *et al.*, 2015). The crossbreeding of non-descript zebu cows with the semen of exotic dairy cattle breeds has resulted in enhancing milk production by 5 to 8 times to that of non-descript cows, reducing the age at first calving and shortening calving intervals in 1st generation crossbred progenies (Wakchaure *et al.*, 2015). The country ranks first in the world with annual milk production of 187.7 million tons per capital availability of 394 grams/days which is higher than ICMR recommendation (280 gram/day) (Basic Animal Husbandry Statistics, 2019).

#### **2.2. Performances of Crossbred Cattle and Associated Genetic and Non-Genetic Factors**

##### **2.2.1. Growth performances and genetic and non-genetic factors**

Growth is considered as an increase in height, length, girth and/or weight, whereas development is a change in composition and structure. Several previous works had indicated that calf growth measurements could be used to predict productivity later in life, but the information in the scientific literature has been limited. Swali and Wathes (2006) reported that lighter heifer calves at birth continued to have lesser body weight during their first lactation.

Also, low birth weight calves produced less milk later in life (Ghoraishy and Rokouei, 2013). These authors and Berry *et al.* (2003) have found heifers with high birth weight attained age at first calving early though they had greater intervals from calving to first service, first service to conception and calving intervals, and an increasing occurrence of dystocia. Van De Stroet *et al.* (2016) studied on the association of calf growth traits with production characteristics in dairy cattle and found that pre-weaning growth had associations with milk yield in later life, differences in milk yield were most apparent during early and peak lactation, and shortest calves had the lowest milk production potential. The growth rate has also been reported to have positive relationships with first lactation milk yield (Moallem *et al.*, 2010; Heinrichs, 2011; Soberon *et al.*, 2012). However higher calf growth rates were not significantly associated with future milk yield although they were associated with higher body weight in lactating cows and higher odds of survival to first lactation (Bahri *et al.*, 2004; Van De Stroet *et al.*, 2016).

#### **2.2.1.1. Influences of genetic and non-genetic factors on growth traits**

Several previous studies had reported that growth performance can be influenced by season of birth, age, parity, year and fertility of the dam, breed and sex of the calf (Mohamed, 2004). As per the findings of Rahman *et al.* (2015), the influences of non-genetic factors like sex, a season of birth and genotype were non-significant ( $P>0.05$ ) for the traits birth weight, three months, six months, weaning weight and average daily gain of calves; though a year of birth was found significant on birth ( $P<0.01$ ), three-month and six-month ( $P<0.05$ ) weight. The same author noticed a non-significant ( $P>0.05$ ) effect of year of birth on weaning weight and average daily gain of calves. However Abera *et al.* (2012) observed genotype, sex, year of birth and parity as the main non-genetic factors that influenced the growth and daily weight gain traits until one year of age in Horro (Zebu) and their crosses with Holstein Friesian and Jersey cattle in Ethiopia. Demeke *et al.* (2003) had also reported that non-genetic factors such as sex of born calves, season and year of birth affected growth traits and directly obscures in the expression of actual genetic worth. Genotype had a non-significant ( $P>0.05$ ) effect on the birth weight of calves as reported by various workers (Manzi (2011) for Brown Swiss, Friesian, Jersey and Sahiwal; Rahman *et al.* (2003) for *Bos indicus* (Boran). Similarly, Nweze *et al.* (2011) and Kabir and Islam (2009) reported significant effects of genotype on the birth weight of local and crossbred calves. Breed/genotype difference might be the major contributing factor for this variation. Period of birth and season of birth has significant ( $p<0.01$ ) effect on birth weight, 3 months weight, 6 months weight, 9 months weight, 12 months weight and 24 months weight (Sagar *et al.*, 2017). The author found calves born in season two (March-June) had higher growths at all ages.

**Table 1. The mean ( $\pm$ SE) for different growth traits in different cattle breeds**

Breeds	Growth traits							References
	Birth weight	3 month weight	6 Month Weight	9 month weight	12 month weight	18 month weight	24 month weight	
Friesian & Bunai crossbred	26.7 $\pm$ 1.3	72.4 $\pm$ 4.5	112.9 $\pm$ 6.9	147.2 $\pm$ 9.2	182.1 $\pm$ 11.1			Malau-Aduli <i>et al.</i> (1993)
HF $\times$ Boran	25.7 $\pm$ 0.3			111.9 $\pm$ 1.0	156.7 $\pm$ 1.5			Demek <i>et al.</i> (2003)
FN $\times$ HR	27.07	54.25 kg	85.8	136.85				Gaur <i>et al.</i> (2003)
Karan Fries	28.83 $\pm$ 1.13	59.38 $\pm$ 2.67						Pal <i>et al.</i> (2004)
Charolais	42.95		278.21					El-Saied <i>et al.</i> (2006)
Local	24.14							Kabir & Islam (2009)
Red Chittagong	15.74	31.48	45.33	60.91	76.18			Rabeya <i>et al.</i> (2009)
Red Chittagong	14.7	29.26 kg	42.60	54.99	66.2 $\pm$ 15.5	74.5 $\pm$ 16.0	111.6 $\pm$ 25.2	Afroz <i>et al.</i> (2011)
Brangus	33.02 $\pm$ 0.04			219.45 $\pm$ 0.35	298.16 $\pm$ 0.74	391.45 $\pm$ 1.14		Neser <i>et al.</i> (2012)
Piedmontese & Nanyang	36.39		194	293				Chen <i>et al.</i> (2012)
Sheko cattle	16.12 $\pm$ 0.22		58.84 $\pm$ 0.51	76.29 $\pm$ 0.45	85.07 $\pm$ 0.50	111.62 $\pm$ 0.74		Bayou <i>et al.</i> (2015)
Dhofari cattle	17.8 $\pm$ 1	88 $\pm$ 1.07	106 $\pm$ 1.03		173 $\pm$ 1.17		257 $\pm$ 4.09	Salim <i>et al.</i> (2015)
HF $\times$ Local cattle	29.33	64.32	99.06	151.77				Rahman <i>et al.</i> (2015)
Vrindavani cattle	22.390 $\pm$ 0.110	53.274 $\pm$ 0.270	89.263 $\pm$ 0.51		151.033 $\pm$ 0.96	229.678 $\pm$ 1.22	291.577 $\pm$ 1.60	Sagar <i>et al.</i> (2017)

## 2.2.2. Reproductive performances and genetic and non-genetic factors

### 2.2.2.1. Age at first service (AFS)

The phenotypic means for age at first service were 3.5 Years (Ali, 1994), 2.6 years (Ashraf, 1998), 1022.3±62.47 days (Islam *et al.*, 2004), 32.2 months (Azizunnesa *et al.*, 2010); 2.7±1.7 years (Hasanuzzaman *et al.*, 2012) and 604.79±13.24 (Kumari, 2015) days for Indigenous cow, Red Chittagong cows, Indigenous cattle, Red Chittagong cows, crossbred cows and HF × Sahiwal cattle, respectively. Kumari (2015) reported that the sire and a genetic group of the cow had a significant ( $P < 0.05$ ) effect on AFS while the same author showed non-significant ( $P > 0.05$ ) effects of season of birth and period of birth on AFS.

### 2.2.2.2. Age at first calving (AFC)

The age at first calving of the dairy cow is of great economic importance in the efficiency of dairy cattle production as it affects the productive life of the cow and its lifetime milk production (Bhagi and Epen, 1988). It is closely related to generation interval and, therefore, influences response to selection. Ashmawy (1985) and El-Sheikh (1995) revealed that reduction of AFC for the dairy cow would minimize the costs of raising and caring for the heifers, shorten generation interval and maximize the number of lactations given per cow during its productive life. The average age at first calving in *Bos indicus* cattle is about 44 months compared with about 34 months in *Bos taurus* and *Bos indicus* × *Bos taurus* crosses in the tropics (Table 2).

**Table 2. The mean (±SE) of age at calving in different cattle breeds**

Breed	Mean (±SE)	References
Friesian	30.1 months	Arora and Sharma (1980)
<i>Bostaurus</i> × <i>Bosindicus</i>	35.5-40.3 months	Galal <i>et al.</i> (1981)
F <sub>1</sub> Friesian × zebu	29.1 months	Alberro (1983)
<i>Bos Taurus</i>	36.5 months	McDowell (1985)
F(RXS)	939.00±15.0 days	Jain <i>et al.</i> (1995)
Egypt HF	23.7±0.60 months	Safaa (2006)
Crossbred cattle	1350.52±13.48 days	Garima (2006)
Karan Fries	1023.0±5 days	Divya (2012)
Karan Fries	957.48±6.54 days	Dash (2014)
HF × Sahiwal	942.39±12 days	Kumari (2015)
HF × Sahiwal	956.97±21.03 days	Singh <i>et al.</i> (2015)
Sahiwal	1045.91±72.01 days	Parveen (2017)
Karan Fries	1045.60±4.58 days	Dimpee (2018)

(a). **Season of birth:** The effects of season of birth on age at first calving was significant as reported by different investigators (Afifi *et al.*, 1992a; Mansour, 1992a; Safaa, 2002), whereas El-Sheikh (1995), Garima (2006), Dash *et al.* (2014), Singh *et*

*al.* (2015), and Kumari (2015) found that the effect of season of birth on age at first calving was insignificant. Also Oliveira (1974) reported that Nellore cows in Brazil that calved first in the dry season were younger than those that calved first in the rainy season.

**(b). Period of birth:** Most of the previous workers reported that effect of period of birth ( $P < 0.05$ ) on age at first calving was significant (Sentitula *et al.*, 2008 and Parveen, 2017 for Sahiwal cattle; Kumari, 2015 for HF  $\times$  Sahiwal; Dahiya *et al.* 2003; Mukharjee, 2005; Garima, 2006 for crossbred cattle). However Nayak and Raheja (1996), Bharti (2004), and Singh *et al.* (2015) could not found significant effect of the factor on this trait for different crossbred cattle.

**(c). Genetic group of cow:** No significant ( $P > 0.05$ ) difference were indicated in age at first calving due to genetic group as per the findings of different researchers (e.g. Dubey and Singh, 2005; Garima, 2006; Kumari, 2015; Singh *et al.* (2015) while significant effect of Genetic group on AFC were observed by Kumar (1992), and Mukharjee, (2005) in various crossbreds.

**(d). Sire of cow:** Sire of the cow was proved to have significant effect on age at first calving in dairy cattle by different research workers(e.g. Garima, 2006; Kumari, 2015; Singh *et al.*, 2015); Parveen, 2017).

### **2.2.2.3. Calving Interval (CI)**

Calving interval can be divided into three periods: gestation, postpartum anoestrus (from calving to first oestrus) and the service period (first postpartum oestrus to conception). Variation in the calving interval is mostly attributable to the service period because gestation period is the least variable trait. It is a trait, which mainly depends on the management and environmental condition of the farm. Regular reproduction in dairy cows with short calving interval is a key feature for rapid multiplication of outstanding genetic material. The average CI ranged from  $338.26 \pm 6.35$  days (Banerjee, 1996) in FXS to  $551 \pm 173$  days (Yadav *et al.*, 2004) in crossbred cattle.

**Table 3. The means ( $\pm$ SE) of first and pooled lactations calving interval in different crossbred cattle**

<b>First lactation</b>		
<b>Cattle Breeds</b>	<b>Mean (<math>\pm</math>SE)</b>	<b>References</b>
Crossbred cattle	494.45 $\pm$ 6.12 (days)	Dubey and Singh (2005)
Crossbred cattle	538.60 $\pm$ 6.66 (days)	Garima (2006)
Egypt HF	452 $\pm$ 0.85 (days)	Safaa (2006)
HF $\times$ Sahiwal	438.5 $\pm$ 13.19 (days)	Singh <i>et al.</i> (2015)
Sahiwal	444.40 $\pm$ 5.41 (days)	Parveen (2017)
<b>Pooled lactation</b>		
Nellore	14.7-15.6 (months)	Miranda <i>et al.</i> (1982b)
Haryana	15.6 (months)	Kumar (1982)
White Fulani	14.2-18 (months)	Oyedipe <i>et al.</i> (1982)
Zebu	14.4 $\pm$ 3.4 (months)	Duarte <i>et al.</i> (1983)
Zebu	18 (months)	Butterworth and McNitt (1984)
Fulani	19.6 $\pm$ 5.1 (months)	Wagenaar <i>et al.</i> (1986)
Highland zebu	25 (months)	Mukasa-Mugerwa <i>et al.</i> (1989)
Karan Fries & Karan Swiss cattle	423 $\pm$ 11 (days)	Singh and Gurnani (2004)
Crossbred cattle	551 $\pm$ 173 (days)	Yadav <i>et al.</i> (2004)

**(a). Effect of season of calving:** The significant effect of season of calving on CI were observed by Reddy and Basu (1985), Raheja (1997), Sahana and Gurnani (2000), Gaur (2001), Dahiya *et al.* (2003), Mukharjee (2005) and Singh *et al.* (2015) in different crossbred cattle while non-significant effect of season of calving on CI were reported by Kumar (1992), Nayak *et al.* (1996), Singh *et al.* (2000), Bharti (2004), Garima (2006) and Safaa (2006) in different crossbred cattle.

**(b). Effect of period of calving:** The significant effect of period of calving on CI were observed by Prasad (1983), Nehra *et al.* (1987), Miliagres *et al.* (1988b), Jadhav *et al.* (1991), Garcha and Dev (1994), Nayak and Raheja (1996), Sahana and Gurnani (2000), Singh *et al.* (2000), Gaur (2001), Dahiya *et al.* (2003), Mukharjee (2005), Dubey and Singh (2005) and Garima (2006) while non-significant effect of period of calving were observed by Reddy and Basu (1985), Raheja (1997), Bharti (2004), Singh *et al.* (2015) and Parveen (2017) in various crossbred cattle.

**(c). Effect of genetic group:** The non-significant effects of Genetic group on CI were observed by Dubey and Singh (2005), Mukharjee (2005) and Singh *et al.* (2015) in various crossbred cattle whereas Garima (2006) had reported significant effect ( $P < 0.05$ ) of animal genetic group on CI (Garima, 2006).

**(d). Sire effect on calving:** Calving interval length was found to be influenced significantly by the effect of sire of the cow by different investigators (Afifi *et al.*, 1992; Shereen, 1998; Singh *et al.*, 2015; Parveen, 2017). However Safaa (2006) reported that sire had exerted insignificant ( $P > 0.05$ ) effect on calving interval.

**2.2.2.4. Service Period:** The period lapsed between calving to conception is known as service period and is considered as an economically important trait in cattle. This period is not only a physiological function but also greatly depends on managerial practices like heat detection and artificial insemination. A long service period reduces the number of lactations which cattle should complete in her life time and there by decreases the overall lifetime production.

**(a). Season of calving:** The significant effect of season of calving on FLSP were observed by Due and Taneja (1984), Sahana and Gurnani (2000), Singh *et al.* (2000), Gaur (2001), Dahiya *et al.* (2003) and Mukharjee (2005) while non-significant effect of season of calving were reported by Kuralkar *et al.* (1995), Bharti (2004) and Dubey and Singh (2005) in crossbred cattle.

**(b). Period of calving:** The significant effect of period of calving on FSP were observed by Due and Taneja (1984), Sahana and Gurnani (2000), Singh *et al.* (2000), Gaur (2001), Dahiya *et al.* (2003), Mukharjee (2005) and Dubey and Singh (2005) while non-significant effect of period of calving were observed by Kuralkar *et al.* (1995a) and Bharti (2004) in different crossbred.

**(c). Genetic group of cow:** The non-significant effects of Genetic group or breed on first lactation service period were observed by Haque *et al.* (1999), Aly *et al.* (2000), Mukharjee (2005) and Dubey and Singh (2005) in different crossbred cattle.

**Table 4. The means ( $\pm$ SE) for first and pooled lactations service period in various crossbred cattle**

<b>First lactation</b>		
<b>Cattle Breeds</b>	<b>Mean<math>\pm</math>SE (days)</b>	<b>Reference</b>
HF(Red Dane $\times$ Sahiwal)	191.3 $\pm$ 10	Jain <i>et al.</i> (1995)
Karan Fries	127.69 $\pm$ 11.27	Saha (2001)
HF $\times$ Sahiwal	280.67 $\pm$ 0.09	Bharti (2004)
HF $\times$ Sahiwal	164.51 $\pm$ 2.51	Mukharjee (2005)
Crossbred cattle	223.0 $\pm$ 6.12	Dubey and Singh (2005)
Karan Fries	124.12 $\pm$ 4.83	Sharama (2010)
<b>Pooled lactation</b>		
HF $\times$ Sahiwal	153 $\pm$ 19.81	Gaur (2001)
Jersey $\times$ Sahiwal	151.07 $\pm$ 13.23	Kumar & Kumar (2003)
BS $\times$ S	148 $\pm$ 12	Singh and Gurnani (2004)
F $\times$ T	143 $\pm$ 11	Singh and Gurnani (2004)
Karan Fries	130 $\pm$ 3.00	Divya (2012)
Karan Fries	130.03 $\pm$ 4.43	Dash <i>et al.</i> (2014)
Karan Fries	134 $\pm$ 7.40	Muller <i>et al.</i> (2018)

#### 2.2.2.5. Number of services per conception (NSPC)

The NSPC depends largely on the breeding system used. It is higher under uncontrolled natural breeding and low where hand-mating or artificial insemination is used. NSPC values greater than 3.0 should be regarded as poor.

**Table 5. The averages ( $\pm$ SE) of first lactation number of services per conception (NSPC) in different breeds**

<b>Fist lactation</b>			
<b>Cattle Breeds</b>	<b>Location</b>	<b>Means</b>	<b>Source</b>
Arsi	Ethiopia	2.4-2.6	Swensson <i>et al.</i> (1981)
Nagori	India	1.5 $\pm$ 0.4	Sharma (1983)
Haryana	India	2.8	Choudhuri <i>et al.</i> (1984)
Dairy cows	Latvia	1.76 $\pm$ 0.01	Lasma <i>et al.</i> (2017)
HF	Indonesia	1.71	Wicaksono <i>et al.</i> (2018)
<b>Pooled lactation</b>			
Zebu	Ethiopia	1.74-1.8	Azage <i>et al.</i> (1981)
East African Zebu	Ethiopia	2.0 $\pm$ 1.2	Alberro (1983)
Friesian and its crosses	Iraqi	2.27 $\pm$ 0.21	Jumat <i>et al.</i> (1988)
Dairy cows	South Africa	2.55 $\pm$ 1.79	Muller <i>et al.</i> (2018)

**Effects of Breed:** Kumar and Bhat (1979) noted that Haryana heifers needed more services per conception than cows. Azage *et al.* (1981) worked his study on 3 local Ethiopian breeds, the Barca, Horro and Boran and he found that NSC was lower for animals from wet areas than for those from drier areas ( $1.74 \pm 0.6$  vs  $1.98 \pm 0.07$ ). Crossbred cows required 0.12 and 0.14 fewer services per conception than local zebu cows in wet and dry areas, respectively. El-Amin *et al.* (1981) concluded that NSC did not differ significantly between Red Butana and Red Butana crosses (average 2.6) but was influenced by month of calving. NSC increased over the study period, probably due to changes in management. This is partly supported by an analysis by Busch and Furstenberg (1984) of 483 600 inseminations performed by 379 technicians on 623 farms in the USA, which showed that the 90- and 120-day non-return rate differed significantly among inseminators and the inseminator effect was greater than the farm effect. However, non-return rate did not differ among bulls.

### 2.2.3. Milk production traits and genetic and non-genetic factors

#### 2.2.3.1. 305 day lactation milk yield (305\_DMY)

305 day milk yield is the most important economic trait in dairy animals that determine productivity and profitability in dairy cattle herds. It is standard measure of production performance, by which it is often used for genetic evaluation, selection of sires and cows and assessing genetic progress of a herd. The least square means of 305 day milk yields for different cattle populations with corresponding standard errors as reported by various workers were organized in Table 6.

**Table 6. The means ( $\pm$ SE) of first and pooled lactations 305 day milk yields for different cattle breeds**

<b>First Lactation</b>		
<b>Cattle Breeds</b>	<b>305 Days Milk Yield (kg)</b>	<b>References</b>
HF (Egypt)	5275 $\pm$ 17	Safaa (2006)
Karan Fries	2470.35 $\pm$ 80.75	Saha <i>et al.</i> (2010)
Sahiwal Cattle	1894.11	Manoj <i>et al.</i> (2012)
HF $\times$ Deoni	1707.25 $\pm$ 13.25	Wondifraw <i>et al.</i> (2013 )
HF $\times$ Sahiwal	3594.58 $\pm$ 89.08	Kumari (2015)
HF $\times$ Sahiwal	2928.78 $\pm$ 105.05	Singh <i>et al.</i> (2015)
HF $\times$ Sahiwal	3447 $\pm$ 44.8	Sharma (2016)
<b>Pooled lactation</b>		
Karan Fries	3173 $\pm$ 82	Singh and Gurnani (2004)
Karan Swiss	2616 $\pm$ 82	Singh and Gurnani (2004)
Ayrshire (Kenya)	3009.8 $\pm$ 1098	Amimo <i>et al.</i> (2007 )
HF $\times$ Sahiwal	2593.84	Lakshmi <i>et al.</i> (2009 )

Crossbred cattle	2070.5±59.1	Thomas and Kumar (2009 )
HF × Jersey × Sahiwal	2700.52±144.84	Dandapat <i>et al.</i> (2010)
Tunisian Holstein	5807.83±78.27	M'hamdi <i>et al.</i> (2012)
HF	3408.17±48.54	Katok and Yanar (2012 )
Jersey crossbred cattle	2234.27±74.94	Mandal <i>et al.</i> (2013)
Karan Fries cattle	4113.61±55.90	Japheth <i>et al.</i> (2015)
Sahiwal cattle	1782.97±68.37	Verma <i>et al.</i> (2015)
Karan Fries	3027±20	Dash <i>et al.</i> (2016)
Jersey crossbred cattle	2141.26±79.32	Poonam <i>et al.</i> (2016)

**(a). Effects of season of calving:** Significant effect ( $P<0.01$ ) of season of calving on 305 days milk yield was reported by various workers (e.g. Atil *et al.* (2001) and Katok and Yanar (2012) in HF cattle; M'hamdi *et al.* (2012) in Tunisian Holstein; Kumari (2015) in HF crossbred cattle, Poonam *et al.* (2016) in Jersey crossbred cattle; Kumari (2015) for HF crossbred cattle) whereas Manoj *et al.* (2012) reported non-significant ( $P>0.05$ ) effect of season of calving on FL305DMY in dairy animals. Similarly a non-significant effect of season of calving on the same trait was reported by Safaa (2006) for Egypt HF cattle and Wondifraw *et al.* (2013) for HF × Deoni cattle.

**(b). Effects of period of calving:** Period of calving exerted significant effects ( $P<0.01$ ) on 305 day milk yield as indicated by various workers (Singh and Gurnani (2004) for Karan Swiss cattle; Safaa (2006) for Egypt HF cattle; Lakshmi *et al.* (2010) for Frieswal cattle; M'hamdi *et al.* (2012) for Tunisian Holstein; Manoj *et al.* (2012) for Sahiwal cattle; Wondifraw *et al.* (2013) in HF × Deoni cattle; Kumari (2015) for HF crossbred cattle; Poonam *et al.* (2016) in Jersey crossbred cattle); however Banik (2004), Mundhe *et al.* (2015), Verma (2015) and Singh *et al.* (2015) reported insignificant influence of period of calving on this trait.

**(c). Sire of the cow effect:** Significant effect of sire on 305-day milk yield was reported by different investigators (Atil *et al.* for HF cattle (2001); Singh and Gurnani (2004) for Karan Fries cattle; Mundhe *et al.* (2015); Kumari (2015) for HF crossbred cattle; Verma *et al.* (2015) for Sahiwal cattle; Poonam *et al.* (2016) for Jersey crossbred; Parveen (2017) for Sahiwal cattle). On the contrary, sire exerted non-significant effect on 305 day milk yield for Egypt HF cattle (Safaa, 2006; Verma 2015).

**(d). Effects of genetic group:** Genetic group of animals had significant effect ( $P<0.05$ ) on 305 milk yield in crossbred cattle as reported by Sahana and Gurnani (2000), Poonam *et al.* (2016) and Lakshmi *et al.* (2010), Mandal *et al.* (2013); but the

effects of animal genetic group on the same trait according to Singh *et al.* (2015), and Kumari (2015) was insignificant ( $P>0.05$ ).

**(e). Effects of age at calving:** The effects of Age at calving on 305 day milk yield were significant ( $P<0.05$ ) as reported by Kumari (2015) and Safaa (2006). Manoj *et al.* (2010) and Monalisa *et al.* (2010) also reported significant effects of Age at calving on 305 day milk yield whereas non-significant influence was noticed by Sentitula *et al.* (2008), Mandal *et al.* (2013), Gupta (2013), Verma (2015), Prakash *et al.* 2015 and Shingare *et al.* (2015).

**(f). Effects of birth weight and weight at calving:** Miller and McGilliard (1959) and Clark and Touchberry (1962) found significant effects of body weight at calving on 305 day milk yield for HF cattle. Ghoraihy and Rokouei (2013) reported that low birth weight calves produced less milk later in life.

### 2.2.3.2. Lactation milk yield (LMY)

Total lactation milk yield is an important indicator of production potential of dairy cows on which it determines productivity and profitability in dairy cattle herds. It provides efficient measure to assess the genetic merits of an animal.

The overall mean values of total lactation milk yield along with standard errors in different breeds as reported by various fellows are summarized in table 7.

**Table 7. The means ( $\pm$ SE) of first and pooled lactation milk yield in different cattle breeds**

<b>First lactation</b>		
<b>Cattle Breeds</b>	<b>First Lactation Milk Yield</b>	<b>References</b>
Egypt		Safaa (2006)
Karan Fries	2822.91 $\pm$ 121.94	Saha <i>et al.</i> (2010)
HF $\times$ Deoni	1661.35 $\pm$ 15.17	Wondifraw <i>et al.</i> (2013)
HF $\times$ Sahiwal	4399.99 $\pm$ 146.09	Kumari (2015)
Sahiwal	2070.41 $\pm$ 79.20	Parveen (2017)
Karan Fries	3832.87 $\pm$ 50.17	Dimpee (2018)
<b>Pooled lactation</b>		
Frieswal cattle	2871.11 $\pm$ 32.64	Kumar <i>et al.</i> (2005)
Holstein cows	6404.77	Tekereli & Gundogan (2005)
Crossbred Cattle	3064.74 $\pm$ 49.40	Singh <i>et al.</i> (2006)
Jersey cattle	1663.15 $\pm$ 70.25	Ahmad <i>et al.</i> (2007)
Sahiwal	1537 $\pm$ 9.03	Zafar <i>et al.</i> (2008)
Iranian Holstein	5123.20 $\pm$ 1519.9	Hashemi <i>et al.</i> (2009)
HF $\times$ Sahiwal	2864.32	Lakshmi <i>et al.</i> (2009)
Girhalf breeds	2971.94 $\pm$ 101.84	Jadhav <i>et al.</i> (2010)
Butana cows	1709.50 $\pm$ 892.10	Badri <i>et al.</i> (2011)

HF Cross	2722.68±1541.1	Gorbani <i>et al.</i> (2011)
HF cattle	3438±887.19	Usman <i>et al.</i> (2011)
Jersey crossbred cattle	2881.35±124.34	Mandal <i>et al.</i> (2013)
Deoni Cattle	358.31±27.18	Bhutkar <i>et al.</i> (2014)
HF	3919.66±42.99	Al-Samarai <i>et al.</i> (2015)
Karan Fries cattle	4677.84±50.35	Japheth <i>et al.</i> (2015)
Sahiwal cattle	1880.39±73.82	Verma <i>et al.</i> (2015)
Jersey crossbred cattle	2496.14±82.57	Poonam <i>et al.</i> (2016)
Karan Fries cattle	3832.87±50.17	Dimpee (2018)

**(a). Effects of season of calving:** The significant influence of season of calving on LMY ( $P < 0.05$ ) was reported by various investigators (Safaa, 2006; Ahmad *et al.*, 2007 for Jersey cattle; Gaur, 2007 for HF×Sahiwal cattle; Mishra and Joshi, 2009 for HF×Karan Fries cattle; Wondifraw *et al.*, 2013 for HF×Deoni cattle; Kumar *et al.*, 2014) for Indigenous × HF crossbred cattle; Kumari, 2015 for HF ×Sahiwal; Japheth *et al.*, 2016 for Karan Fries; Poonam *et al.*, 2015 for Jersey crossbred cattle) whereas non-significant effect of season of calving on LMY was observed (Jadhav and Khan, 1995 for HF × Sahiwal cows; Kothekar, 2004 for Holstein Friesian cows; Garima, 2006 for Egypt HF cattle; Abou-Bakr, 2009; Al-Masri, 2012 and Varaprasad *et al.*, 2013 for Jersey × Sahiwal cattle; Al-Samarai *et al.*, 2015 for HF cattle; Verma *et al.*, 2015 for Sahiwal cattle).

**(b). Effects of period of calving:** The lactation milk yield was affected by period of calving ( $P < 0.01$ ) as reported by different authors (e.g. Garima, 2006; Ahmad *et al.*, 2007 for Jersey cattle; Jadhav *et al.*, 2010 for Gir halfbreds; Komatwar *et al.*, 2010; Lakshmi *et al.*, 2010 for HF × Sahiwal cattle; Mandal *et al.*, 2013 for Jersey crossbred cattle, Wondifraw *et al.*, 2013 for HF×Deoni cattle; Bhutkar *et al.*, 2014 for Deoni cattle; Japheth *et al.*, 2015 for Karan Fries cattle; Kumari, 2015 for HF × Sahiwal cattle; Parveen, 2017 for Sahiwal cattle). However, Gadmade (1999), Verma *et al.* (2015), Das *et al.* (2006) and Pundir *et al.* (2007) reported non-significant effect of period of calving on LMY for Jersey × Tharparkar cattle, for Sahiwal cattle, for Holstein Friesian × Sahiwal cows, and for Red Sindhi × Jersey, respectively.

**(c). Sire of the cow effect:** Sire of the cow had significant effect ( $P < 0.05$ ) on LMY (Garima 2006; Ayied *et al.*, 2011; Nawaz *et al.*, 2013; Pantelici *et al.*, 2014 for in Simmental cattle; Kumari, 2015; Parveen, 2017). Significant effect of sire on LMY was also observed by Al-Samarai *et al.* 2015 for HF cattle, Verma *et al.* (2016) for Sahiwal cattle and Poonam *et al.* (2015) for Jersey crossbred cattle. On the other hand, sire exerted non-significant effect on LMY (Safaa, 2006; Verma, 2015).

**(d). Effects of genetic groups:** The effect of animal genetic group on LMY was found to be significant according to various authors (Banda, 1996 for crosses of Friesian and Jersey with Zebu cattle; Garima, 2006; Sahana and Gurnani, 2000; Lakshmi *et al.*, 2010; and Elemam *et al.*, 2012 for crossbred cattle; Singh *et al.*, 2013 for Frieswal cattle; Mandal *et al.*, 2013 for Jersey crossbred cattle; Kumar *et al.* 2014). However Garima (2006) and Kumari (2015) reported non-significant effect of genetic group of animal on LMY.

**(e). Effects of year of calving:** Year of calving exerted significant effect on LMY as reported by several workers (Banda, 1996 for crosses of Friesian and Jersey with Zebu cattle; Pantelici *et al.* (2014) for Simmental Cows and Al-Samarai *et al.* (2015) for HF cows; Parveen (2017) for Sahiwal cattle.

**(f). Effects of age at calving:** The effects of age at calving on LMY were significant ( $P < 0.05$ ) as reported by Manoj *et al.* (2010) and Monalisa *et al.* (2010) whereas non-significant effect was reported by Mohanty and Gandhi (2003), Sentitula *et al.* (2008); Mandal *et al.* (2013), Gupta (2013), Verma (2015) and Parveen (2017).

**(g). Effects of birth weight and weight at calving:** Miller and McGilliard (1959) and Clark and Touchberry (1962) found significant effects of body weight at calving on LMY for HF cattle. Ghoraishy and Rokouei (2013) reported that low birth weight calves produced less milk later in life.

### 2.2.3.3. Lactation length (LL)

Length of lactation period is an important production trait which has a major impact on milk yield (Alhammad, 2005). Length of lactation period was found to be short for Sahiwal and its crosses with other breeds (240–329 days) as compared to HF and its crosses (296–365 days) (Poonam *et al.*, 2016). The phenotypic mean values of lactation length along with standard errors in different cattle breeds as noticed by various workers were compiled in Table 8.

**Table 8. The means ( $\pm$ SE) of first and pooled lactations length in different cattle breeds**

First lactation		
Cattle Breeds	Lactation Length (days)	Reference
Sahiwal $\times$ Friesian	260.38 $\pm$ 4.48	Das <i>et al.</i> (2003)
Crossbred cattle	361.42 $\pm$ .61	Garima (2006)
Karan Fries	315.25 $\pm$ 10.10	Saha <i>et al.</i> (2010)
Sahiwal Cattle	290.41	Manoj <i>et al.</i> (2012)
HF $\times$ Deoni	296.80 $\pm$ 2.29	Wondifraw <i>et al.</i> (2013)

Sahiwal (S)×HF	393.12±9.93	Kumari (2015)
Sahiwal	323.17±7.22	Parveen (2017)
<b>Pooled lactation</b>		
Karan Fries	346±11	Singh and Gurnani (2004)
Karan Swiss	328±8	Singh and Gurnani (2004)
Frieswal cattle	313.34±2.21	Kumar <i>et al.</i> (2005)
Crossbred Cattle	356.63±5.12	Singh <i>et al.</i> (2006)
Sahiwal	262±1.04	Zafar <i>et al.</i> (2008)
HF × Sahiwal	329.03	Lakshmi <i>et al.</i> (2009)
Girhalf breeds	333.59±6.34	Jadhav <i>et al.</i> (2010)
Butana cows	248.40±91.30	Badri <i>et al.</i> (2011)
HF cattle	366.5±76.71	Usman <i>et al.</i> (2011)
Tunisian Holstein	309.60±7.01	M'hamdi <i>et al.</i> (2012)
Jersey crossbred cattle	373.63±15.64	Mandal <i>et al.</i> (2013)
Deoni Cattle	213.9±13.74	Bhutkar <i>et al.</i> (2014)
HF	298.28±5.48	Al-Samarai <i>et al.</i> (2015)
Karan Fries cattle	365.10±3.34	Japheth <i>et al.</i> (2015)
Jersey crossbred cattle	337.73±6.9	Poonam <i>et al.</i> (2016)

**(a). Effects of season of calving:** Singh and Gurnani (2004) for Karan Fries cattle, Safaa (2006) for Egypt HF, Auradkar (1999) and Komatwar *et al.* (2010) for HF×Sahiwal cattle reported significant effect of season of calving on LL. Cows calving in dry season were milked significantly ( $P<0.05$ ) longer than those calving in rainy season. The lactation length was not significantly affected by season of calving as reported by Garima (2006), Chavan (2001), Jadhav *et al.* (2010), Manoj *et al.* (2012), Wondifraw *et al.* (2013), Kumar *et al.* (2014) and Kumari (2015).

**(b). Effects of period of calving:** Period of calving significantly affected LL as reported by different authors (Manoj *et al.*, 2012; Chavan, 2001; Komatwar *et al.*, 2010; Wondifraw *et al.*, 2013 for HF×Deoni cattle; Pantelici *et al.*, 2014 for Simmental cattle; Al-Samarai *et al.*, 2015 and Japheth *et al.*, 2015 for HF and Karan Fries cattle; Parveen, 2017). Whilst non-significant effects of period of calving on LL was found by Banda (1996) for crosses of Friesian and Jersey with Zebu cattle Gadmade (1999), Jadhav *et al.* (2010) for Gir halfbreeds, Singh *et al.* (2013) for Frieswal cattle, Mandal *et al.* (2013) for Jersey crossbred cattle, Bhutkar *et al.* (2014) for Deoni cattle, Kumari (2015) for HF×S.

**(c). Effects of sire of the cow:** Sire effect on LL was statistically significant as per findings of Garima (2006), Pantelici *et al.* (2014), Kumari (2015) and Parveen (2017) whereas Safaa (2006) and Al-Samarai *et al.* (2015) reported non-significant effect of sire on LL.

**(d). Effects of genetic groups:** The influence due to genetic group of animal on LL was obtained significant as the findings of different authors (Nehra *et al.*, 1987; Dubey and Singh, 2005; Kumar *et al.*, 2014; Kumari, 2015). However non-significant effect due to genetic group was observed on the LL as per the reports of different workers (Banda (1996) for crosses of Friesian and Jersey with Zebu cattle; Bharti (2004); Garima (2006) for crossbred cattle, Mandal *et al.* (2013) for Jersey crossbred cattle)

**(e). Effect of age at calving:** The influence of age group on LL was seen to be significant (Safaa, 2006; Parveen, 2017); whilst non-significant effect of age group on LL was reported by Mandal *et al.* (2013) for crossbred cattle and Kumari (2015) for HF×S cattle.

**(f). Effects of birth weight and weight at calving:** Miller and McGilliard (1959) and Clark and Touchberry (1962) found significant effects of body weight at calving on LL for HF cattle. Ghoraishy and Rokouei (2013) reported that low birth weight calves produced less milk later in life.

#### 2.2.3.4. Dry period (DP)

Dry period is an important trait of cow productive life since it enables the cow to restore its weight. Schmidt and Van Vleck (1974) reported that dry period is important for replenishing body supplies if the cow is in a poor condition at calving and to regenerate the udder secretory tissue. The standard dry period among cows is considered to be about 60-90 days to the cost of milk production low.

The mean ± SE. values of DP with corresponding standard error for different breed of cattle as reported by various investigators were organized in Table 9.

**Table 9. The means (±SE) of first lactation dry period for different breeds**

<b>First lactation</b>		
<b>Cattle Breeds</b>	<b>Dry Period (days)</b>	<b>References</b>
Crossbred cattle	177.20±6.47	Garima (2006)
Egypt HF cattle	81.0±21.70	Safaa (2006)
HF×Sahiwal	80.77±3.99	Singh <i>et al.</i> (2015)
<b>Pooled lactation</b>		
Jersey×Sahiwal	75.88±17.80	Kumar (1994)
F (Red Dane ×Sahiwal)	185.43±40.30	Kumar (1994)
Egypt HF cattle	86±14.00	Shitta <i>et al.</i> (2002)
Egypt HF cattle	108±59.5	El-Arian <i>et al.</i> (2003)
HF×Sahiwal	115.64±1.86	Mukharjee (2005)
Egypt HF cattle	64±11.6	Salem <i>et al.</i> (2006)

**(a). Effects of season of calving:** The significant effect of season of calving on DP were observed by Mukharjee (2005), Safaa (2006) in different crossbred cattle while non-significant effect of season of calving on FDP were reported by Singh *et al.* (1993), Sahana and Gurnani (2000), Gaur (2001), Bharti (2004) and Dubey, Singh (2005), Garima (2006) and Singh *et al.* (2015) in various crossbred cattle.

**(b) Effects of periods of calving:** The significant effect of period of calving on FDP were observed by Garcha and Dev (1994), Nayak and Raheja (1996), Mukharjee (2005), Safaa, 2006 while non-significant effect of period of calving on DP were observed by Singh *et al.* (1993), Sahana and Gurnani (2000), Bharti (2004), Dubey and Singh (2005), Garima, 2006 and Singh *et al.* (2015) in different crossbred cattle.

**(c). Effects of genetic group:** The significant effects of Genetic group on DP were observed by Kumar (1994) and Dubey and Singh (2005) in different crossbred cattle while non-significant effect of Genetic group on FDP were observed by Garcha and Dev (1994) and Mukharjee (2005) in various crossbreds.

**(d). Effect of sire of cow:** Effect of sire on DP was significant (Garima, 2006); but Singh *et al.* (2015) and Safaa (2006) reported non-significant effect of Sire on DP.

**(e). Age of cow effect:** As per the Findings of El-Khashab (1993) Khalil *et al.* (1994), Soliman and Hamed (1994) and Safaa, 2006 indicated that length of dry period was significantly influenced by age at calving. Abdel Glil (1991) and Salem (1998) showed a significant curve linear association bet length of dry period and age of the cow at calving, whilst Hamed and Soliman (1994), Alnajjar (1997) and Alhammad (2005) found insignificant effect of age at calving on DP.

#### **2.2.3.5. Peak yield (PY)**

Peak yield is the point where the cow reaches the highest milk production level during the entire lactation. Heifers peak at 70 to 75 percent of mature cows and second lactation cows peak at 90 percent of mature cows. Normally the peak is reached four to ten weeks after calving. The time it takes to reach peak yield varies with many factors, for example breed, nutrition and yield potential. Higher producing animals tend to peak later than low producing ones. A high peak yield normally means a higher total yield. Research shows that each one kilogram increase in peak yield usually means an additional 100 to 200 kilograms of milk produced during the actual lactation. The mean  $\pm$  SE. values of peak yield with respective standard error for different breeds as reported by different investigators were summarized (Table10).

**Table 10. The means ( $\pm$ SE) of peak yield for different cattle breeds**

Cattle Breeds	Peak Yield (kg)	References
Haryana cattle	6.24	Dhaka <i>et al.</i> (2002)
Crossbred cattle	11.858 $\pm$ 1.41	Thomas and Kumar (2009)
HF $\times$ Sahiwal	13.3	Lakshmi <i>et al.</i> (2009)
Deoni Cattle	3.14 $\pm$ 0.18	Bhutkar <i>et al.</i> (2014)
HF $\times$ Sahiwal	15.41 $\pm$ 0.47 (First lactation)	Singh <i>et al.</i> (2015) (FL)
Jersey crossbred cattle	11.89 $\pm$ 0.28	Poonam <i>et al.</i> (2016)

(a). **Effects of season of calving:** The significant effect of season of calving on PY was reported by Poonam *et al.* (2016) for Jersey crossbred cattle, by Singh *et al.* (2015) for HF $\times$ Sahiwal and Japheth *et al.* (2015) for Danish HF.

(b). **Effects of periods of calving:** Various workers reported that period of calving exerted significant effect ( $P < 0.05$ ) on PY (Dhaka *et al.*, 2002 for Haryana cattle; Bhutkar *et al.*, 2014 for Deoni cattle; Poonam *et al.*, 2016 for Jersey crossbred cattle; Anarase *et al.*, 2015 for HF $\times$ Deoni cattle); but Singh *et al.* (2015) indicated the insignificant effects of Period of calving on the same trait.

(c). **Effects of sire of cow:** Poonam *et al.* (2016) and Singh *et al.* (2015) found significant effect of sire on PY for Jersey crossbred cattle and for HF $\times$ Sahiwal cattle, respectively.

(d). **Effects of genetic group:** As per the findings of Belayneh *et al.* (2001) for HF $\times$ Arsi cattle, Lakshmi *et al.* (2010) for HF  $\times$  Sahiwal, Kumar *et al.* (2014) for HF crossbred cattle, Singh *et al.* (2015) for HF $\times$ Sahiwal cattle and Poonam *et al.* (2016) for Jersey crossbred cattle, the effect of genetic group on PY was seen to be significant ( $P < 0.05$ ).

#### **2.2.3.6. Days to attend peak yield (DPY)**

The least square mean of days to attend peak yield for HF  $\times$  Sahiwal crossbred cows was 51.30 $\pm$ 2.13 (Singh *et al.*, 2015). The effects of sire of the cow, genetic group of animal, season of calving and period of calving on days to attend peak yield were significant ( $P < 0.05$ ) whereas period of calving had non-significant effect on this trait (Singh *et al.*, 2015).

### **2.3. Genetic parameters of Performance Traits**

Genetic parameters, which consist of heritability, repeatability, genetic and phenotypic correlations are found to be a guide for animal breeder in deciding the method and intensity of selection of various traits of interest. The knowledge of breeding value of bulls is of paramount importance for accurate selection in order to maximize the genetic progress. Precise and accurate knowledge of genetic parameters

such as heritability, repeatability and phenotypic and genetic correlations are useful for designing and evaluating of animal breeding plans, predicting breeding values of the animals in order for selection, estimating the response to selection over the year/generation. All these genetic parameters should be considered at a time while choosing a breeding animal for improvement of traits of interest, thereby the losses in productivity and response to selection in each trait, and in the remuneration of these by industry may be prevented (Madalena, 1988; Lobo *et al.*, 2000).

### 2.3.1. Heritability of performance traits

Heritability is the portion of the total phenotypic variation in quantitative traits caused by genetic factor. Theoretically the heritability of a trait varies between 0-1. On the basis of the heritability value, quantitative traits can be grouped as highly ( $h^2 \Rightarrow > 0.4$ ), moderately ( $h^2 \Rightarrow > 0.2-0.4$ ) and lowly ( $h^2 = 0.1-0.2$ ) heritable (Bourdon, 2000). Bourdon (2000) reported that lactation, milk composition and growth traits are moderately heritable traits ( $h^2$  about 0.25), thereby they can, therefore well respond to selection. Whilst the reproductive traits are lowly heritable, thus they often receive less relevance in genetic improvement programs, rather more attention have usually been given to the use of good herd management practices for their improvement.

#### 2.3.1.1. Heritability estimates of growth traits

Heritability of growth traits is generally intermediate to high indicating that these traits are influenced by both genetic and environmental factors and having good rooms to use mass selection along with pedigree selection for improving the traits.

**Table 11. Heritability estimates of different cattle breeds for growth traits**

S.No.	Breeds	Traits	$h^2$	References
1	Bhagnari & its crosses	BW0	0.59±0.29	Khan (2001)
2	Nelore	BW0	0.21±0.14	Nobre <i>et al.</i> (2003)
3	Crossbred cattle	BW0	0.33±0.09	Islam <i>et al.</i> (2004)
4	Charolais beef cattle	BW0	0.36±0.04	El-Saied <i>et al.</i> (2006)
5	Charolais beef cattle	BW270	0.36±0.01	
6	Dairy cattle	BW0	0.58±0.078	Brotherstone <i>et al.</i> (2007)
7	Dairy cattle	BW90	0.41±0.027	
8	Dairy cattle	BW270	0.63±0.040	
9	Dairy cattle	BW180	0.66±0.032	
10	Dairy cattle	BW540	0.50±0.040	
11	Dairy cattle	BW720	0.59±0.047	
12	Red Chittagong cattle	BW0	0.498	
13	Red Chittagong cattle	BW90	0.456	

14	Red Chittagong cattle	BW180	0.50	Rabeya <i>et al.</i> (2009)
15	Red Chittagong cattle	BW365	0.478	
16	Red Chittagong cattle	BW270	0.447	
17	Crossbred cattle	BW0	0.19±0.09	Raja <i>et al.</i> (2010)
18	HF × Horro	BW0	0.68±0.09	Abera <i>et al.</i> (2011)
19	Swedish Red & White Cattle	BW0	0.57±0.22	Aksakal <i>et al.</i> (2012)
20	Brangus Cattle	BW0	0.16±0.019	Neser <i>et al.</i> (2012)
21	Brangus Cattle	BW365	0.05±0.024	
22	Brangus Cattle	BW540	0.17±0.046	
23	Brangus Cattle	BW270	0.10±0.021	
24	HF × Sahiwal	BW0	0.149±0.106	Kumari (2015)
25	HF × local cattle	BW0	0.40±0.09	Rahman <i>et al.</i> (2015)
26	HF × local cattle	BW90	0.46±0.08	
27	HF × local cattle	BW180	0.39±0.12	
28	HF × local cattle	BW270	0.50±0.12	

### 2.3.1.2. Heritability estimates of reproduction traits

Heritability of age at puberty, at first conception and at first calving are generally low indicating that these traits are highly influenced by environmental factors. Heritability of estimates of different cattle breeds reported by various authors for first reproduction traits were compiled in Table 12.

**Table 12. Heritability estimates of first and all lactation reproduction traits of different breeds**

S.No.	Breeds	Traits	$h^2$	Reference
<b>First lactation traits</b>				
1	Crossbred cattle	AFC	0.20±0.05	Garima (2006)
2	Crossbred cattle	FCI	0.16±0.05	
3	Egypt HF	AFC	0.43 ± 0.126	Safaa (2006)
4	Egypt HF	FCI	0.05 ± 0.051	
5	Sahiwal	AFC	0.21±0.11	Sentitula <i>et al.</i> (2008)
6	Sahiwal	AFC	0.19±0.44	Manoj <i>et al.</i> (2010)
7	Sahiwal	AFC	0.24±0.11	Gupta (2013)
8	Sahiwal	AFC	0.21±0.08	Shinghare <i>et al.</i> (2015)
9	HF×Sahiwal	AFC	0.70±0.18,	Singh <i>et al.</i> (2015)
10	HF×Sahiwal	FCI	0.23±0.10	
11	HF×Sahiwal	WFC	0.37±0.13	
12	Crossbred cattle	AFS	0.46±0.19	Kumar <i>et al.</i> (2017)
13	Crossbred cattle	AFC	0.30±0.19	Parveen (2017)
14	Sahiwal	FCI	0.03±0.08	
15	Sahiwal	AFC	0.45±0.14	
<b>Pooled lactation traits</b>				
1	Sindhi	PP	0.01±0.26	Sharma and Prabhu (1968)
2	Hallikar	PP	-0.39±0.34	
3	Ongole	PP	-0.12±0.40	

4	Egypt HF	CI	0.07 ± 0.011	Safaa (2006)
5	Sahiwal	CI	0.10±0.01	Manoj <i>et al.</i> (2010)
6	Sahiwal	CI	0.07±0.15	Dongre <i>et al.</i> (2013)
7	Sahiwal	CI	0.12±0.16	Gupta (2013)
8	Sahiwal	CI	0.11±0.14	Mundhe <i>et al.</i> (2015)
9	Sahiwal	CI	0.14±0.05	Shinghare <i>et al.</i> (2015)
10	Frieswal Cattle	CI	0.11 ± 0.09	Parineeta <i>et al.</i> (2017)
11	Dairy cows	NSPC	0.07	Muller <i>et al.</i> (2017)
12	Dairy cows	SP	0.08	
13	Sahiwal	CI	0.03±0.02	Ilatsia <i>et al.</i> (2007)
14	Sahiwal	CI	0.04±0.02	
15	Sahiwal	NSPC	0.01±0.01	

### 2.3.1.3. Heritability estimates of milk production traits

Heritability of milk production traits are generally intermediate to high indicating that these traits are influenced by both genetic and environmental factors.

**Table 13. Heritability estimates of different breeds for first and pooled lactations milk production traits**

First lactation traits				
S.No.	Cattle Breeds	Traits	h <sup>2</sup>	Reference
1	Sahiwal × Friesian	LL	0.46±0.33	Das <i>et al.</i> (2003)
2	Crossbred cattle	DP	0.18±0.05	Garima (2006)
3	Egypt HF	DP	0.04±0.049	Saafa (2006)
4	HF×Sahiwal	LL	0.263±0.118	Kumari (2015)
5	HF×Sahiwal	LMY	0.408±0.132	
6	HF×Sahiwal	305_DMY	0.492±0.140	
7	HF×Sahiwal	DP	0.039±0.07	Singh <i>et al.</i> (2015)
8	HF×Sahiwal	PY	0.35±0.13	
9	HF×Sahiwal	DPY	0.11±0.09	
10	HF×Sahiwal	305_DMY	0.43±0.14	
12	Sahiwal	305_DMY	0.16±0.0.11	Parveen (2017)
13	Sahiwal	LMY	0.17±0.11	
14	Sahiwal	LL	0.18±0.11	
Pooled lactation traits				
1	HF cattle	305_DMY	0.26	Rekaya <i>et al.</i> (2000)
2	HF cattle	PY	0.26	
2	Sahiwal Cattle	LL	0.06±0.04	Javed <i>et al.</i> (2001)
3	Sahiwal Cattle	LMY	0.01±0.02	
4	Holstein Friesian	305_DMY	0.29	Ojango and Pollot (2001)
5	Holstein Friesian	LL	0.09	
6	Holstein Friesian	LMY	0.25	
7	Haryana cattle	PY	0.29±0.13	Dhaka <i>et al.</i> (2002)
8	Haryana cattle	LMY	0.26±0.12	
9	Karan Fries	LMY	0.41±0.13	Lee and Han (2004)

10	Karan Swiss	LMY	0.49±0.17	Singh and Gurnani (2004)
11	Holstein	305_DMY	0.25	Lee and Han (2004)
12	Karan Fries	305_DMY	0.44±0.19	Singh and Gurnani (2004)
13	Karan Fries	LL	0.51±0.15	
14	Karan Swiss	LL	0.42±0.16	
15	Crossbred cattle	LL	0.37±0.27	Singh <i>et al.</i> (2005)
16	Friesian	305_DMY	0.22	Khattab <i>et al.</i> (2005)
17	Crossbred cattle	LMY	0.55±0.19	
18	Frieswal Cattle	LL	0.04±0.06	Kumar <i>et al.</i> (2005)
19	Iranian Holstein	LMY	0.15-0.23	Singh <i>et al.</i> (2005)
20	Crossbred cattle	LMY	0.28	Edriss <i>et al.</i> (2006)
21	Brown Swiss	LMY	0.14±0.08	Filho <i>et al.</i> (2006)
22	Crossbred Cattle	LMY	0.23±0.08	Cilek <i>et al.</i> (2006)
23	Crossbred cattle	LL	0.19	Filho <i>et al.</i> (2006)
24	Frieswal Cattle	LMY	0.35±0.11	Amimo <i>et al.</i> (2007)
25	Ayrshire (Kenya)	305_DMY	0.12 ±0.05	
26	Crossbred Cattle	LL	0.22±0.07	Singh <i>et al.</i> (2007)
27	Sahiwal	DP	0.05	Rehman <i>et al.</i> (2008)
28	Holstein	305_DMY	0.35	Aziz <i>et al.</i> (2014)
29	Brown Swiss	LMY	0.26	
30	Holstein	LL	0.05	
31	HF cattle	LMY	0.35	Zavadilova and Zink (2013)
32	Brown Swiss	305_DMY	0.25	Aziz <i>et al.</i> (2014)
33	Brown Swiss	LL	0.10	
34	Brown Swiss	DP	0.06	
35	Jersey crossbred cattle	LMY	0.51±0.13	Al-Samarai <i>et al.</i> (2015)
36	HF cattle	LL	0.06	
37	Jersey crossbred cattle	305_DMY	0.58±0.14	Poonam <i>et al.</i> (2016)
38	Holstein	LMY	0.34	
39	Jersey crossbred cattle	LL	0.15	
40	Jersey crossbred cattle	PY	0.51±0.13	

### 2.3.2. Repeatability of production and reproduction traits

Repeatability is the measure of the strength (consistency, reliability) of the relationship between repeated records for a trait in a population (Bourdon, 2000). It is also defined as a measure of the strength (consistency, reliability) of the relationship between single performance records and producing abilities for a trait in a population. Repeatability can be determined for any trait in which individuals commonly have more than one performance record. Theoretically the repeatability of a trait varies between -1 to +1. On the basis of the repeatability value, quantitative traits can be

grouped as highly ( $r \geq 0.4$ ), moderately ( $r = 0.2-0.4$ ) and lowly ( $r < 0.2$ ) repeatable (Bourdon, 2000). The majority of procedures for predicting breeding values in dairy cattle either consider only first lactations, implying a genetic correlation of one between all lactations and also, performances in later lactations are assumed to be genetically due to genes that influenced performance in first lactation. Selection decisions are often based on first lactations (Da *et al.*, 1992). Delayed selection increases generation interval and thereby slows rate of progress. Many authors have presented the argument that milk production in all lactation is determined more or less by the same genes (Meyer 1984; Bagnicka *et al.*, 2004). First parity yields are therefore considered to be an efficient selection criterion.

**Table 14. Repeatability estimates of different breeds for production and reproduction traits**

Cattle breeds	305_DMY	LMY	LL	NSPC	CI	SP	References
Sahiwal		0.49	0.40	0.18	0.11		Ilatsia <i>et al.</i> (2007)
Sahiwal	0.43±0.10						Kumar <i>et al.</i> (2009)
HF cattle	0.35	0.34	0.10				Aziz <i>et al.</i> (2014)
Sahiwal	0.40±0.02						Rehman & Khan (2012)
Sahiwal	0.41±0.028						Verma (2015)
Ethiopian HF	0.41±0.02	0.45±0.02	0.12±0.02		0.22±0.02	0.19±0.02	Wondossen <i>et al.</i> (2017)

### 2.3.3. Phenotypic and genetic correlations

Different traits recorded on the same animal may tend to be related each other. For example high milk producing cows have lower fat percentage, been lighter in body weight and low in reproduction efficiency. This relationship is known as correlation, namely phenotypic, genetic and environmental correlation. Knowledge of estimates of such correlation coefficients is very helpful for the animal breeder in constructing selection indices (Hazel, 1943) needed for selection for more than one trait at a time to improve the considered traits. Genetic correlation coefficient between any two traits measures the association between the breeding values of these two traits (Falconer, 1996). Phenotypic correlation between two traits is a measure of the degree of association between their phenotypic values. Environmental correlations between two traits are a measure of the degree of association between environmental factors associated with the two traits.

**Table 15. Estimates of genetic and phenotypic correlations of first lactation traits in different breeds**

Traits	Breed/Genetic Group	Genotypic correlations	Phenotypic correlations	References
AFC×LMY	F×T	0.33±0.04	0.68±0.12	Singh and Gurnani (2004)
AFC×LMY	BS×S	0.16±0.05	0.19±0.05	
AFC×LMY	crossbred	0.07±0.4	-0.30±0.19	Dubey and Singh (2005)
DP×CL	crossbred	0.53±0.11	0.59±0.13	
AFC×LMY	crossbred	0.17±0.36	0.01±0.02	Garima (2006)
AFC×LL	crossbred	-0.23±0.33	0.02±0.02	
AFC×CI	crossbred	0.8±0.48	0.04±0.02	
AFC×SP	crossbred	0.07±0.53	0.02±0.02	
LMY×LL	crossbred	0.35±0.28	0.15±0.02	Garima (2006)
LMY×DP	crossbred	0.16±0.39	0.05±0.02	
LMY×CI	crossbred	0.48±0.49	0.12±0.02	
LMY×SP	crossbred	0.25±0.49	-0.01±0.03	
LL×DP	crossbred	-0.39±0.37	-0.01±0.03	
LL×CI	crossbred	0.47±0.31	0.51±0.02	
LL×SP	crossbred	0.31±0.46	-0.01±0.03	
DP×CI	crossbred	0.62±0.28	0.28±0.02	
DP×SP	crossbred	0.03±0.58	0.58±0.01	
CI×SP	crossbred	0.33±0.66	-0.02±0.02	
DP×305_DMY	HF	-0.28±0.054	-0.074	Safaa (2006)
DP×LL	HF	-0.98±0.033	-0.021	
CI×305_DMY	Egyptian HF	0.36±0.051	-0.124	
CI×LL	Egyptian HF	0.69±0.49		
CI×DP	Egyptian HF	0.05±0.068	0.589	
CI×AFC	Egyptian HF	-0.41±0.277		Parveen (2017)
AFC×LL	Sahiwal	0.12±0.29	-0.016	
AFC×LMY	Sahiwal	-0.06±0.28	0.016	
LMY×LL	Sahiwal	0.72±0.21	0.85	
LMY×CI	Sahiwal	0.28±0.36	0.29	
AFC×CI	Sahiwal	0.38±0.39	-0.018	
AFC×305-d MY	Sahiwal	-0.08±0.19	0.048	
305_DMY×LMY	Sahiwal	0.91±0.06	0.93	
LL×CI	Sahiwal	0.89±0.18	0.37	
<b>Pooled lactation traits</b>				
AFC×DP	HF×S	0.01±0.08	-0.83±0.00	Chaudhary (1983)
AFC×LL	HF×T	0.20±0.04	0.29±0.34	Singh and Gurnani (2004)
AFC×LL	BS×S	0.07±0.05	0.69±0.13	
AFC×SP	BS×S	-0.03±0.05	0.43±0.23	
LMY×LL	BS×S	0.71±0.03	0.83±0.08	
LMY×CI	BS×S	-0.59±0.02	0.41±0.04	
LMY×DP	BS×S	-0.21±0.05	-0.63±0.38	

LMY×SP	BS×S	0.39±0.09	-0.48±0.36	Singh and Gurnani (2004)
LL×CI	BS×S	0.75±0.03	-0.99±0.13	
LL×SP	BS×S	0.67±0.05	-0.94±0.13	
SP×DP	BS×S	0.43±0.05	-0.45±0.56	
SP×CI	BS×S	0.91±0.11	0.91±0.13	
DP×CL	BS×S	0.57±0.04	-0.27±0.49	
SP×DP	Crossbred	0.51±0.12	0.57±0.14	Dubey and Singh (2005)
SP×CI	Crossbred	0.33±	0.56±0.14	
AFC×LL	Crossbred	0.03±0.15	-0.25±0.21	
AFC×CI	Crossbred	-0.04±0.15	-0.31±0.21	
AFC×DP	Crossbred	0.01±0.15	-0.08±0.23	
AFC×SP	Crossbred	0.027±0.12	-0.26±0.22	
LMY×LL	Crossbred	0.66±0.16	0.65±0.10	Dubey and Singh (2005)
LMY×CI	Crossbred	0.24±0.17	0.53±0.13	
LMY×DP	Crossbred	-0.13±0.1	0.20±0.18	
LMY×SP	Crossbred	0.20±0.15	0.32±0.17	
LL×DP	Crossbred	-0.22±0.10	-0.02±0.18	
LL×CI	Crossbred	0.39±0.18	0.75±0.10	
LL×SP	Crossbred	0.23±0.18	0.22±0.19	Safaa (2006)
LL×305_DMY	HF	0.34±0.55	0.065	
305_DMY×LL	Sahiwal	0.26±0.38	0.71	Parveen (2017)
305_DMY×CI	Sahiwal	-0.17±0.34	0.15	
AFC×CI	Ethiopia	0.16±0.12	0.11±0.03	Wondossen <i>et al.</i> (2017)
AFC×SP	Ethiopia	0.06±0.13	0.10±0.02	
LMY×305-DMY	Ethiopian HF	0.99±0.01	0.84±0.01	
LMY×LL	Ethiopia	0.91±0.08	0.51±0.02	
LMY×AFC	Ethiopia	-0.41±0.11	-0.41±0.11	
LMY×CI	Ethiopia	0.16±0.12	0.15±0.02	
LMY×SP	Ethiopia	0.25±0.13	0.17±0.02	
305_DMY×LL	Ethiopia	0.74±0.19	0.05±0.02	
305_DMY×AFC	Ethiopia	-0.24±0.11	-0.24±0.11	
305_DMY×CI	Ethiopia	-0.10±0.13	-0.12±0.02	
305_DMY×SP	Ethiopia	-0.02±0.14	-0.11±0.02	
LL×AFC	Ethiopia	-0.72±0.38	0.08±0.04	
LL×CI	Ethiopia	0.99±0.10	0.39±0.01	
LL×SP	Ethiopia	0.98±0.19	0.42±0.02	
CI×SP	Crossbred	0.99±0.01	0.98±0.01	

#### 2.4. Genetic and Phenotypic Trends

Dairy cattle have a long generation interval and low reproductive rate. In addition, it is costly and time-consuming to carry out dairy cattle selection on a large experimental scale. Methods to determine variance component have been greatly improved over the last three decades (Mashhadi *et al.*, 2008). In a population, which selection has carried out and mating between animals designed based on genetic characteristics, a lot of changes that obtained in several years from animal breeding programs must be investigated, thus genetic trend of selected traits in population estimated. The change in production per unit of time due to change in mean breeding

value is called the genetic trend (Harville and Henderson, 1966). The understanding of trends in genetic progress will help future genetic direction to be established by definition of specific goals for breeding a profitable and sustainable dairy herd (Missanjo *et al.*, 2012). Genetic evaluation is also important to assess genetic improvement program progress, to make adjustments aiming to optimize genetic gain, and to increase farm profitability in the future (Silva *et al.*, 2001). Several researchers (Lee *et al.*, 1985; VanVleck *et al.*, 1986; Meinert and Pearson, 1992) have studied genetic trends in dairy cattle. Most of these researchers estimated genetic trends over periods of less than 20 year; however the precision of genetic trend estimates is enhanced greatly as the number of years studied increases (Burnside and Legates, 1967).

Ferreira *et al.* (2006) reported a genetic trend of 6.71 kg of milk yields per year for Holstein breed when all paths of selection were combined, while Santana Júnior *et al.* (2010) reported a genetic trend of  $-0.018/\text{month}$  for age at first calving per year for Gir dairy cattle. Genetic trends in the Holstein and other breeds dairy cattle population in Central Thailand from 1991 to 2005 were small for milk yield (Koonawootrittriron *et al.*, 2009). Roman *et al.* (1999) reported genetic trend of 57 kg for milk yield in Jersey breed during 1967-1979 years. Freeman and Lindberg (1993) estimated genetics trend for milk yield of 135 kg. Deb *et al.* (1974) investigated first lactation records of Jersey cattle; they found that the phenotypic increase in milk yield was 36 kg per year and annual increase mature equivalent mean milk yield was 0.9%. Annual genetic trends were for 33 kg milk yield Holsteins; 22 kg for Jerseys and 92 kg for Guernsey. Environmental trends for milk yield were positive for Holsteins (57 kg) but negative for Jerseys and Guernsey (10 and 23 kg) (Verde *et al.*, 1972).

Ali *et al.* (2016) did a study on genetic trend estimates for milk yield production and fertility traits of the Girolando cattle in Brazil and found that the estimated annual genetic changes for 305MY and AFC were 7.40 milk/year and  $-0.13$  day/year and a range of 0.04 to 0.18 for FCI in the all selection paths whereas Aziz *et al.* (2014) studied genetic and environmental parameters and trends for milk production of Holstein cattle in Turkey and observed that trends were inconsistent with some phenotypic increase in yields during the period between 2001 and 2005. This improvement was associated with increased environment parameter estimates during that period.

Yaeghoobi *et al.* (2011) reported that annual genetic and phenotype trend for milk and fat yield traits was 19.61, 0.171, 71.99 and 1.401, respectively for Holstein's Dairy Cattle of West Provinces of Iran.

Kumar *et al.* (2017) reported the rate of change/year (trend) in the traits were - 40.58 days in age at first calving, 41.38 kg in first lactation milk yield, 2.67 days in first lactation length, 0.71 kg in first peak yield, 1.70 days in first dry period, 0.80 days first service period, 10.84 days in calving interval, 0.09 kg in wet average and 0.06 kg in herd average from 2011 to 2015 for Sahiwal cattle.

## **2.5. Most Probable Producing Ability (MPPA)**

The concept of MPPA was first introduced by Lush (1945) as a means of estimating the producing ability of each cow under standard conditions within a herd. MPPA allows the comparison of cows with different numbers of records. MPPA measures both genetic and permanent environmental effects. Use of lifetime records reduces the effects of the temporary environment. The classical (selection index theory) MPPA predicts a cow's MPPA as the regression of MPPA on the average of the cow's lactation records, adjusted for all the fixed effects. This assumes and presumes that the means of all the fixed effects are known without error, which will rarely be the case. Thus, mixed models equations (Henderson, 1984) are more appropriate, in that they allow simultaneous estimation of both the fixed effects and the random effects and account for the uncertainty of estimation. It is also a method of selection for traits, which are, repeated several times in the life of an animal e.g. milk production in cows, litter size in pigs etc. It is used to predict the future performance of animals and helps to rank the animals especially dams in a herd for selection.

As most of the economic traits are influenced by environment, the error due to environmental variation can be eliminated if selection based on several records of the same individual. The repeatability is an indicator of the extent to which an animal superiority in one measurement will be seen in subsequent measurements of the same animal. Therefore the repeatability value is used in estimating MPPA. For herds with regular yield recording, repeatability ( $r$ ) and most probable production ability (MPPA) are commonly used statistical estimates used in methods to evaluate cows (Soysal and Tuna, 2000). An MPPA value can be considered as a deviation of a cow's predicted performance from an average value for the herd. It cannot be used as a method of comparison among cows in different herds since it is a deviation from a herd average (Itulya, 1980). In traits with a low repeatability, the value of the first lactation

production is not a good indicator of future performance, it is better to decide based on the average of more than one lactation, by waiting a year or two more to identify the animals to be selected, or conversely culled (Arıtürk and Yalçın, 1996; Sehar *et al.*, 2011). The expected producing abilities of cows in a herd for different production traits was estimated using the following formula as developed by Lush (1945):

$$\text{MPPA} = \mu + \left( \frac{nr}{1 + (n-1)r} \right) (\bar{x}_i - \mu)$$

Where,  $\mu$  = herd average;  $n$  = numbers of lactations;  $r$  = repeatability;  $\bar{x}_i$  = average of all lactations of the  $i^{\text{th}}$  animal.

The animals which produce less average MPPA is culled from the herd. Lakshmi *et.al.* (2009) studied the Most Probable Producing Ability (MPPA) using the total lactation milk yield and 300-days lactation milk yield in the HF and Sahiwal crossbred cattle and found that the highest and lowest MPPA for total lactation milk yield were 7911.31 kg and 5713.42 kg, respectively, while for MPPA based on 300-days lactation milk yield, the highest and lowest estimates were 4635.70 kg and 2270.0 kg, respectively while Mikail *et al.* (2019) reported that the average MPPA values of HF and Brown Swiss herds was found to be 7.278 kg.

## 2.6. Sire Evaluation

Sire evaluation is one of the most important aspects of dairy breed improvement programme as the contribution of sire path is higher than the dam path for overall genetic improvement of a trait. The success of a breeding programme depends on how early and how accurately bulls can be proved. Therefore, an accurate evaluation of the bull at minimum possible cost is of paramount importance for bringing about rapid genetic progress in dairy cattle (Kokate *et al.*, 2012).

Danish breeders were among the first to record herd data on performance, while use of that data for progeny testing of bulls began in 1902. Since then many specialized procedures for measuring individual performance and for family, sib and progeny testing have been developed to enhance accuracy and efficiency of evaluation of breeding value of sires. Each individual receives a random sample half of its sire's genes and another random sample half of its dam's genes. Sire evaluation includes two stages. First, a progeny performance test is conducted to ascertain the transmitting ability of a sire, i.e. whether a sire will produce daughters, on an average, better to the dam or not. Secondly, such sires, which have proven their worth in their

transmitting ability test, are required to be ranked with the help of some indices so as to enable appropriate choice between them.

### **2.6.1. Methods of sire evaluation**

#### **2.6.1.1. Minimum Variance Quadratic Unbiased Estimation (MIVQUE0)**

MINQUE demands no assumptions about the form of the distribution of  $y$ . But if the usual normality assumptions are invoked, the MINQUE solution has the properties of being that unbiased quadratic form of the observations which has minimum variance; i.e. it is a minimum variance quadratic unbiased estimator, MIVQUE. The MINQUE procedure demands a weight vector for the pre-assigned value for  $\sigma^2$ . No iteration is involved; but having obtained a solution,  $\sigma_1^2$  say, its existence prompts the idea of using it as a new pre-assigned value for getting a new estimate of  $\sigma^2$ , say  $\sigma_2^2$ . This leads to using the MINQUE equations iteratively to yield iterative MINQUE, or I-MINQUE estimators. They are, of course, if one iterates to convergence, the same as REML estimators. Hence I-MINQUE = REML. Even in the absence of normality assumptions on  $y$ , the I-MINQUE solutions do have large-sample normality (Jain, 1982).

#### **2.6.1.2. Restricted maximum likelihood method (REML)**

Restricted maximum likelihood estimation (REML) is often preferred as a method of estimating covariance parameters in linear models because it takes account of the loss of degrees of freedom in estimating the mean and produces unbiased estimating equations for the variance parameters. Graser *et al.* (1987) used derivative free restricted maximum likelihood (DFREML) algorithm for solving the mixed model equations. Singh *et al.* (2014) reported that rank correlations between breeding values for first lactation 305-day milk yield estimated by BLUP-AM was highest(0.94) with BLUP-SM, followed by LSM (0.76) and SRLSM (0.62) concluding that BLUP-AM can be used efficiently for genetic evaluation of Murrah sires in place of conventional BLUP-SM.

#### **2.6.1.3. Least squares method (LSM)**

The least squares method for determining the genetic worth of sires was based on the principle to minimize the error variance after adjusting the data for various non-genetic or environmental factors. Harvey (1987) gave the concept of least squares analysis for non-orthogonal data. By incorporating sire as a random effect in the model of least squares analysis, the effect of sire can be determined for their genetic merit for effective sire evaluation. The least squares analysis for estimation of

breeding value of sires has widely been used in India by different workers. Tajane and Rai (1990) used least squares method for estimation of breeding value of 29 Holstein-Friesian sires and 8 Sahiwal sires based on their 1257 (Holstein-Friesian X Sahiwal) and 519 (Sahiwal X Holstein-Friesian) daughters. Gandhi and Gurnani (1991) estimated breeding value of Sahiwal sires on the basis of first lactation 305 days or less milk yield of their daughters maintained at five farms by least squares technique. Singh *et al.* (1992) used the least squares method for estimation of breeding values of Haryana bulls. Raheja (1992) used least squares method for estimating the breeding value of Sahiwal sires. Parekh *et al.* (1994) evaluated Friesian, Jersey and Brown Swiss sires based on least squares method. Banik (2004) used LSM along with other methods (Contemporary comparison method, SRLS, BLUP and DFREML) for evaluation of Sahiwal sires and reported highly significant rank correlation of LSM with Contemporary comparison method (0.91), SRLSM (0.98), BLUP (0.85) and DFREML (0.96). Mukherjee (2005) also used LSM along with other methods (Contemporary comparison method, SRLS, BLUP and DFREML) for evaluation of Frieswal sires and reported highly significant rank correlation of LSM with Contemporary comparison method (0.91), SRLS (0.94), BLUP (0.96) and DFREML (0.91). It was inferred that ranking of sires by these methods did not alter significantly.

### **2.6.2. Relative efficiencies of various sire evaluation methods**

Minimum error variances, maximum accuracy of prediction, maximum coefficient of variation, high rank correlation are some of the criteria that define a method as more effective in comparison to other methods of sire evaluation. Gaur *et al.* (2001) estimated the breeding value of Frieswal sires using simple daughter's average, contemporary comparison (CC), least squares (LS) and BLUP procedures and computed rank correlations among the values obtained in order to judge the efficiency of various methods. All the rank correlations were greater than 0.86. Rank correlations among breeding value of sires estimated from BLUP, LS and CC procedures were near to unity (0.96 to 0.97). They suggested that either of the methods employed in the study could be used for the selection of sires for breeding purpose. Banik and Gandhi (2006) evaluated 81 Sahiwal sires for milk yield using least squares, best linear unbiased prediction (BLUP) and derivative free restricted maximum likelihood (DFREML) methods. The accuracy, efficiency and stability of different sire indices were compared to judge their effectiveness. The error variance

of DFREML method was lowest and therefore, it was considered to be the most efficient out of three sire evaluation methods. The higher (0.6688 to 0.9802) and statistically significant ( $P < 0.01$ ) rank correlations between different sire evaluation methods indicated that there was higher degree of similarity of ranking sires by different methods. They concluded that multi trait animal model did not enhance accuracy of sire evaluation as compared to single trait animal model.

## **2.7. Growth Curve and Non-linear Models**

Growth constitutes one of the most important economic attributes of cattle. It starts from single cell (zygote) and assumes s-shaped (sigmoid) growth curve which is actually plotted using postnatal growth records. Knowledge of genotypic and phenotypic relationships among live weights, degree of maturity and growth rate during all phases of growth is necessary to formulate breeding programmes to improve lifetime efficiency (Swatland, 1994). Studying dairy cattle growth curves are used for investigating optimum feeding programmes, determining optimum slaughtering age and the effects of selection on curve parameters and on live weight at a certain age. Growth is also connected with other economic attributes such as production and breeding (Hassen *et al.*, 2004; Tariq *et al.*, 2013; Jahan *et al.*, 2013; Du *et al.*, 2013). Moreover, it is important for scientists, farmers and, animal keepers to have knowledge of the growth curve characteristics for a certain cattle breed to make a reliable selection decision at early age as they can change due to selection response (Gwaze *et al.*, 2002; Gupta *et al.*, 2011; Rehman and Khan, 2012) and for life time production efficiency (Fitzhugh, 1976; Salem *et al.*, 2013). Estimated growth parameters such as the average mature weight (A) could be one way to make correct decision for selection for high growth rate as it possessed high additive genetic variance as shown in Nelore cattle (Fornis *et al.*, 2006; Mignon-grastean *et al.*, 2000).

Growth in animals can be predicted by graphical plotting age versus weight using mathematical models (Bathaei and Leory, 1996; Garnero *et al.*, 2006; Forni *et al.*, 2009; Souza *et al.*, 2010). Non-linear growth models (Table 16) are used in identifying the growth models of dairy and fattening cattle in terms of weight (Berry *et al.*, 2005a). Despite the fact that non-linear models are harder to implement than the linear models, estimations can be obtained through iteration (Ratkowsky, 1990; Bilgin *et al.*, 2004). These models have the ability to give a reliable description of animal growth into an understandable explanation which is vital for animal producers and farmers (Menchaca *et al.*, 1996). Several studies have suggested that the Brody model

provides the best fit to describe beef cattle growth curves (Arango & Van Vleck, 2002; Garnero *et al.*, 2006). However, the literature has also reported studies where other models fit cattle data more satisfactorily. Oliveira *et al.* (2000) selected the Von Bertalanffy model to represent the mean growth curve of Nelore cattle. Souza *et al.* (2010) reported that the Logistic equation presented the best goodness of fit for the growth curve in the indubrasil breed. Similarly, Ozgur and Serkan (2014) did their study on determination of growth curves of female Holstein calves using five non-linear models and concluded that the Logistic model can be exclusively used for estimating the growth curves and live weights of the calves in their early periods of lives, while Gormertez and Richards models can be used for post-weaning period. Several workers (Bahriet *al.*, 2004; Berry *et al.*, 2005; Salim *et al.*, 2015) used the determination coefficient ( $R^2$ ), the mean squared error (MSE), the mean absolute deviation (MAD) and the percentage of convergence (C%) as the goodness of fit of the models.

**Table 16. Non-linear models with their equations for growth curve in crossbred cattle**

S.No.	Non-linear Models	Equations
1	Brody (Brody, 1945)	$Y_t = A \times (1 - B \times e^{-k \times t}) + \varepsilon$
2	Von Bertalanffy (Von Bertalanffy, 1957)	$Y_t = A \times (1 - B \times e^{-k \times t})^3 + \varepsilon$
3	Richards's functions (Richard, 1959)	$Y_t = A \times (1 - B e^{-k \times t})^M + \varepsilon$
4	Logistic (Nelder, 1961)	$Y_t = A / (1 + B \times e^{-k \times t}) + \varepsilon$
5	Gompertz (Laird, 1965)	$Y_t = A \times e^{-B} \times e^{-k \times t} + \varepsilon$
6	Quadratic (Moore, 1985)	$Y_t = A_0 + Bt + Kt^2 + \varepsilon$
7	Cubic (Moore, 1985)	$Y_t = A_0 + Bt + Kt^2 + Mt^3 + \varepsilon$

Where,  $Y_t$  is the observed body weight of individuals ( $i=1 \dots n$ ) at measurement time  $j$  ( $j=1 \dots n_i$ ) for animal  $i$ ;  $t$ : age of animal in days;  $A$ : the asymptotic body weight of animal, which was interpreted as mature weight;  $B$ : the proportion of the asymptotic mature weight to be obtained after birth for animal;  $k$ : the maturation rate of animal, which is interpreted as weight change in relation to mature weight to indicate how fast the animal approaches adult weight;  $M$  is the parameter that shapes the curve;  $e$  is the natural base logarithm;  $\varepsilon$ : the random residual term

Initial live weight is converted to asymptotic live weight ( $A$ ) by the following formulas:

$$A = A_0 - \frac{B^2}{4K} \text{ for the quadratic model}$$

$$= A_0 + BT_{\max} + KT_{\max}^2 + MT_{\max}^3 \text{ for the Cubic model}$$

Where,  $A_0$  is the initial live weight; B, K, and M are the model parameters which characterize the shape of the curve and T is age of animal.

**Table 17. Growth Curve parameters of different cattle breeds**

Cattle Breeds	Growth Curve Parameters			Fitted Model	References
	A	B	K		
Brown Swiss	499±6.4	0.63±0.024	0.06±0.004	Richards	Bahriet <i>et al.</i> (2004)
Female HF dairy cattle	542.7±8.97	62.5±0.74	3.4±0.08	Von Bertalanffy	Berry <i>et al.</i> (2005)
Frisian crossbred calves	450±13.4	146±2.1	0.20±0.0	Broody	Salem <i>et al.</i> (2013)
Holstein calves	213.0±12.3	1.77±0.05	0.017±0.001	Logistic	Ozgur & Serkan (2014)
Dhofari cows	322 ±1.32	0.522 ±0.004	0.09 ±0.001	VonBertalanffy	Salim <i>et al.</i> (2015)

A: the asymptotic body weight; B: the proportion of the asymptotic mature weight to be obtained after birth for animal; K: the maturation rate

## 2.8. Lactation Curve and Non-linear Models

The graphical representation of milk production over the course of lactation in dairy cow is lactation curve. Typical lactation curves for dairy cows show a peak or maximum daily output between 4 and 8 weeks after calving, followed by a daily decrease in the amount of milk (persistence) until drying, where the lactation will be naturally terminated (Macciotta *et al.*, 2005). Costs of milk production depend on lactation yield and the persistency of lactation, which is an expression of the ability of the cow to continue to produce milk at peak level throughout lactation (Suresh *et al.*, 2014). Persistency is the ability of the lactating animal to maintain a more or less constant milk yield in the declining phase of lactation and it represents the inherent capacity of the animal for sustainable milk production (Dongre, 2012). High persistency is associated with a slow rate of decline in milk production, whereas low persistency is associated with a rapid rate of decline in milk yield. Declining rate of milk production is generally about 7% per month after the peak yield (Val-Arreola *et al.*, 2004). Scott *et al.* (1996) reported that lactation curve provides valuable information about the pattern of milk production during lactation which is determined by the biological efficiency of the cow. Lactation curve functions are currently implemented in dairy farm management software. At cow level, lactation curve modeling is of help for monitoring individual yields for diet planning, early detection of diseases before the appearance of clinical signs and for selecting animals to be culled (Vargas *et al.*, 2000; Nicolò *et al.*, 2016). It also helps for predicting expected missing values on field records and gives concise summary of biological efficiency of

dairy cows and persistency of cow. Besides to management, breeding is another important field of application where it has been used on determining optimum strategies for insemination and replacement of dairy cows as well as for genetic evaluation of dairy cows for improvement of milk production traits (Macciota *et al.*, 2005).

Several non-linear models (Table 18) were proposed recently to describe the lactation curve and they have been also under modification by various investigators (Grossman and Koops, 1988; Guo and Swalve, 1995; Gengler, 1996). However computational difficulties due to an increased number of parameters to be estimated and the need of greater amount of data are there in some of them.

**Table 18. Equations of non-linear models for lactation curves in crossbre cattle**

Models	Equations
Exponential decline function (Broody <i>et al.</i> ,1923)	$Y_t = ae^{-ct}$
Parabolic exponential model (Sikka,1950)	$Y_t = a \exp(bt - ct^2)$
Inverse polynomial model (Nelder,1966)	$Y_t = t(a + bt + ct^2)^{-1}$
The gamma-type function (Wood,1967)	$Y_t = at^b \times e^{-ct}$ or $\ln(Yt) = \ln(a) + b \times \ln(t) - c \times t$
Mixed log function (Guo and Swalve,1995)	$Y_t = a + b \times \sqrt{t} + c \times \log(t)$

Where,

$Y_t$  = Average daily milk yield in the  $t^{\text{th}}$  day of lactation;

$a$  = initial milk yield after calving;  $b$  = ascending slope parameter up to the peak yield

$c$  = descending slope parameter;  $t$ = length of time since calving

$e_t$ = residual error

**Table 19. Equations of Polynomial Regression Model for the lactation curve in crossbred cattle**

Polynomial Regression Model (Ali and Schaeffer, 1987)	$Y_t = a_0 + bt + ct^2 + d \log\left(\frac{1}{t}\right) + f \log\left(\frac{1}{t}\right)^2$
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Where,

$Y_t$  = Average daily milk yield in  $t^{\text{th}}$  day of lactation;  $a$  = associated with peak yield;  $b$  and  $c$  = associated with the decreasing slope;  $d$  and  $f$ : associated with the increasing slope parameter;  $t$  = length of time since calving. For Gamma-type function, the days in milk at peak yield (DIMP) was defined as  $b/c$  and the peak yield was estimated as:  $a \times (b/c)^b e^{-b}$  whereas the persistency (P) of lactation was evaluated using:  $P = - (b + 1) \ln (c)$  (Tekerli *et al.*, 2000).

**Table 20. Lactation curve parameters and fitted models in different cattle breeds**

Cattle Breeds	Lactation Curve Parameters				Fitted Model	R <sup>2</sup>	References
	a	b	c	d			
Holstein cows	2.71	0.211	0.004		Log transformed Gamma Function	70.80	Tekerli <i>et al.</i> (2000)
Dairy cattle	13.01	0.27	0.003		Wood	91.25	Cole and Null (2009)
Frieswal	217.37±2.06	1.09±0.09	1.01±0.09	0.03±0.001	Mitscherlich & Exponential	99.20	Dohare <i>et al.</i> (2014)
Jersey crossbred	0.44±1.386	5.788±2.299	-3.49±1.16	4.658±0.73	Ali & Schaeffer	74.00	Subham <i>et al.</i> (2017)
Gir crossbred	1545±0.59	0.43±0.09	0.21±0.02		Gamma type function	90.50	Yogesh <i>et al.</i> (2017)

a: initial milk yield after calving; b = ascending slope parameter up to the peak yield; c = descending slope parameter; d: associated with the increasing slope parameter

## **2.9. Heat Stress and Dairy Cattle**

Livestock, depending on the species and level of productivity, have an optimal environmental zone and they must be maintained within this zone for optimal growth, lactation and reproductive functions (Johnson, 1988). The efficiency of conversion of food energy for maintenance and production while maintaining a reasonable thermal balance of the animals in its environment is seldom to achieve in tropical climates for most highly productive stocks. As animal agriculturalists strive for increased rate of growth, lactation and fertility by improved feeding, especially in the more stressful humid tropics they are immediately confronted with the problems of dissipation of the increased metabolic heat. Genetic blending of heat in addition to nutritional adaptability and disease resistance with productivity is essential for animal production in climate zones where portions of the day, seasons, or year exceed the thermo-neutral zone for production. The thermo-neutral zone for various mammals, as indicated earlier, has been described by Bianca (1976), Johnson (1965), Yousef (1965), Kibler (1964), NRC (1971), Mader *et al.* (2006) and Bohmanova *et al.* (2007). Be an animal in an optimal environment or stressed is of current interest in most developed nations due to a rapid proliferation of animal welfare laws. Heat stress is the perceived discomfort and physiological strains associated with exposure to an extreme hot or cold environment. Thermal stress includes both heat stress during extreme summer season as well as cold stress during extreme winter season. The surplus of produced heat needs to be emitted to the surrounding air. However, this is difficult when the air temperature is already high and relative air humidity is elevated. As a result, body temperature of animals increases. In order to prevent overheating, cows consume less feed which leads to lower milk production. Moreover, the thermal stress is most often conditioned by air temperature, relative air humidity, solar radiation and air movement velocity (West, 2003; West *et al.*, 2003).

### **2.9.1. Definition of terms**

The definition and use of terms for describing responses of animals to adverse environments have been documented by Folk (1974) and International Commission for Thermal Physiology (Bligh and Johnson, 1973).

**Table 21. Descriptions of terms related to responses of animals to adverse environments**

<b>Terms</b>	<b>Descriptions</b>
Adaptation	<p>A change which reduces the physiological strain produced by a stressful component of the total environment. This change may occur within the lifetime of an organism (phenotypic) or be the result of genetic selection in a species or subspecies (genotypic).</p> <ul style="list-style-type: none"> <li>• Genetic adaptation (genotypic adaptation): A genetically fixed condition of a species or subspecies, or its evolution, which favors survival in a particular total environment.</li> <li>• Phenotypic or monogenetic adaptation: A change which reduces the physiological strain produced by a stressful component of the total environment and occurring within the lifetime of the organism.</li> </ul>
Acclimation	A physiological change, occurring within the lifetime of an organism, which reduces the strain caused by experimentally induced stressful changes in particular climatic factors.
Acclimatization	A physiological change occurring within the lifetime of an organism which reduces the strain caused by stressful changes in the natural climate (e.g. seasonal or geographical).
Habituation	Reduction of responses to, or perception of repeated stimulation.
Tolerance/resistance	In principle, a heat-tolerant animal is one that maintains homoeothermic under high environmental heat loads. Hair and coat characteristics including hair shedding rate and body surface to mass ratio are related to the animal's ability to dissipate internal heat whereas disease tolerance describes animals that exhibit little disease damage despite substantial pathogen levels and disease resistance is the reduction of pathogen growth on or in the animal (and hence a reduction of disease) relative to a susceptible animal.
Thermo-neutral zone (TNZ)	The range of ambient temperature within which metabolic rate is at a minimum, and within which temperature regulation is achieved by no evaporative physical processes alone.

**2.9.2. Basic temperature and humidity Index (THI) as predictor of heat stress**

THI is a single value depicting the integrated effects of air temperature and humidity associated with the level of heat stress. It is a useful and easy way to assess the risk of heat stress and was first introduced to describe the effect of ambient temperature on humans but later it has been adapted to describe thermal conditions

that drive heat stress in dairy cattle (Berry *et al.*, 1964; De Rensis *et al.*, 2015). This index has been developed as a weather safety index to control and decrease the heat stress-related losses (Bohmanova *et al.*, 2007). THI is widely used in hot areas all over the world and is commonly used as a practical indicator for the degree of stress on dairy cattle caused by weather conditions (Hahn and Mader, 1997). Different temperature and humidity Index equations have been developed by various previous workers to describe the severity of heat stress (e.g. Bianca, 1965; Johnson, 1965; Yousef, 1965; Kibler, 1964; NRC, 1971; Mader *et al.*, 2006; Bohmanova *et al.*, 2007). Those equations which place more weight on the humidity work better in humid climates, whereas in drier climates, those which place more weight on the temperature work best (Bohmanova *et al.*, 2007).

Cows are homoeothermic animals, so they exhibit optimum performance in their neutral environment which is known as thermo-neutral zone (TNZ). For lactating dairy cows from European breeds, this TNZ ranges between 5 and 25°C, (lower critical temperature (LCT) and upper critical temperature (UCT) respectively)(Armstrong, 1994). When THI is less than 72 corresponding to temperatures between -5°C to 25°C, within which they maintained a physiological body temperature of 38.4-39.1°C, the animal is most comfortable. Heat stress in dairy cows occurs when the THI index is higher than 72 (Armstrong 1994; Ravagnolo and Misztal, 2000; Bohmanova *et al.*, 2007; Dikmen and Hansen, 2009; Espinoza *et al.*, 2009) although mild heat stress has been noted for THI as low as 68 (Howden and Turnpenny 1997; Silanikove, 2000; Verkerk, 2009) and When THI>72, milk yield and feed intake start to decline (Bouraoui *et al.*, 2002; Herbut *et al.*, 2012), a causal relationship between THI and body temperature, which leads to increased cattle mortality with increasing THI: most cattle deaths in summer are heat stress related (Verwoerd *et al.* 2006). Their calf rates are also affected (Leonel, 2012). When it exceeds 78, cows' milk production is seriously affected and when the THI rises above 82, very significant losses in milk production are likely, cows show signs of severe stress and may ultimately die (Leonel, 2012). While THI values greater than 80 indicate moderate to severe heat stress for cattle (Armstrong, 1994; Howden and Turnpenny, 1997; Silanikove, 2000; Bohmanova *et al.*, 2007; Verkerk, 2009). According to West (1999), Mader *et al.* (2006), and Vitali *et al.* (2009), the number of heat related deaths on dairy farms begins to increase when THI values are above 70 and risk of death is greatest above a THI of 77. Whilst THI values of 70 or less

considered to be comfortable, 72 to 78 as mild, 78 to 88 as moderate and above 88 extremely stressful and animals are unable to maintain normal body temperature (Wiersma and Armstrong, 1989). Upadhyay and Singh (2009) reported that when THI crosses the index value of 72, it influenced milk production negatively in both lactating Karan Fries and Sahiwal cows at different levels. The average milk production of lactating Karan Fries and Sahiwal animals was 13.4 and 6.6 liters/day at around THI of 72, which reduced to around 9 and 5 liters/day, respectively at around THI of 82. Bryant *et al.* (2007) found that the onset of the effects of heat stress in New Zealand cattle occurred at lower THI values than in the USA. Further concerns regarding THI thresholds arise from the continued genetic selection of cattle for milk yield. It has been suggested that the onset of heat-stress for modern Holstein cattle is at a lower threshold than those in earlier studies, perhaps as low as 65–69 (Bouraoui *et al.*, 2002, Bryant *et al.*, 2007, Zimelman *et al.*, 2009). The difference between temperature and relative humidity inside and outside cattle barns changes with the seasons, and also depends on the barns' construction (Seedorf *et al.*, 1998). In general, the temperature is higher indoors (3–5 °C for northern Europe), but the relative humidity varies, depending on the external temperature (Seedorf *et al.*, 1998, Erbez *et al.*, 2010). The resulting effect on THI is therefore complex, but it is on the whole higher indoors than outdoors.

Studies have shown that cattle prefer shade to sprinklers when outdoors despite other benefits of sprinklers (e.g. reducing the annoyance by insects, Schütz *et al.*, 2011).

### **2.9.3. Adjusted temperature and humidity index (THI<sub>adj</sub>)**

Normal/basic THI does not account for the effects of wind speed and solar radiation. However, Mader *et al.* (2006) extended the THI to include wind speed and solar radiation, to improve its effectiveness. Solar radiation can greatly influence heat load while changes in wind speed result in altered convective cooling. Both solar radiation and wind speed alter the ability of the animal to maintain thermal balance. They would also greatly improve the applicability of the LWSI under varying environmental conditions. LWSI (The Livestock Weather Safety Index) has taken into account the wind speed and the solar radiation since 1970 and it was first used by the US National Weather Service. Mader (2006) studied on wind speed and solar radiation corrections for the temperature-humidity index and reported Adjustments in THI based on daily averages were for each 1 m/s increase in WSPD, THI would be

reduced 3.14 units, and for each 100 W/m<sup>2</sup> decrease in RAD, THI would be reduced 1.49 units.

$$\text{THI}_{\text{adj}} = 4.51 + \text{THI} - (1.922 \times \text{WS}) + (0.0068 \times \text{SR}) \text{ [Mader } et al., 2006]$$

Where,  $\text{THI}_{\text{adj}}$ : Adjusted Temperature Humidity Index; WS: Wind speed (m/s); SR: Intensity of Solar Radiation (w/m<sup>2</sup>)

The formula can be applied for various conditions to be found in cow husbandry in pastures, including under sheds or shed roofs, near lines of shade-providing trees in open fields and in unprotected open areas exposed to direct sunlight (Mader *et al.*, 2006).  $\text{THI}_{\text{adj}}$  also takes into account biological differences among cows, including breed and coat color.  $\text{THI}_{\text{adj}}$  assumes a lower limit for the occurrence of heat stress as 74, while values from 75 to 78 indicate the alert stage, from 79 to 83 danger conditions, and >84 emergency conditions (Mader *et al.*, 2006; Hahn *et al.*, 2009; Arias and Mader, 2010).

#### **2.9.4. Effects of heat stress on performance traits**

##### **2.9.4.1. Effects on growth traits**

Lacetera *et al.*, 1994 reported that exposure to a hot environment may negatively affect growth of young calves. They found lower wither height, oblique trunk length, hip width (-35, -26, -29% respectively) and body condition score (0.0 vs +0.4 points) in six 5-month-old female Holstein Friesian calves exposed to hot conditions as compared with a control group (the corresponding six sisters of six pairs of twins), kept under thermo-neutrality conditions. Temperatures between 15–29°C do not seem to exert any influence on growth performance. Temperature above 30°C adverse effects was recorded in daily weight gain. Under high ambient air temperature and solar radiation, steers reduce daily dry matter intake, hence average daily gain and carcass weight fall down, fat thickness drops (Mitlohner *et al.*, 2002).

##### **2.9.4.2. Effects on reproduction traits**

Heat stress has adverse effects on reproduction of dairy cattle (Kadzere *et al.*, 2002; West, 2003; Verwoerd *et al.*, 2006; Hansen, 2007) and conception and mortality rates (Hahn, 1999; Dikmen and Hansen, 2008). Heat stress does not prevent the occurrence of normal estrus cycles. It does, however, amplify the problem of heat detection by reducing the length of the estrus period, from 18 hours down to about 10 hours, and lowering the intensity of estrus behavior (Shearer and Beede, 1990). Heat stress compromises oocyte growth in cows by altering progesterone, luteinizing hormone and follicle-stimulating hormone secretions during the oestrus cycle (Ronchi

*et al.*, 2001), as well as impairing embryo development and increasing embryo mortality (Wolfenson *et al.*, 2000). Moreover, heat stress may reduce the fertility of dairy cows in summer by poor expression of oestrus due to a reduced estradiol secretion from a dominant follicle developed in a low luteinizing hormone environment (De Rensis and Scaramuzzi, 2003). About a 20-27% drop in conception rates (Lucy, 2002) or decrease in 90-day nonreturn rate to the first service in lactating dairy cows (Al-Katanani *et al.*, 1999) can occur in summer. In these situations the calving interval is longer, the birth rate is lower and farm milk yield per year can be reduced. Heat stress during pregnancy slows down growth of the fetus, although active mechanisms attenuate excursions in fetal body temperatures when mothers are thermally stressed. There are a number of changes in reproductive performance (decreased foetal growth and calf size, increased risk of early embryonic deaths and increased number of AI per conception) that have been reported (Upadhyay and Singh, 2009). Besides, heat stress has been also associated with deterioration of embryo development and increased embryo loss in cattle (Hansen, 2007). It also affected testicular volume, hormonal profiles, sexual behavior and semen quality that affect the reproductive performance of males (Calvosa *et al.*, 2009).

#### **2.9.4.3. Effects on milk production traits**

Heat stress has adverse effects on milk production and reproduction of dairy cattle (Kazdere *et al.*, 2002; West, 2003; Verwoerd *et al.*, 2006; Hansen, 2007). Reduced performances under heat and cold stress are due to associated effects on thermal regulation, energy balance, water balance and endocrine changes among other factors. Reduced milk yield under heat stress is caused by associated effects on thermal regulation, energy balance and endocrine changes (Yousef, 1985; Ominski *et al.*, 2002) and reported a decrease of 4.8 % in milk production when cows were exposed to heat stress compared to their milk production in the thermo neutral zone. Bouraoui *et al.*, 2002 reported that for every degree above temperature humidity index of 69 in dairy cattle a 0.4 kg decrease of milk production. Berman (2005) estimated that effective environmental heat loads above 35°C activated the stress response system in lactating dairy cows

Milk yield reductions of 10 to 40% have been reported for Holstein cows during summer as compared to winter (Broucek *et al.*, 2009). Brügemann *et al.* (2012) indicated a milk yield decline between 0.08 and 0.26 kg for every increase in THI unit in Germany. When the THI value increased from 68 to 78, milk production was

reduced by 21% and dry matter intake was reduced by 9.6% (Bouraoui *et al.*, 2002). Könyves *et al.* (2017) did his study on relationship of temperature and humidity index with milk production and feed intake of Holstein-Friesian cows in different year seasons and found that heat stress reduced daily milk yield by 1.32 kg or 9.46%, by 0.92 kg or 9.62% and by 1.27 kg or 9.48% as the THI values went from 64 in the spring, from 66 in the autumn and from 42.34 in the winter periods to 79 in the summer period. A study by Robert *et al.* (2014) on analysis of heat stress in UK dairy cattle and impact on milk yields indicated that the number of days where the THI exceeds this threshold ( $>70$ ) could increase to over 20 days  $\text{yr}^{-1}$  in southern parts of England by the end of the century. Forough *et al.* (2018) did study on effect of the temperature and humidity index and lactation stage on milk production traits and somatic cell score of dairy cows in Iran and found that greatest milk yields were recorded in  $\text{THI} \leq 60$  ( $P < 0.05$ ). The highest decrease in milk yield in connection with THI values were recorded in the early lactation (0 to 100 DIM). SCS was positively associated with the THI and increased more in early period of lactation.

#### **2.9.5. Economic losses from heat stress**

Heat stress causes severe economic loss in approximately up to 45%-60% of the dairy farms incomes around the world (Bernabucci *et al.*, 2010; Prathap, *et al.*, 2017). The reduction of productive performance in cattle with devastating economic consequences to the global dairy industry due to warm environment has been documented by researchers (St-Pierre *et al.*, 2003; Bernabucci *et al.*, 2010). They have estimated a total economic loss incurred by the US livestock sector due to heat stress at between 1.69 and 2.36 billion US\$. About 45%-60% of this loss observed in the dairy industry [\$897 million], 20% in the beef industry [\$369 million], 15% in pigs (\$299 million) and the remaining 7% (\$128 million) in the poultry industry (Bernabucci *et al.*, 2010; Prathap, *et al.*, 2017). Upadhyay and Singh (2009) reported that the annual total milk loss due to thermal stress at the all-India level was 1.8 million tons or approximately 2% of the total milk production of the country amounting to a whopping Rs. 2661.62 crores per year. The negative impact of global warming on total milk production in India is also estimated to about 3.2 million tons by 2020 and more than 15 million tons by 2050. Study showed that without heat abatement (minimum intensity), total losses across animal classes averaged \$2.4 billion annually. However by 2050, an estimated nine billion people will live on the

planet and in order to feed the planet, we will need to increase food production dramatically.

### **2.9.6. Heat stress reduction measures**

Heat stress mitigation measures were identified and documented (Armstrong, 1994; Silanikove, 2000; Chandra *et al.*, 2015; Amaral-Phillips, 2016). Commonly used heat stress reduction strategies included modification of the physical environment, breeding for heat-tolerant dairy cattle, nutrition management and timed artificial insemination (TAI) protocol (Armstrong 1994; Silanikove, 2000). Herd's physical environment management (introduction of shaded areas under which cows can graze via the retention of trees in paddocks and the planting of shelter belts and housing in pens in which they are exposed to evaporative cooling and spray and/or fan cooling (Ghosh *et al.*, 2017). Breeding for heat-tolerant: this is a long-term strategy that uses heat-tolerant breeds such as indigenous, (Sahiwal), Senepol and Carona for breeding. Nutrition management is supplying high energy feeds along with bypass protein and ration with >18% protein, low fiber and vitamins C, E and A and mineral such as zinc (Amaral-Phillips, 2016). Scientific literature provides a number of clear examples where the availability of shade for cattle can significantly reduce their heat load largely by reducing the solar radiation they receive (Armstrong, 1994; Kendall *et al.*, 2006; Fisher *et al.*, 2008). The scientific literature that monitors animal behavior also reports that cows with access to shade begin to preferentially use it when air temperatures rise above 25°C or when THI is above 73, and that uptake increases exponentially as air temperature increases (Kendall *et al.*, 2006). Ghosh *et al.* (2017) did a study on the efficacy of shading and spraying to alleviate heat stress and found that the shade the structure proved to be more successful at reducing moderate and severe heat stress occurrence than spray treatment. There were 53% fewer moderate and 86% fewer severe heat stress events with the shade treatment. The spray treatment proved effective at reducing only the number of severe heat stress events. During the 182 day period, 46% fewer severe heat stress events were measured for the spray treatment. For low susceptibility herds, simulated milk loss was 67% lower for the shade treatment and only 20% lower in the spray treatment.

## CHAPTER III

### MATERIALS AND METHODS

#### 3.1. Sources of Data

The study used the performance data on crossbred cattle which were collected from growth, daily milk yield, calving, drying/production, reproduction and stock registries maintained at Directorate of Livestock Farms (DLF), Guru Angad Dev Veterinary and Animal Sciences University (GADVASU), Ludhiana whereas the meteorological data were obtained from School of Climate Change and Agricultural Meteorology, Punjab Agricultural University (PAU), Ludhiana.

#### 3.2. Characterization of Research Location

The current study was performed on crossbred cattle at DLF of GADVASU in Ludhiana, India covering on twenty eight years (1991 to 2018) of performance data. Ludhiana is located at 30.9°N 75.85°E. It has an average elevation of 244 meters (798 ft) meters above mean sea level (m.a.s.l). It features a humid sub-tropical climate under the Köppen climate classification, with three defined seasons; summer (March to June), monsoon (July to September) and winter (October to February). The average high and low temperatures of the area were 29.8°C and 16.7°C, respectively whereas the average maximum and minimum relative humidity were 82% and 46%, respectively. The district received annual average precipitation of 890 mm (35 in) (Prabhiyot-Kaur *et al.*, 2013).

#### 3.3. History and Breeding Program of Herd

DLF of GADVASU was established since 1968 aimed to improve the performances of Sahiwal breed via crossbreeding program under the Dairy Cattle Breeding Project. The genetic improvement of the breed was begun by crossing of Red Dane bulls with Sahiwal cows at the PAU, in now GADVASU (Inaugurated since 2006), Ludhiana. Initially the two-breed crossbreds consisting of 50% Red Dane and 50% Sahiwal (RS) were produced by mating Sahiwal cows with Red Dane bulls. The RS cows were further crossed with Holstein-Friesian via artificial insemination (AI) to produce three-breed crossbreds with 50% Holstein-Friesian, 25% Red Dane and 25% Sahiwal germ plasm (HRS). Later on the breeding programme was modified to concentrate on Holstein-Friesian crossbreds and the use of Red Dane breed was discontinued in the mating plan.

Two-breed crosses possessing 50% Holstein-Friesian and 50% Sahiwal inheritance (HS) were produced which were again inseminated with semen of Holstein-Friesian bulls to produce crossbreds with 75% HF and 25% S germ plasm (HHS) followed by selection and interse mating in the subsequent generations. The same method of breeding has been used till to date. The crossbred cows in elite group were mated to top ranked sires and their male progenies were reared as future young sires whereas their female progenies were kept as replacement heifers. Selection was made among the heifers on the basis of their dam milk production performance, growth and health condition. Similarly the male crossbred calves for future AI use was initially selected based on dam milk yield and reproduction performances. They were then evaluated on their own growth performances over the series of age, health, libido, semen quality and its free-ability. Being satisfactory for these pre-settled selection criteria, they were transferred for progeny testing program. At the age of 18 months, the young breeding bulls were used for semen collection and thereby used to further evaluation in the progeny testing stations/villages. The AI was often practiced for breeding of crossbred cows following proper detection of estrous signs. Estrus detection was done by parading the vasectomized bull and through observing of the signs exhibited by the animals in the heat.

These days, the DLF farm has served as center for education, research and extension. It has been also one of the key actors in the dairy livestock development of Punjab State of India. According to GADVASU (2016-17), the farm accommodated modern barn, feed processing plant, identification and recording unit, bull station with semen laboratory, milking parlor with installed milking machine, office and other facilities. It supplied crossbred calves and many doses of crossbred chilled and frozen semen to gaushalas, farmers and other dairy development agencies of the state. It is also demonstration site for improved livestock technology and undertook field progeny testing program of All India Coordinated Research Project (AICRP) in order to improve milk production as well as age at first calving. The program was the highest among all Field Progeny Testing (FPT) centers in the country for crossbred cattle. In the DLF farm, there were 173 crossbred cattle and 14 Sahiwal cattle. In the farm, a crossbred cow that produce the average 305 days lactation milk yield and daily peak milk yield of 10,493 kg and 54.30 kg (FC1133), respectively (GADVASU Annual Reports, 2016-17).



III. 1. Sahiwal cattle in Directorate of Livestock Farm



III. 2. Crossbred cows (Sahiwal×HF) in Directorate of Livestock Farm



III. 3. Directorate of Livestock Farm

### **3.4. Breeding Stock under the Research**

The breeding stocks under the research were crossbred cows, consisting of four genetic groups namely, HRS, HS, HHS and different upgrade generations, maintained at DLF, GADVASU, Ludhiana.

### **3.5. Herd Management Practices**

The animals were housed under loose housing system with some covered parts. Each age category of animals (calves up to four month of age, calves over four month up to one year, heifers from 1 to 2 years of age, breeding heifers, pregnant heifers, dry cows and cows in milk) were provided with separate sheds. The animals in the category were kept in groups in loose housing system; but male calves were housed separately in individual bull beds. The advanced pregnant animals were segregated to the calving pens at least eight weeks before the expected date of calving. The cows in the 3rd trimesters were subjected to adequate exercises which help in lighting the uterine muscles and ease of parturition in the exercise yard. The freshly calved cattle were kept in calving line for one week after which the animals with normal calving are shifted to the milking herd. The calves were separately maintained in individual calf pens having adequate protection from adverse weather conditions, usually up to four month of age; thereby they were made to shift into loose housing system.

#### **3.5.1. Feeds and feeding management practices**

The sources of feed were generally two in kind, namely roughage and concentrate. The animals in the farm were having free access to roughage feed and water. Feeding of the animals depended on the age and physiological status. They were fed ration containing all the nutrients required for meeting both maintenance and production requirements of their body. Sudden changes in the diet were properly controlled. Maintenance ration was fed to the animals in the morning hours once in a day while the production ration containing enough mineral matters were supplied to the milking crossbred cows at the time of milking.

##### **3.5.1.1. Feed resources**

The common and frequently used feed resources for feeding animals in the farm included berseem, oats, jowar, bajra, maize, makchari and wheat straw; however availability of some feed resource depended on season variation.

Berseem and oats were fed to animals during the Rabi season whereas jowar, bajra, makchari and maize during kharif season given as green fodder and wheat straw were

given as dry fodder. During kharif season, silage has been prepared from jowar, bajra and maize and oats in rabi season was fed to animals in the periods of lean fodder production. Under cereal brans, wheat bran was considered as the best. Sugar beet pulp could be stored as silage by adding wheat straw at 5% or wheat straw along with acidic additives as feed sources.

#### **3.5.1.2. Calf feeding practices**

Proper identification and recording system was applied to calves immediately after birth using ear tag applicator. The calves were weaned immediately just post birth and the correct feeding were followed by periodic weighting of calves. They were fed on colostrum for the first five days and thereby they were fed with milk. After fifth days of post calving, clean wholesome and warmed milk were conferred to the calves till three months of age. The milk was warmed at calf body temperature level (38 °c). The amounts of milk offered were controlled not to exceed beyond 1/10<sup>th</sup> of calf body weight so as to avoid scour problem. When the calf got old, the amount milk supplied was gradually reduced till to 1/40<sup>th</sup> of the live body weight of the calf. The calves were regularly weighed in monthly interval. The green fodder and calf starter consisting of grains, cakes, brans (rice/wheat), bypass protein and mineral mixture were offered from one month of age onward.

#### **3.5.1.3. Heifer feeding practices**

The feeding strategy of heifers was targeted to make heifers reaching age at first maturity/service as early as possible, so that they calve early. Breeding of heifers have to be decided on the basis of their body sizes rather than their ages. The heifers were bred when they attained 60% of their mature body weight. Much care were given due attentions to the feeding of heifers weaned in summer season as they might grow poorly and even loose weight during this period largely due to fall in status of feeding.

#### **3.5.1.4. Pregnant, lactating and dry cow feeding practices**

During late pregnancy stage, the cows were experienced with challenge feeding/steaming-up feeding. Challenge feeding were started two weeks before the expected date of calving.

Cows with high milk production potentials were fed increasing quantity of concentrates to challenge them in order to produce the maximum level of milk. Challenge feeding was started with 500 gm of concentrate mixture with daily increase

this amount by 300-400 gm unit until the cow consumed 500-1000 gm concentrate for every 100 Kg body weight.

At the time of early milking, production ration was given to the milking cows. Concentrate ration (crude protein (CP) =18% and Total digestible nutrient (TDN) 70%) was formulated using cereals, cakes, brans, mineral mixture, salt and additives depending upon season and physiological status of animal. A let down ration of 0.5 kg of concentrate was provided at the time of milking and additional concentrate was offered at the rate of 0.5 kg for every 1 kg milk yield to meet the requirements of milk production. The concentrates were feed in divided allowance during two times of milking. In high producing crossbred dairy cows, the supplementation of bypass fat (200 g/day) along with 12 g niacin could be used to improve production and health. In mid and late lactation, the cows would be fed a well-balanced ration of good quality fodders and concentrates according to milk yield and fat % of milk. From 7 and one half months to 10 months of lactation, the cows were offered with 1-2 kg of concentrate feeds in addition to their maintenance and production requirements to replenish the body condition they lost in the early lactation whilst feeding of the dry cows were depends on the body conditions of them. Concentrate feeding during the dry period has partially relied on the body condition of the cows at the time of drying off. Cows in the poor condition at drying off were supplied additional concentrates.

### **3.5.2. Health management practices**

Animals of both sex and all age group in the herd of the farm were regularly vaccinated against common diseases of the area. They were also dewormed strategically three times a year against gastro-intestinal parasites and sprayed for exo-parasites when necessary. Similarly the animals were cared against milk fever, mastitis diseases and other diseases. Vaccination and Deworming Program Schedule of the Herd were presented in table 22.

**Table 22. Vaccination and deworming program schedules for crossbred cattle**

Vaccination schedule					
S.No.	Name of vaccines	Age categories	Diseases	Interval	Months
1	Foot and Mouth Disease	2 months and 6 months	Foot & Mouth	6 months	May & Nov
2	Hemorrhagic Septicemia	Above 5 months	Hemorrhagic Septicemia	Annually	Apr, Aug & Dec
3	Black Quarter	Above 6 months	Black Quarter	6 months	July
4	Brucellosis (female)				
4.1	Calf hood vaccine	Calf	Brucellosis		
4.2	Adult Vaccine	4-9 months once only when abortion rate is high	Brucellosis	It can be repeated after 1 or 2 calving	Feb, June & Oct
Deworming schedule					
S.No.	Months of Deworming	Medicines used on Deworming			
1	March to April	Fenbendazole			
2	June –July	Ivermectin and Closantel			
	October to November	Fenbendazole			

### 3.5.3. Milking management practices

Regular milking time schedule were followed. The crossbred cows were milked twice a day in regular interval. Times for morning milking were 4:30 AM-7:00 PM for winter season and 3:30 AM-7:00 PM for summer season whereas time for afternoon milking was 3:30 PM-7:00 PM. Some high yielding cows were milked three times a day, i.e 4:30 AM-7:00 PM for morning milking, 10:30 AM for midday milking (for only elite crossbred cows) and 3:30 PM-7:00 PM for evening milking. Both machine and manual milking system have been used for milking of crossbred cows depending upon yields of cows and adaptation by individual cow to machine milking. The manual milking often practiced have been full hand methods while the machine milking has been performed using DELAVAL. The milk yield is weighed at each milking and recorded separately for each cow.

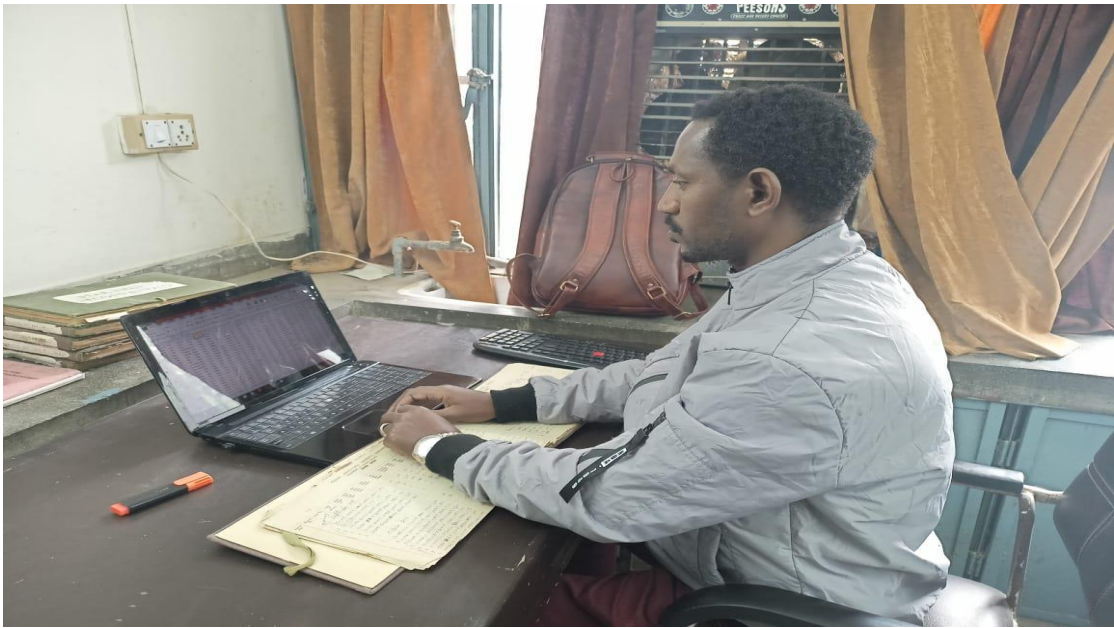
### 3.6. Data Collection

The performance data on crossbred cows were collected from registered sheets handled in DLF Farm of GADVASU covering over 28 years (1991-2018).

The general information gathered on pertaining for identification and classification, and traits studied and recorded under the study were presented as follow.



III. 4. Dairy cattle loose house/barn



III. 5. Researcher while collecting data from different cattle registries

**General information:**

1. Animal Number
2. Date of Birth
3. Sire Number
4. Dam Number
5. Date of Calving
6. Lactation Order
7. Date of drying off
8. Records of growth
9. Records on calving, milk production and reproduction

**Growth performance traits:**

1. Birth Weight (BW0)
2. Body Weight at 30 days (BW30)
3. Body Weight at 60 days (BW60)
4. Body Weight at 90 days (BW90)
5. Body Weight at 120 days (BW120)
6. Body Weight at 150 days (BW150)
7. Body Weight at 180 days (BW180)
8. Body Weight at 270 days (BW270)
9. Body Weight at 365 days (BW365)
10. Body Weight at 450 days (BW450)
11. Body Weight at 540 days (BW540)

**Reproduction performance traits:**

1. Age at first Service (AFS)
2. Age at first Calving (AFC)
3. Weight at first calving (WFC)
4. Number of Service per conception (NSPC)
5. Pregnancy Period (PP)
6. Service period (SP)
7. Calving Interval (CI)

**Milk production performance traits:**

1. Daily milk yield (DMY)
2. 305 days' milk yield (305\_DMY)
3. Total lactation milk yield (LMY)
4. Lactation Length (LL)
5. Peak yield (PY)
6. Days to Peak Yield (DPY)
7. Dry Period (DP)

**Meteorological factors:**

1. Temperature (Temp) (°c)
2. Relative Humidity (RH) (%)
3. Wind Speed (WS)(m/s)
4. Sunshine (Hr)

**Meteorological factors generated:**

1. Temperature and Humidity Index (THI)
2. Adjusted Temperature and Humidity Index (THIadj)
3. Solar Radiation (SR)

### 3.7. Defining of Performance Traits under the Research

Performance traits of crossbred cows were operationally defined as per the objectives of this study as specified in table 32.

**Table 23. Descriptions of performance traits and meteorological factors**

S.No.	Performance traits and meteorological factors	Descriptions
1	Age at first service	was recorded as the difference in days between date of birth and date of first estrus manifestation and AI service
2.	Age at first calving	The interval in numbers of days from date of birth to date of first calving.
3	Weight at age first calving	The body weight (Kg) of cows measured and recorded immediately post first calving.
4	Service Period	The period in days between dates of calving to successful AI. It was calculated as CI-PP.
5	Number of service per conception	The numbers of AI services used to achieve successful conception
6	Pregnancy Period	The interval in numbers of days between successful AI to date of calving. It was computed as CI-SP
7	Calving Interval	Differences in numbers of days between two successive calvings for all cows with more than one parity.
8	Daily Milk Yield	Quantity of milk (Kg) recorded in a day per head of cow
9	Lactation Length	The interval in numbers of days for which the cow is in milk which vary from date of calving to the cow dries off.
10	305_Days Lactation Milk Yield	The amount of milk (Kg) recorded per cow in 305 days lactation.
11	Lactation Milk Yield	The total quantity of milk (kg) produced per a cow in a complete lactation that ranges from date of calving to the cow dries off
12	Dry Period	The differences in numbers of days between date of termination of milking and date of calving of the next calf.
13	Peak Yield	The highest quantity of milk (Kg) recorded per cow on a given day in the lactation.
14	Days to attend peak yield	The numbers of days the cows are in peak milk production over the lactation.
15	Persistency	The degree with which the milk yield is maintained after reaching peak, during decline phase of lactation
16	Growth records	The different body weight measurements of calves taken and recorded over series of ages
17	Dry bulb temperature	It is measured by thermometer exposed to air but shielded from radiation and moisture. This indicates the amount of heat in the air.

### 3.8. Data Structure

Performance data consisted of 1735 lactations/calvings of 765 crossbred cows born between 1985 and 2016 and which were daughters of 125 sires and 537 dams and born during the twenty two years period (1985-2016) were used for the study (Fig. 1), whereas 12444 daily meteorological records pertaining for Temp (°C), Hum (%), SR (w/m<sup>2</sup>), and WS (m/s) distributed over the entire study period (1985 to 2018) were used. The average and range of number of daughters per sire in the unadjusted dataset were 13.88 and 1-62, respectively.

Table 24. Number of sires, dams and progenies across genetic groups

Genetic Group	Sires	Dams	Progenies
GG1 (50% H, 25% R, 25% S)	15	78	129
GG2 (50% H, 50% S)	63	237	331
GG3 (75% H, 25% S)	11	30	49
GG4 (Grades (1F, 2F ...and 7F)	36	192	256
Total	125	537	765

### 3.9. Editing and Standardization of Data

Crossbred cows with unknown pedigree, incomplete lactation and abnormal calving records (abortion, premature birth, still birth, and delayed calving) were excluded from the present study. Sick, soled/auction, culled and dead animal performance records were not also considered. Animals used for embryo transfer were similarly excluded from the study. For the study, only those crossbred cows which had at least 200days lactation lengths and produced greater than 1000 Kg lactation milk yield were retained. The records of the cows with known pedigree were used for analysis. For normalization of data of performance traits, mean±2SD were employed.

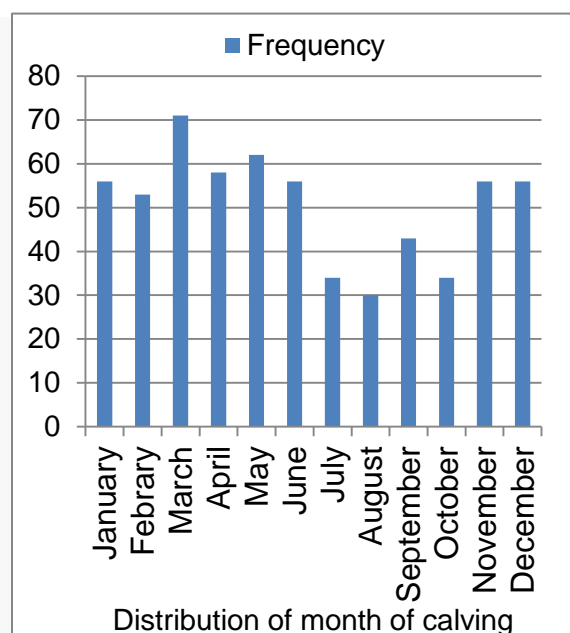
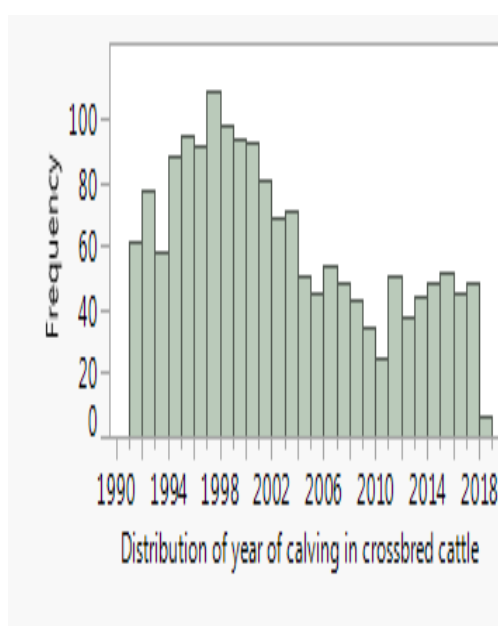
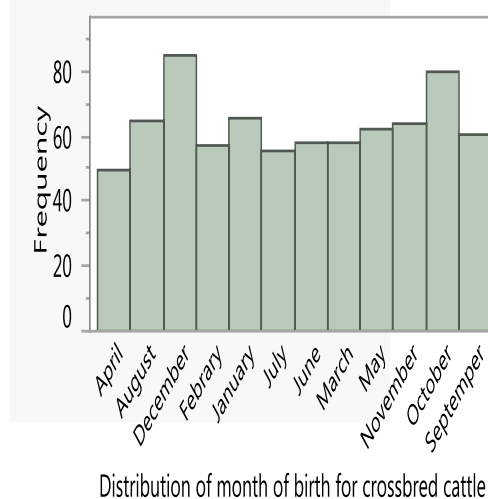
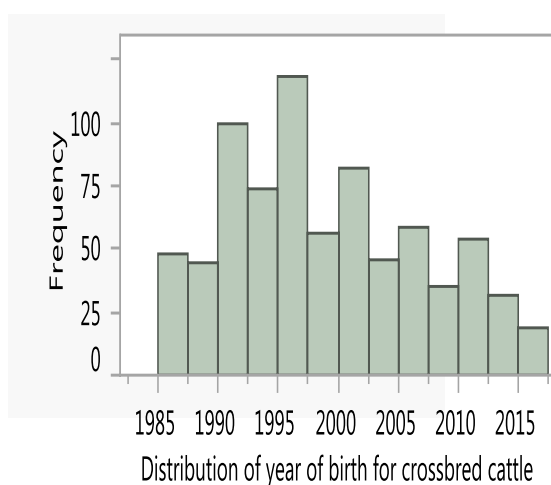
### 3.10. Classification of Data

#### 3.10.1. Classification of month of birth and month of calving

The entire performance data distributed over the study periods were classified and coded according to month of birth and month of calving (table 25). This classification was made since the values of THI and other climate variables have varied across the different months in the study place.

**Table 25. Classification of months of birth (MOB) and calving (MOC)**

S.No.	Month of birth	Code	Month of calving	Code
1	January	MOB1	January	MOC1
2	February	MOB2	February	MOC2
3	March	MOB3	March	MOC3
4	April	MOB4	April	MOC4
5	May	MOB5	May	MOC5
6	June	MOB6	June	MOC6
7	July	MOB7	July	MOC7
8	August	MOB8	August	MOC8
9	September	MOB9	September	MOC9
10	October	MOB10	October	MOC10
11	November	MOB11	November	MOC11
12	December	MOB12	December	MOC12



**Fig. 1. Distribution of datasets of months and years of birth/calving in the crossbred cattle**

### 3.10.2. Classification of periods of birth and period of calving

The performance data distributed across the whole study years (1985 to 2018) were classified according to period of birth and period of calving to assess the trends of performances on crossbred cows (table 26) as modification of management practices in the farm might occur over a period of four to five.

**Table 26. Classification of periods of birth and calving**

S.No.	Period of birth	Code	Period of calving	Code
1	Before 1989	POB1	1991-1994	POC1
2	1989-1992	POB2	1995-1998	POC2
3	1993-1996	POB3	1999-2002	POC3
4	1997-2000	POB4	2003-2006	POC4
5	2001-2004	POB5	2007-2010	POC5
6	2005-2008	POB6	2011-2014	POC6
7	2009-2012	POB7	2015-2018	POC7
8	2013-2016	POB8		

### 3.10.3. Classification of age at calving and weight at calving

The age at calving and weight at calving of crossbred cows under the study were classified into different groups depend upon Sturges's Formula (Sturges's, 1962) after normalizing the distributions of their observations using mean±2SD (table 27).

$$\text{Sturge's Formula} = \frac{\text{Max.Value} - \text{Min.Value}}{1 + 3.322 \log_{10} N}$$

**Table 147. Classification of age and weight at calving**

S.No.	Age at calving (Days)	Code	Weights at calving (Kg)	Code
1	<903	AAC1	<327	WAC1
2	903-1181	AAC2	327-363	WAC2
3	1182-1460	AAC3	364-400	WAC3
4	1461-1739	AAC4	401-437	WAC4
5	1740-2018	AAC5	438-474	WAC5
6	2019-2297	AAC6	475-511	WAC6
7	2298-2576	AAC7	512-548	WAC7
8	2577-2855	AAC8	549-585	WAC8
9	2856-3134	AAC9	>585	WAC9
10	>3134	AAC 10		

### 3.10.4. Classification of genetic groups

The whole performance data of the study were classified in different genetic groups based on the types of inheritances the animal composed of in order to evaluate the differences among them (table 28).

**Table 158. Classification of genetic group of cow**

S.No.	Genetic group (GG)	Blood inheritance	Remark
1	GG1	50%H, 25%R, 25%S	
2	GG2	50%H, 50%S	
3	GG3	75%H, 25%S	
4	GG4	Grades (1F, 2F ...and 7F)	Produced by interse mating

**3.10.5. Classification of seasons of birth and season of calving**

The seasons of birth and calving were classified into different seasons depending upon month of birth and month of calving (table 29).

**Table 29. Classification of season of birth and calving**

S.No.	Seasons of birth	Code	Season of calving	Code	Month
1	Winter	SOB1	Winter	SOC1	Nov-Jan
2	Spring	SOB2	Spring	SOC2	Feb-March
3	Summer	SOB3	Summer	SOC3	Apr-Jun
4	Rainy	SOB4	Rainy	SOC4	Jul-Aug
5	Autumn	SOB5	Autumn	SOC5	Sep-Oct

**3.10.6. Classification of temperature, humidity, solar radiation, temperature and humidity index (THI) and adjusted THI**

The temperature ( $^{\circ}\text{C}$ ), humidity (%), solar radiation ( $\text{W}/\text{m}^2$ ), temperature and humidity index (THI), and adjusted THI data were classified into various groups using Sturges's Formula (Sturges's, 1962) according to range of variations within each climatological variable data to assess their effects on daily milk yields. The reasons for classification of Adjusted THI were because it included solar radiation and wind speed. Solar radiation can greatly influence heat load, while changes in wind speed result in altered convective cooling.

$$\text{Sturge's Formula} = \frac{\text{Max.Value} - \text{Min.Value}}{1 + 3.322 \log_{10} N}$$

**Table 30. Classification of temperature, humidity, solar adiation, temperature and humidity index and adjusted temperature and humidity index**

Temp (°C)	Code	RH (%)	Code	SR (w/m <sup>2</sup> )	Code	THI	Code	THIadj	Code
<7	Temp1	<26	RH1	<112	SR1	<45	THI1	<48	THIadj1
7-11	Temp2	26-35	RH2	112-152	SR2	45-50	THI2	48-53	THIadj 2
12-16	Temp3	36-45	RH3	153-193	SR3	51-56	THI3	54-59	THIadj 3
17-21	Temp4	46-55	RH4	194-234	SR4	57-62	THI4	60-65	THIadj 4
22-26	Temp5	56-65	RH5	235-275	SR5	63-68	THI5	66-71	THIadj 5
27-31	Temp6	66-75	RH6	276-316	SR6	69-74	THI6	72-77	THIadj 6
32-36	Temp7	76-85	RH7	317-357	SR7	75-80	THI7	78-83	THIadj 7
>36	Temp8	86-95	RH8	>357	SR8	81-86	THI8	84-89	THIadj 8
		>95	RH9		SR9	>86	THI9	>89	THIadj 9

### 3.11. Statistical Analysis

The statistical analysis was carried out by classifying the whole performance data into two sets. Data set one included data of all first lactation performance traits whereas data set two consisted of data of performance traits from all lactations. Therefore, data set one and two were separately analyzed.

#### 3.11.1. Descriptive statistical analysis

Descriptive Statistical Procedure (proc means) of SAS version 9.3 (2011) was applied to estimate descriptive statistics for data sets of first and all lactation performance traits and meteorological factors.

#### 3.11.2. Fixed and random effects analysis

Phenotypic data of both first and all lactation performance traits were analyzed using Multi-traits General Linear Model (MTGLM) Procedure of SAS version 9.3 (SAS institute Inc. 2011. Cary, NC, USA) to estimate the fixed and random effects; though the model components differed from traits to traits. When a main effect was a significant source of variation, levels from each main effect were separated using a Tukey-Kramer adjustment, whilst Microsoft Excel 2010 were used to depict the association of data of both first and all lactation performance traits with meteorological factors and the trends of changes in breeding values of crossbred sires for performance traits over time (year) graphically.

##### 3.11.2.1. Growth trait data analysis

The fitted model to analyze the effects of genetic and non-genetic factors on growth traits (BW0, BW90, BW180, BW270, BW365, BW450, and BW540) was:

$$Y_{ijklm} = \mu + GG_i + SOB_j + POB_k + S_l + e_{ijklm} \text{ (Model 1)}$$

Where

$Y_{ijklm}$  = Observations of  $m^{\text{th}}$  crossbred calve that is progeny of  $l^{\text{th}}$  sire in  $j^{\text{th}}$  season and  $k^{\text{th}}$  period with  $i^{\text{th}}$  genetic group;  $\mu$  = the overall population mean;  $GG_i$  = the fixed effect of the  $i^{\text{th}}$  genetic groups;  $SOB_j$  = the fixed effects of the  $j^{\text{th}}$  seasons of birth;  $POB_k$  = the fixed effects of the  $k^{\text{th}}$  periods of birth;  $S_l$  = the random effects of the  $l^{\text{th}}$  sire  $NID \sim (0, \sigma_e^2)$ ;  $e_{ijklm}$  = Random residual error, which is  $NID \sim (0, \sigma_e^2)$

### 3.11.2.2. Reproductive trait data analysis

Separate models were used to analyze first lactation and all lactation data of reproductive traits. Mixed model 2 was used to analyze data of reproductive traits (FLNSPC, FLPP, FLSP and FCI) from the first lactation.

$$Y_{ijklmnop} = \mu + POB_i + SOC_j + POC_k + GG_l + AAC_m + WAC_n + S_o + e_{ijklmnop} \text{ (Model 2)}$$

Where,

$Y_{ijklmnop}$  = the  $ijklmno^{\text{th}}$  Observations of crossbred cows;  $\mu$  = the overall population mean

$POB_i$  = the fixed effects of the  $i^{\text{th}}$  period of birth;  $SOC_j$  = the fixed effects of the  $j^{\text{th}}$  seasons of calving;  $POC_k$  = the fixed effects of the  $k^{\text{th}}$  periods of calving;  $GG_l$  = the fixed effect of the  $l^{\text{th}}$  genetic group;  $AAC_m$  = the fixed effect of the  $m^{\text{th}}$  age at calving;  $WAC_n$  = the fixed effect of the  $n^{\text{th}}$  weights at calving;  $S_o$  = the random effects of the  $o^{\text{th}}$  sire  $NID \sim (0, \sigma_e^2)$   $e_{ijklmnop}$  = Random residual error, which is  $NID \sim (0, \sigma_e^2)$ . It includes all the other effects not specified in the model of the analysis.

Whilst data of AFS, AFC and WFC was analyzed by applying model 3.

$$Y_{ijklm} = \mu + GG_i + SOB_j + POB_k + S_l + e_{ijklm} \text{ (Model 3)}$$

Where

$Y_{ijklm}$  = Observations of  $m^{\text{th}}$  crossbred cows that is progeny of  $l^{\text{th}}$  sire in  $j^{\text{th}}$  season and  $k^{\text{th}}$  period with  $i^{\text{th}}$  genetic group;  $\mu$  = the overall population mean;  $GG_i$  = the fixed effect of the  $i^{\text{th}}$  genetic groups;  $SOB_j$  = the fixed effects of the  $j^{\text{th}}$  seasons of birth;  $POB_k$  = the fixed effects of the  $k^{\text{th}}$  periods of birth;  $S_l$  = the random effects of the  $l^{\text{th}}$  sire  $NID \sim (0, \sigma_e^2)$ ;  $e_{ijklm}$  = Random residual error, which is  $NID \sim (0, \sigma_e^2)$

Data of reproduction traits from all lactations (ALNSPC, ALPP, ALSP and ALCI) were also analyzed for the effects included in Model 2.

### 3.11.2.3. Milk production trait data analysis

Separate models were also used to analyze first lactation data and data from all lactations. For analysis of data of milk production traits (FLMY, FL305\_DMY, FLL, FLDP, FLPY and FLDPY) from first lactation, the following models were employed.

$$Y_{ijklmnop} = \mu + POB_i + SOC_j + POC_k + GG_l + AAC_m + WAC_n + S_o + e_{ijklmnop} \text{ (Model 4)}$$

Where,

$Y_{ijklmnop}$  = the  $ijklmno$ <sup>th</sup> Observations of crossbred cows;  $\mu$  = the overall population mean;  $POB_i$  = the fixed effect of the  $i$ <sup>th</sup> Periods of birth;  $SOC_j$  = the fixed effects of the  $j$ <sup>th</sup> seasons of calving;  $POC_k$  = the fixed effects of the  $k$ <sup>th</sup> periods of calving;  $GG_l$  = the fixed effect of the  $l$ <sup>th</sup> genetic group;  $AAC_m$  = the fixed effect of the  $m$ <sup>th</sup> age at calving;  $WAC_n$  = the fixed effect of the  $n$ <sup>th</sup> weight at calving;  $S_o$  = the random effects of the  $o$ <sup>th</sup> sire  $NID \sim (0, \sigma^2_e)$ ;  $e_{ijklmnop}$  = Random residual error, which is  $NID \sim (0, \sigma^2_e)$ . Data of milk production traits of the whole lactations (ALMY, AL305\_DMY, ALL, ALDP, ALPY and ALDPY) were also analyzed for the effects included in Model 4.

### 3.11.3. Estimation of variance components for performance traits

Least-Square Analyses (Harvey, 1990) under the MTGLM Procedure of SAS Version 9.3 (2011) were first performed for both first and all lactation performance traits to identify significant sources of variation which would be considered for the genetic analysis and thereby fixed factors (main effects) were tested and sequentially rejected from the model, if found non-significant ( $P > 0.05$ ). Restricted Maximum Likelihood (REML) procedure of the same software under Univariate Mixed Model Equation (UMME) for first lactation performance traits whereas Univariate Repeatability Model (URM) with REML for data of performance traits from all lactations were involved to estimate (a) the components of variance (additive, permanent environmental (for only repeatable traits), and residual for each of the traits of the study); (b) genetic and phenotypic parameters once when using records of all the available lactations and another time when using records of the first lactation only. Moreover, sires which possessed of three and more than three daughters were incorporated for estimation of variance components and thereby genetic parameters.

Generally the fitted MME was  $Y = X\beta + Z_1\mu + e$  for data of first lactation performance traits whereas  $Y = X\beta + Z_1\mu + Z_2\alpha + e$  for data of performance traits from all available lactations. Where  $Y$  is the vector of observations on the different traits,  $\beta$  is the vector of fixed effects for all performance traits,  $\mu$  is the vector of direct additive genetic effects of sire,  $\alpha$  is the vector of permanent environmental effects

including non-additive genetics of cow,  $e$  is the vector of residual effects and  $X$ ,  $Z_1$ , and  $Z_2$  are incidence design matrices relating the fixed effects, direct additive genetic effects, and permanent environmental effects, respectively, to vector of  $Y$ . The residual effects are  $NID \sim (0, \sigma^2_e)$ .

### 3.11.3.1. Variance component analysis for growth traits

Model 5 was used for analysis of data of BW0, BW90, BW270, BW365, BW450 and BW540.

$$Y_{ijkl} = \mu + a_i + SOB_j + POB_k + e_{ijkl} \text{ (Model 5)}$$

Where,  $Y_{ijkl}$  = the  $ijkl^{\text{th}}$  observation,  $\mu$  general mean, common element to all observations,  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire,  $SOB_j$  = the fixed effect of the  $j^{\text{th}}$  seasons of birth,  $POB_k$  = the fixed effect of the  $k^{\text{th}}$  periods of birth,  $e_{ijkl}$  = random error particular to the  $ijkl^{\text{th}}$   $NID \sim (0, \sigma^2_e)$ . It includes all the other effects not specified in the model of analysis.

Model 6 was used for Analysis of data of BW180 trait.

$$Y_{ijk} = \mu + a_i + GG_j + e_{ijk} \text{ (Model 6)}$$

Where

$Y_{ijk}$  = the  $ijk^{\text{th}}$  observation,  $\mu$  general mean, common element to all observations,  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire,  $GG_k$  = the fixed effect of the  $k^{\text{th}}$  genetic groups,  $e_{ijk}$  = random error particular to the  $ijk^{\text{th}}$   $NID \sim (0, \sigma^2_e)$ .

### 3.11.3.2. Variance component analysis for reproductive traits

The following models were applied to estimate variance components for data of first lactation reproductive traits (AFS, AFC, WFC, FLNSPC, FLSP, FLPP and FCI).

Model 7 was applied for analysis of data of AFS and AFC:

$$Y_{ijk} = \mu + a_i + POB_j + e_{ijk} \text{ (Model 7)}$$

$Y_{ijk}$  = the  $ijk^{\text{th}}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $POB_j$  = the fixed effect of the  $j^{\text{th}}$  periods of birth;  $e_{ijk}$  = random error particular to the  $ijk^{\text{th}}$  observations which is  $NID \sim (0, \sigma^2_e)$ .

For data of WFC:

$$Y_{ijk} = \mu + a_i + SOB_j + e_{ijk} \text{ (Model 8)}$$

$Y_{ijk}$  = the  $ijk^{\text{th}}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $SOB_j$  = the fixed effect of the  $j^{\text{th}}$  seasons of birth;  $e_{ijk}$  = random error particular to the  $ijk^{\text{th}}$  observations which is  $NID \sim (0, \sigma^2_e)$ .

For data of FLNSPC, the model was:

$$Y_{ijkl} = \mu + a_i + \text{POC}_j + \text{GG}_k + e_{ijkl} \text{ (Model 9)}$$

$Y_{ijkl}$  = the  $ijkl^{\text{th}}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $\text{POC}_j$  = the fixed effect of the  $j^{\text{th}}$  Periods of calving;  $\text{GG}_k$  = the fixed effect of the  $k^{\text{th}}$  genetic groups;  $e_{ijkl}$  = random error particular to the  $ijkl^{\text{th}}$  observations which is  $\text{NID} \sim (0, \sigma^2 e)$ .

For data of FLSP and FCI, model 10 was used.

$$Y_{ijk} = \mu + a_i + \text{POC}_j + e_{ijk} \text{ (Model 10)}$$

$Y_{ijk}$  = the  $ijk^{\text{th}}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $\text{POC}_j$  = the fixed effect of the  $j^{\text{th}}$  periods of calving;  $e_{ijk}$  = random error particular to the  $ijk^{\text{th}}$  observations which is  $\text{NID} \sim (0, \sigma^2 e)$ .

For data of FLPP, the model was:

$$Y_{ijkl} = \mu + a_i + \text{GG}_j + \text{POB}_k + e_{ijkl} \text{ (Model 11)}$$

$Y_{ijkl}$  = the  $ijkl^{\text{th}}$  observations of crossbred cattle;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $\text{GG}_j$  = the fixed effect of the  $j^{\text{th}}$  genetic groups;  $\text{POB}_k$  = the fixed effect of the  $k^{\text{th}}$  periods of birth;  $e_{ijkl}$  = random error particular to the  $ijkl^{\text{th}}$  observations which is  $\text{NID} \sim (0, \sigma^2 e)$ .

The following URM's were employed for analysis of reproductive data of all lactations.

For data of ALNSPC, the model was:

$$Y_{ijklmno} = \mu + a_i + \text{PE}_j + \text{POC}_k + \text{GG}_l + \text{AAC}_m + \text{WAC}_n + e_{ijklmno} \text{ (Model 12)}$$

$Y_{ijklmno}$  = the  $ijklmno^{\text{th}}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $\text{PE}_j$  = random permanent environmental effect of the  $j^{\text{th}}$  cow;  $\text{POC}_k$  = the fixed effect of the  $k^{\text{th}}$  periods of calving;  $\text{GG}_l$  = the fixed effect of the  $l^{\text{th}}$  genetic groups;  $\text{AAC}_m$  = the fixed effect of the  $m^{\text{th}}$  Ages at calving;  $\text{WAC}_n$  = the fixed effect of the  $n^{\text{th}}$  weights at calving;  $e_{ijklmno}$  = random error particular to the  $ijklmno^{\text{th}}$  observations which is  $\text{NID} \sim (0, \sigma^2 e)$ .

For data of ALSP and ALCI, model 13 was used.

$$Y_{ijklmno} = \mu + a_i + \text{PE}_j + \text{POB}_k + \text{POC}_l + \text{AAC}_m + \text{WAC}_n + e_{ijklmno} \text{ (Model 13)}$$

$Y_{ijklmno}$  = the  $ijklmno^{\text{th}}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $\text{PE}_j$  = random permanent environmental effect of the  $j^{\text{th}}$  cow;  $\text{POB}_k$  = the fixed effect of the  $k^{\text{th}}$  periods of birth;  $\text{POC}_l$  = the fixed effect of the  $l^{\text{th}}$  periods of calving;  $\text{AAC}_m$  = the fixed effect of the  $m^{\text{th}}$  ages at calving sub-groups;

$WAC_n$  = the fixed effect of the  $n^{th}$  weights at calving sub-groups;  $e_{ijklmno}$  = random error particular to the  $ijklmno^{th}$  observations which is  $NID \sim (0, \sigma^2e)$ .

For data of **ALPP**, the model was:

$$Y_{ijkl} = \mu + a_i + PE_j + GG_k + e_{ijkl} \text{ (Model 14)}$$

$Y_{ijkl}$  = the  $ijkl^{th}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{th}$  sire;  $PE_j$  = random permanent environmental effect of the  $j^{th}$  cow;  $GG_k$  = the fixed effect of the  $k^{th}$  genetic groups;  $e_{ijkl}$  = random error particular to the  $ijkl^{th}$  observations which is  $NID \sim (0, \sigma^2e)$ .

### 3.11.3.3. Variance component analysis for milk production traits

The following MME were employed.

#### a). Milk production traits from first lactation

For data of **FLMY and FL305\_DMY**, model 15 was used.

$$Y_{ijklm} = \mu + a_i + GG_j + POC_k + WAC_l + e_{ijklm} \text{ (Model 15)}$$

$Y_{ijklm}$  = the  $ijklm^{th}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{th}$  sire;  $GG_j$  = the fixed effect of the  $j^{th}$  genetic groups;  $POC_k$  = the fixed effect of the  $k^{th}$  periods of calving;  $WAC_l$  = the fixed effect of the  $l^{th}$  weights in calving;  $e_{ijklm}$  = random error particular to the  $ijklm^{th}$  observations which is  $NID \sim (0, \sigma^2e)$ .

For data of **FLL**, model 16 was used.

$$Y_{ijk} = \mu + a_i + POC_j + e_{ijk} \text{ (Model 16)}$$

$Y_{ijk}$  = the  $ijk^{th}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{th}$  sire;  $POC_j$  = the fixed effect of the  $j^{th}$  periods of calving;  $e_{ijk}$  = random error particular to the  $ijk^{th}$  observations which is  $NID \sim (0, \sigma^2e)$ .

For data of **FLDP**, model 17 was used.

$$Y_{ijklm} = \mu + a_i + POB_j + AAC_k + WAC_l + e_{ijklm} \text{ (Model 17)}$$

$Y_{ijklm}$  = the  $ijklm^{th}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{th}$  sire;  $POB_j$  = the fixed effect of the  $j^{th}$  periods of birth;  $AAC_k$  = the fixed effect of the  $k^{th}$  ages at calving;  $WAC_l$  = the fixed effect of the  $l^{th}$  weights at calving;  $e_{ijklm}$  = random error particular to the  $ijklm^{th}$  observations which is  $NID \sim (0, \sigma^2e)$ .

For data of **FLPY**, model 18 was used.

$$Y_{ijklm} = \mu + a_i + GG_j + AAC_k + WAC_l + e_{ijklm} \text{ (Model 18)}$$

$Y_{ijklm}$  = the  $ijklm^{th}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{th}$  sire;  $GG_j$  = the fixed effect of the  $j^{th}$  genetic groups;  $AAC_k$  = the fixed effect of

the  $k^{\text{th}}$  ages at calving;  $WAC_l$  = the fixed effect of the  $l^{\text{th}}$  weights at calving;  $e_{ijklm}$  = random error particular to the  $ijkl^{\text{th}}$  observations which is  $NID \sim (0, \sigma^2e)$ .

For data of **FLDPY**, model 19 was used.

$$Y_{ijk} = \mu + a_i + SOC_j + e_{ijk} \text{ (Model 19)}$$

$Y_{ijk}$  = the  $ij^{\text{th}}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $SOC_j$  = the fixed effect of the  $j^{\text{th}}$  seasons of calving;  $e_{ijk}$  = random error particular to the  $ij^{\text{th}}$  observations which is  $NID \sim (0, \sigma^2e)$ .

### b). Milk production traits from all lactation

For data of **ALMY**, model 20 was used.

$$Y_{ijklm} = \mu + a_i + PE_i + POB_j + GG_k + AAC_l + e_{ijklm} \text{ (Model 20)}$$

$Y_{ijklmnop}$  = the  $ijkl^{\text{th}}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $PE_i$  = random permanent environmental effect of the  $i^{\text{th}}$  cow;  $POB_j$  = the fixed effect of the  $j^{\text{th}}$  period of birth;  $GG_k$  = the fixed effect of the  $k^{\text{th}}$  genetic groups;  $AAC_l$  = the fixed effect of the  $l^{\text{th}}$  weight at calving sub-groups;  $e_{ijklm}$  = random error particular to the  $ijkl^{\text{th}}$  observations which is  $NID \sim (0, \sigma^2e)$ .

For analysis of data of **AL305\_DMY**, model 21 was used.

$$Y_{ijklmn} = \mu + a_i + PE_i + POB_j + GG_k + AAC_l + WAC_m + e_{ijklmn} \text{ (Model 21)}$$

Where, all components of the model except  $WAC$  are as defined for Model 20.  $WAC_m$  = the fixed effect of the  $m^{\text{th}}$  weights at calving sub-groups;  $e_{ijklmn}$  = random error particular to the  $ijklm^{\text{th}}$  observations which is  $NID \sim (0, \sigma^2e)$ . It includes all the other effects not specified in the model of analysis.

The fitted model for data of **ALL** was:

$$Y_{ijk} = \mu + a_i + PE_i + POB_j + e_{ijk} \text{ (Model 22)}$$

$Y_{ijkl}$  = the  $ij^{\text{th}}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $PE_i$  = random permanent environmental effect of the  $i^{\text{th}}$  cow;  $POB_j$  = the fixed effect of the  $j^{\text{th}}$  periods of calving;  $e_{ijk}$  = random error particular to the  $ij^{\text{th}}$  observations which is  $NID \sim (0, \sigma^2e)$ .

Model 23 was used for analysis of data of **ALDP**.

$$Y_{ij} = \mu + a_i + PE_i + e_{ij} \text{ (Model 23)}$$

$Y_{ij}$  = the  $i^{\text{th}}$  observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i^{\text{th}}$  sire;  $PE_i$  = random permanent environmental effect of the  $i^{\text{th}}$  cow;  $e_{ij}$  = random error particular to the  $i^{\text{th}}$  observations which is  $NID \sim (0, \sigma^2e)$ .

For data of **ALPY**, the fitted model was:

$Y_{ijklmno} = \mu + a_i + PE_i + POB_j + GG_k + SOC_l + AAC_m + WAC_n + e_{ijklmno}$  (**Model 24**)

$Y_{ijklmno}$  = the  $ijklmno$ <sup>th</sup> observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i$ <sup>th</sup> sire;  $PE_i$  = random permanent environmental effect of the  $i$ <sup>th</sup> cow;  $POB_j$  = the fixed effect of the  $j$ <sup>th</sup> periods of birth;  $GG_k$  = the fixed effect of the  $k$ <sup>th</sup> genetic groups;  $SOC_l$  = the fixed effect of the  $l$ <sup>th</sup> seasons of calving;  $AAC_m$  = the fixed effect of the  $m$ <sup>th</sup> age at calving;  $WAC_n$  = the fixed effect of the  $n$ <sup>th</sup> weights at calving;  $e_{ijklmno}$  = random error particular to the  $ijklmno$ <sup>th</sup> observations which is  $NID \sim (0, \sigma^2_e)$ .

For data of **ALDPY**, the fitted model was:

$Y_{ijklm} = \mu + a_i + PE_i + SOC_j + POC_k + WAC_l + e_{ijklm}$  (**Model 25**)

$Y_{ijklm}$  = the  $ijkl$ <sup>th</sup> observations;  $\mu$  = over all mean;  $a_i$  = random additive genetic effect of the  $i$ <sup>th</sup> sire;  $PE_i$  = random permanent environmental effect of the  $i$ <sup>th</sup> cow;  $SOC_j$  = the fixed effect of the  $j$ <sup>th</sup> seasons of calving;  $POC_k$  = the fixed effect of the  $k$ <sup>th</sup> periods of calving;  $WAC_l$  = the fixed effect of the  $l$ <sup>th</sup> weights in calving;  $e_{ijklm}$  = random error particular to the  $ijkl$ <sup>th</sup> observations which is  $NID \sim (0, \sigma^2_e)$ .

### 3.11.4. Estimation of genetic parameters

#### 3.11.4.1. Estimation of heritability and repeatability

The heritability of performance traits considered under the study was estimated as:

$$h^2 = \frac{4\sigma_s^2}{\sigma_s^2 + \sigma_{PE}^2 + \sigma_e^2} \text{ for repeatable traits}$$

$$h^2 = \frac{4\sigma_s^2}{\sigma_s^2 + \sigma_e^2} \text{ for non repeatable traits}$$

Where,  $h^2$  is heritability and  $\sigma_s^2$ ,  $\sigma_{PE}^2$  and  $\sigma_e^2$  are sire, permanent environmental related to repeated records and residual error variances, respectively. The method of estimation was paternal half-sib correlation, whereas the following formula was applied to estimate repeatability values for traits having  $\geq 2$  lactations.

$$r = \frac{\sigma_B^2}{\sigma_B^2 + \sigma_e^2}$$

Where,  $r$  = repeatability and  $\sigma_B^2$  and  $\sigma_e^2$  are animal component variance and residual error component variance, respectively. The standard error of  $h^2$  was estimated using the formula of Swiger *et al.*, (1964) as follows:

$$S. E. (h^2) = \frac{\sqrt[4]{2 * (1 - T)^2 * [1 + (k - 1) * t]^2}}{\sqrt{K(K - 1)(S - 1)}} K = \frac{1}{S - 1} \left( n - \frac{\sum ni^2}{n} \right)$$

$$T = \frac{\sigma_s^2}{\sigma_s^2 + \sigma_{PE}^2 + \sigma_e^2} \text{ for repeatable traits, } T = \frac{\sigma_s^2}{\sigma_s^2 + \sigma_e^2} \text{ for non-repeatable traits}$$

Where,

T = intra-class correlation

S = Number of sires

n = Total number of observations

K= average number of progenies per sire

$\sigma_s^2$ ,  $\sigma_{PE}^2$ ,  $\sigma_e^2$  are sire, permanent environmental and residual variances, respectively.

### 3.11.4.2. Genetic and phenotypic correlations

Pearson correlation for estimation of phenotypic correlation and a combination of Mixed Model Equation (MME) and Pearson correlation for genetic correlation were employed. The genetic correlation were estimated as the ratio of additive covariance of the two traits (trait i and j) to the product of additive genetic standard deviations of the two traits whilst phenotypic correlations were estimated similarly as the ratio of the sum of genetic and environmental covariance (phenotypic covariance) to the product of phenotypic standard deviations of the two traits.

$$r_g = \frac{\sigma_{ai} * \sigma_{aj}}{\sqrt{\sigma_{ai}^2 * \sigma_{aj}^2}} \quad \& \quad r_p = \frac{\sigma_{pi} * \sigma_{pj}}{\sqrt{\sigma_{pi}^2 * \sigma_{pj}^2}}$$

Where,  $r_g$  and  $r_p$  are genetic and phenotypic correlations, respectively,  $\sigma_{ai}^2$  = additive genetic variance for trait i,  $\sigma_{aj}^2$  = additive genetic variance for trait j,  $\sigma_{pi}^2$  = phenotypic variance for trait i,  $\sigma_{pj}^2$  = phenotypic variance for trait j,  $\sigma_{aij}$  is additive genetic covariance between trait i and j, and  $\sigma_{pij}$  = phenotypic covariance between trait i and j.

The standard error of phenotypic correlation was obtained as per the following formula developed by Panse and Sukhatme (1967).

$$S.E(r_p) = \frac{\sqrt{1 - r_p^2(i,j)}}{\sqrt{N - 2}}$$

Where,  $r_p^2(i,j)$  = phenotypic correlation between traits i and j; (N-2) = degree of freedom.

### 3.11.5. Estimation of performance trends

#### 3.11.5.1. Estimation of phenotypic trend

The changes in yearly mean phenotypic effects over years represent the phenotypic trends over time. Phenotypic trend per year for performance traits of crossbred cattle was estimated as the linear regression of the phenotypic value (P) on year of birth/calving. The phenotypic trends were expressed as deviations from the overall mean.

$$\Delta p = b_{P,T}$$

Where,  $b_{P,T}$  = Linear regression of phenotypic value (P) on time (T) year of birth/calving)

### **3.11.5.2. Estimation of genetic trend**

Restricted Maximum Likelihood under Mixed model equation (back solutions) was applied to predict the estimated breeding values (EBV) of the cows over year of birth and thereby the genetic trends were estimated by regression of the average breeding values over year of birth.

### **3.11.5.3. Environmental trend analysis**

The environmental values were estimated as the difference of breeding values from phenotypic value. The environmental trend was then obtained by regressing the environmental value over the birth year for all growth traits, AFS, AFC and WFC and calving year for all other traits. The trends were expressed as deviations from the overall mean.

### **3.11.6. Sire evaluation**

Four methods, namely Least Square (Harvey, 1990), REML (Meyer, 1998) and MIVQUE were applied to estimate genetic merits (breeding values) of the sires for performance traits. Sires which had five and more than five daughters in the herd were considered for the evaluation. Spearman's rank correlations (Steel and Torrie, 1980) and product moment correlations between breeding values of sires derived by various methods were also used to judge the effectiveness of different methods. After estimation of breeding value of sires, the sires were given ranks as per their genetic merit.

### **3.11.7. Estimation of most probable producing ability (MPPA)**

The expected producing abilities of cows in a herd for different production traits was estimated using the following formula as developed by Lush (1945):

$$\text{MPPA} = \mu + \left( \frac{nr}{1+(n-1)r} \right) (\bar{x}_i - \mu) \text{ (Lush, 1945)}$$

Where,

$\mu$  = herd average;  $n$ = numbers of lactations;  $r$ = repeatability;  $\bar{x}_i$ = average of all lactations of the  $i^{\text{th}}$  animal. Moreover, cows which possessed of two and more than two lactations were included for estimation of the MPPA.

### 3.11.8. Analyses of growth and lactation curves

The non-linear (NLIN) procedure of the Statistical Analysis Software (SAS) version 9.3 (SAS institute Inc. 2011. Cary, NC, USA) was used to fit non-linear models to average lactation and growth curves (table 31 & 32) whereas regression procedure (proc reg) of the same software was applied to compute the model selection criteria for each non-linear model. To compare the different non-linear models for efficiency of goodness of fit, the statistical criteria [coefficient of determination ( $R^2$ ), Coefficient of variation (CV), Akaike information criterion (AIC), mean square error (MSE), and Conceptual predictive criterion (CP)] were employed.

#### 3.11.8.1. Growth curve modeling

**Table 31. Non-linear models with their equations for fitting growth data in crossbred cattle**

S.No.	Non-linear Models	Equations
1	Brody (Brody, 1945)	$Y_t = A \times (1 - B \times e^{-k \times t}) + \epsilon$
2	Von Bertalanffy (Von Bertalanffy, 1957)	$Y_t = A \times (1 - B \times e^{-k \times t})^3 + \epsilon$
3	Logistic (Nelder, 1961)	$Y_t = A / (1 + B \times e^{-k \times t}) + \epsilon$
4	Gompertz (Laird, 1965)	$Y_t = A \times e^{-B} \times e^{k \times t} + \epsilon$
5	Richards's functions (Richard, 1959)	$Y_t = A \times (1 - B \times e^{-k \times t})^M + \epsilon$
6	Quadratic (Moore, 1985)	$Y_t = A_0 + Bt + Kt^2 + \epsilon$
7	Cubic (Moore, 1985)	$Y_t = A_0 + Bt + Kt^2 + Mt^3 + \epsilon$

Where,  $Y_t$  is the observed body weight of individuals ( $i=1 \dots n$ ) at measurement time  $j$  ( $j=1 \dots n_i$ ) for animal  $i$ ;  $t$ : age of animal in days;  $A$ : the asymptotic body weight of animal, which was interpreted as mature weight;  $B$ : the proportion of the asymptotic mature weight to be obtained after birth for animal;  $k$ : the maturation rate of animal, which is interpreted as weight change in relation to mature weight to indicate how fast the animal approaches adult weight;  $M$  is the parameter that shapes the curve;  $e$  is the natural base logarithm;  $\epsilon$ : the random residual term

Initial live weight is converted to asymptotic live weight ( $A$ ) by the following formulas:

$$A = A_0 - \frac{B^2}{4K} \text{ for the quadratic model}$$

$$= A_0 + BT_{\max} + KT_{\max}^2 + MT_{\max}^3 \text{ for the Cubic model}$$

Where,  $A_0$  is the initial live weight;  $B$ ,  $K$ , and  $M$  are the model parameters which characterize the shape of the curve and  $T$  is age of animal.

### 3.11.8.2. Lactation curve modeling

**Table 32. Equations of non-linear models for lactation curve in crossbre cattle**

S.No.	Models	Equations
1	Exponential decline function (Brody <i>et al.</i> , 1923)	$Y_t = ae^{-ct}$
2	Parabolic exponential model (Sikka, 1950)	$Y_t = a \exp(bt - ct^2)$
3	Inverse polynomial model (Nelder, 1966)	$Y_t = t(a + bt + ct^2)^{-1}$
4	The gamma-type function (Wood, 1967)	$Y_t = at^b \times e^{-ct}$
5	Mixed log function (Guo and Swalve, 1995)	$Y_t = a + b \times \sqrt{t} + c \times \log(t)$

Where,  $Y_t$  = Average daily milk yield in the  $t^{\text{th}}$  day of lactation;  $a$  = initial milk yield after calving;  $b$  = ascending slope parameter up to the peak yield;  $c$  = descending slope parameter;  $t$  = length of time since calving;  $e_t$  = residual error

**Table 33. Equations of polynomial regression for lactation curve of crossbred cattle**

Polynomial regression model (Ali and Schaeffer, 1987)	$Y_t = a_0 + bt + ct^2 + d \log\left(\frac{1}{t}\right) + f \log\left(\frac{1}{t}\right)^2$
--	---

Where,  $Y_t$  = Average daily milk yield in  $t^{\text{th}}$  day of lactation;  $a$  = associated with peak yield;  $b$  and  $c$  = associated with the decreasing slope;  $d$  and  $f$ : associated with the increasing slope parameter;  $t$  = length of time since calving.

For Gamma-type function, the days in milk at peak yield (DIMP) was defined as  $b/c$  and the peak yield was estimated as:  $a \times (b/c)^b e^{-b}$  whereas the persistency (P) of lactation was evaluated using:  $P = - (b + 1) \ln (c)$  (Tekerli *et al.*, 2000).

### 3.11.9. Analyses of association of performance traits with meteorological factors

#### 3.11.9.1. Estimation of temperature humidity index (THI)

The daily THI was estimated using daily average ambient temperature and relative humidity by applying the following four common mathematical equations; but the computed values from the four equations were not significantly different and so we selected the 4<sup>th</sup> equation as it was recently developed. THI were also estimated on monthly basis from January to December by the use of monthly average ambient temperature and relative humidity for each year of the entire study period.

**Table 34. Formulas for temperature and humidity index (THI)**

S.No.	Formulae	References
1	$THI = 1.8T_{db} - (1 - RH)(T_{db} - 14.3) + 32$	Kibler <sup>a</sup> (1964)
2	$THI = (1.8 \times T_{db} + 32) - (0.55 - 0.0055 \times RH) \times (1.8 \times T_{db} - 26)$	National Research Council (1971)
3	$THI = T_{db} + (0.36 \times T_{dp}) + 41.2$	Yousef (1985)
4	$THI = (0.8 \times T_{db}) + [(RH/100) \times (T_{db} - 14.4)] + 46.4$	Mader <i>et al.</i> (2006)

T<sub>db</sub>: dry bulb air temperature, °C, RH: relative air humidity, %<sup>a</sup>. In Kibler formula RH is fraction of the unit

The minimum temperature and relative humidity were recorded during morning on 7:30 AM every day whereas the maximum temperature and relative humidity were recorded in the afternoon on 2:30 PM. The sunshine and wind velocity were; however recorded once in a day.

### 3.11.9.2. Estimation of solar radiation

The sunshine data collected and maintained in School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana were used to generate solar radiation which has been used for computation of Adjusted THI. Conversion of sunshine (hour) into solar radiation (Watt-hour/m<sup>2</sup>) was first suggested by Angstrom (1924) and modified by Penman (1948) in the form:

$$Q = Q_A * [a + b * \left(\frac{n}{N}\right)]$$

Where

Q = the radiation received at the surface of the earth; Q<sub>A</sub> = the total radiation received if the atmosphere is perfectly transparent; n = the actual sunshine hours received; N = the maximum possible duration of sunshine; a = 0.31 & b = 0.46 (Yadav *et al.*, 2012) are constants which can be determined

### 3.11.9.3. Adjusted temperature and humidity index (THI<sub>adj</sub>) estimation

For calculation of daily THI<sub>adj</sub>, two environmental variables, namely wind speed and solar radiation were accounted in addition to average daily ambient air temperature and relative humidity as solar radiation can greatly influence heat load, while changes in wind speed results in altered convective cooling. The mathematical equation employed for computation of THI<sub>adj</sub> was

$$THI_{adj} = 4.51 + THI - (1.922 * WS) + (0.0068 * SR) \text{ (Mader *et al.*, 2006)}$$

THI<sub>adj</sub> were also estimated on monthly basis from January to December by the use of monthly average ambient temperature and relative humidity, wind speed and solar radiation for each year and the entire study period.

#### **3.11.9.4. Performance data versus meteorological data**

Depending on the nature of the traits under the study, the performance data were matched with meteorological data as follows:

1. The month wise averages of major growth traits (BW90, BW180, BW270, BW365, BW450 and BW540) were matched with month wise average of meteorological factors using month of birth for each month during the entire 28 years study periods.
2. The month wise averages of AFC, AFS and WFC were matched with month wise average of meteorological factors using month of birth for each month during the entire 28 years study periods.
3. The month wise averages of reproduction traits (NSPC, SP, PP and CI) were matched with month wise average of meteorological factors using month of calving for each month during the entire 28 years study periods.
4. Daily milk yield data was matched with daily meteorological data using the milk recording date.
5. The month wise averages of all milk production trait (LMY, 305\_DMY, LL, DP, PY and DPY) data were matched with month wise average of meteorological factors on the basis of month of calving for each month during the entire 28 years study periods.

#### **3.11.9.5. Effects of month and year on meteorological variables**

The effects of month and year on data of climate variables was estimated using Least Square Analysis (Harvey, 1990) under fixed model of SAS ver. 9.3 (2011).

$$Y_{ijk} = \mu + M_i + Y_j + e_{ijk}$$

$Y_{ijk}$  = the  $Y_{ij}$ <sup>th</sup> Observations of climate variables;  $\mu$  = Overall population mean;  $M_i$  = Fixed effects of  $i$ <sup>th</sup> month;  $Y_j$  = Fixed effects of the  $j$ <sup>th</sup> year;  $e_{ijk}$  = Random error  $NID \sim (0, \sigma_e^2)$ .

#### **3.11.9.6. Trend analysis for meteorological factors**

The trends of change in those variables over years/months of whole study periods were predicted by regressing environmental variable values on time (years). Trends of changes in environmental variables over time were also shown by different graphs.

#### **3.11.9.7. Effects of environmental factors on daily milk yield**

Univariate GLM procedure of SAS ver. 9.3 (2011) was employed to analyse data of DMY over environmental factors.

- a) Model including THI:  $Y_{ijkl} = \mu + MOC_i + POC_j + THI_k + e_{ijkl}$   
 b) Model including THIadj:  $Y_{ijkl} = \mu + MOC_i + POC_j + THIadj_k + e_{ijkl}$

Where,

$Y_{ijkl}$  = the  $ijkl$ <sup>th</sup> Observations of crossbred cows;  $\mu$ = the overall population mean

$SOC_i$ = the fixed effects of the  $i$ <sup>th</sup> season of calving;  $POC_j$ = the fixed effects of the  $j$ <sup>th</sup> period of calving;  $THI_k$ = the fixed effects of the  $k$ <sup>th</sup> THI sub-classes;

$THIadj_k$  = the fixed effect of the  $k$ <sup>th</sup> Adjusted THI sub-classes;  $e_{ijkl}$  = Random residual error, which is  $NID \sim (0, \sigma^2_e)$

- c) Model including Temp, RH and SR:  $Y_{ijklmn} = \mu + MOC_i + POC_j + Temp_k + RH_l + SR_m + e_{ijklmn}$

Where,

$Y_{ijklmn}$  = the  $ijklmn$ <sup>th</sup> Observations of crossbred cows

$\mu$ = the overall population mean;  $MOC_i$ = the fixed effects of the  $i$ <sup>th</sup> month of calving;  $YOC_j$ = the fixed effects of the  $j$ <sup>th</sup> year of calving;  $T_k$  = the fixed effects of the  $k$ <sup>th</sup> temperature sub classes;  $RH_l$  = the fixed effects of the  $l$ <sup>th</sup> relative humidity sub classes;  $SR_m$ = the fixed effects of the  $k$ <sup>th</sup> Solar Radiation sub classes

$e_{ijklmn}$ =Random residual error, which is  $NID \sim (0, \sigma^2_e)$ .

### 3.11.9.8. Regression Analysis

Both simple linear regression model and polynomial regression model with three orders were fitted to analyze the association first and all lactation performance data with meteorological data or to explore the change in performance traits with unit change in the climate variables (Draper and Smith, 1962).For both model analysis, GLM procedure of SAS ver. 9.3 (2011) was engaged.

$$Y_{ij} = a + \sum bX_i + e_{ij}$$

$Y_{ij}$ = Performance traits of  $j$ <sup>th</sup> cow      $a$ = intercept;  $b$ = regression coefficient;  $X_i$ =  $i$ <sup>th</sup> climate variable values;  $E_{ij}$ = random error  $NID \sim (0, \sigma^2_e)$

$$Y_{ij} = a + b_1x + b_2x^2 + b_3x^3 + e_{ij}$$

$Y_{ij}$ = performance traits of  $j$ <sup>th</sup> cow

$a$ = intercept;  $b_1$ ,  $b_2$  and  $b_3$ = regression coefficients

$X_i$ =  $i$ <sup>th</sup> climate variable values

$E_{ij}$ = random error  $NID \sim (0, \sigma^2_e)$

## CHAPTER IV

### RESULTS AND DISCUSSION

The results of the study are generally organized and presented in two main sets. Discussion is also made based on these sets. Set one included all results and discussion of first lactation performances traits whereas set two encompassed all results and discussion of data of performance traits from all (pooled) lactations. Under both sets, the following headings are discussed as per the objectives of the study.

- ✓ **Effect of genetic and non-genetic factors on performance traits**
- ✓ **Genetic and phenotypic parameters for performance traits**
- ✓ **Annual genetic, phenotypic and environmental trends for performance traits**
- ✓ **Estimated producing ability for milk production traits**
- ✓ **Sire evaluation for performance traits**
- ✓ **Growth and lactation curves**
- ✓ **Relationships between meteorological factors and performance traits**

#### 4.1. Descriptive Statistics and First Lactation Performance Traits

##### 4.1.1. Growth traits

The overall mean, standard error, standard deviation, coefficient of variations, minimum and maximum values for BW0, BW90, BW180, BW270, BW365, BW450 and BW540 are presented in Table 35.

##### 4.1.1.1. Birth weight (BW0)

The mean of crossbred female calves for birth weight was  $29.40 \pm 0.18$  kg with coefficient of variation (CV) of 16.37%. This average birth weight was found to be comparable with previous results reported by various authors [Gaur *et al.* (2003) for FN×HR; Pal *et al.* (2004) for Karan Fries; Rahman *et al.* (2015) for HF × Local cattle]. However it was higher than average birth weight reports of Demek *et al.* (2003) for HF×Boran, Afroz *et al.* (2011) for Red Chittagong, Salim *et al.* (2015) for Dhofari and Sagaret *et al.* (2017) for Vrindavani cattle and lower than previous studies undertaken by El -Saied *et al.* (2006) for Charolais, Nesar *et al.* (2012) for Brangus, and Chen *et al.* (2012) for Piedmontese. This might be attributed to the calf rearing systems, environmental conditions of the production area and breed difference.

#### **4.1.1.2. Body weight at 90 days of age (BW90)**

The average BW90 of female crossbred cattle with CV was  $59.42 \pm 0.45$  kg and 20.21%, respectively. The average BW90 value observed in our study was in line with calf average BW90 of Karan Fries [ $59.38 \pm 2.67$  kg] (Pal *et al.*, 2004) but it was higher than calf average BW90 of FN×HR [ $54.25$  kg] (Gaur *et al.*, 2003), and Red Chittagong [ $31.48$  kg] (Rabeya *et al.*, 2009) and Vrindavani cattle [ $53.27 \pm 0.27$  kg] (Sagar *et al.*, 2017) and lower than calf average BW90 of Friesian and Bunaii [ $72.4 \pm 4.50$  kg] (Malau-Aduli *et al.*, 1993) and HF × Local [ $64.32$  kg] (Rahman *et al.*, 2015).

#### **4.1.1.3. Body weight at 180 days of age (BW180)**

The average body weight at 180 days of age along with CV for female crossbred cattle was  $102.77 \pm 0.76$  kg and 20.24%, in that order. This average BW180 was comparable with the previous findings of various investigators [ $106 \pm 1.03$  kg] (Salim *et al.*, 2015) for Dhofari cattle and 99.06 kg (Rahman *et al.*, 2015) for HF × Local cattle) but higher than the reports of Vrindavani cattle, Red Chittagong (Afroz *et al.*, 2011), Sheko cattle (Bayou *et al.*, 2015) and (Sagar *et al.*, 2017) and lower than the average body weight [ $112.9 \pm 6.90$  kg] (Malau-Aduli *et al.*, 1993) for Friesian and Bunaii, and [ $278.21$  kg] for Charolais (Pal *et al.* (2004) and [ $194$  kg] for Piedmontese and Nanyang (Chen *et al.*, 2012).

#### **4.1.1.4. Body weight at 270 days of age (BW270)**

The mean BW270 of female crossbred cattle with CV values was  $146.80 \pm 1.17$  kg and 21.60%, correspondingly. Similar results were reported by Malau-Aduli *et al.* (1993) for Friesian and Bunaii, and Rahman *et al.* (2015) for HF × Local cattle. Nesar *et al.* (2012) for Brangus, and Chen *et al.* (2012) for Piedmontese and Nanyang reported higher BW270 as compared as the present finding. On the contrary, Kabir and Islam (2009) for Jersey×Boran, Afroz *et al.* (2011) for Red Chittagong and Bayou *et al.* (2015) for Sheko cattle reported lower values for the trait.

#### **4.1.1.5. Yearling body weight (BW365)**

Yearling body weight of female crossbred cattle averaged  $195.49 \pm 1.44$  kg and its CV value was 19.94%. In line with this result, Malau-Aduli *et al.* (1993) found  $182.1 \pm 11.10$  kg for BW365 in Friesian and Bunaii cattle whereas the results reported for the same trait were higher for Brangus (Nesar *et al.*, 2012). Lower findings as compared as the finding in our study were observed by Demek *et al.* (2003) for HF×Boran, Salim *et al.* (2015) for Dhofari cattle and Sagar *et al.* (2017) for

Vrindavani cattle, which could be due to artificial rearing of the calves where maternal effects on calf growth tended to die out earlier and management difference.

#### 4.1.1.6. Body weight at 540 days of age (BW540)

The average BW540 of female crossbred cattle with CV values was  $291.57 \pm 1.57$  kg and 14.47%, in that order. The estimated average BW540 was in comparable with mean body weight at 540 days of age reported by Sagar *et al.* (2017) for Vrindavani cattle. Whilst Nesar *et al.* (2012) found higher finding ( $391.45 \pm 1.14$ ) for the same trait in the Brangus. However Bayou *et al.* (2015) for Sheko cattle and Afroz *et al.* (2011) for Red Chittagong indicated lower results for the trait.

**Table 35. Descriptive statistics of first lactation datasets of performance traits in crossbred cattle**

Traits	N	Mean	SE	SD	CV%	Min	Max	Kurt	Skew
BW0 (kg)	765	29.40	0.18	4.81	16.37	19.00	39.00	-0.41	0.04
BW90 (kg)	760	59.42	0.45	12.01	20.21	25.00	100.00	-0.01	0.31
BW180 (kg)	752	102.77	0.76	20.80	20.24	38.00	180.00	0.33	0.34
BW270 (kg)	752	146.80	1.17	31.71	21.60	59.00	256.00	-0.14	0.06
BW365 (kg)	751	195.49	1.44	38.97	19.94	73.00	310.00	-0.17	-0.11
BW450 (kg)	750	243.88	1.49	40.22	16.49	119.00	360.00	0.33	-0.09
BW540 (kg)	750	291.57	1.57	42.20	14.47	125.00	425.00	0.80	-0.06
AFS (days)	750	712.05	9.24	252.92	35.52	345.00	1635.00	2.61	1.73
AFC (days)	750	1008.01	9.52	260.72	25.87	326.00	1920.00	2.28	1.58
WFC (kg)	750	404.55	2.09	56.53	13.97	260.00	585.00	0.00	0.44
FLNSPC (no.)	750	2.34	0.06	1.66	70.88	1.00	8.00	1.36	1.40
FLPP (days)	750	276.96	0.27	7.36	2.66	249.00	300.00	1.67	-0.71
FLSP (days)	526	177.52	5.18	117.75	66.33	17.00	577.00	0.76	1.09
FCI (days)	526	454.21	5.22	118.61	26.11	220.00	859.00	0.81	1.06
FLTMY (kg)	750	4323.53	73.83	2022.04	46.77	1004.70	17510.90	3.11	1.20
FL305_DMV(kg)	750	3646.92	48.38	1325.00	36.33	1004.70	10493.10	0.55	0.47
FLL (days)	750	370.74	4.41	120.89	32.61	154.00	928.00	2.88	1.32
FLDP (days)	750	93.32	1.53	41.86	44.85	20.00	264.00	2.51	1.45
FLPY (kg)	750	20.70	0.29	7.87	38.03	7.00	54.30	11.74	2.40
FLDPY (days)	750	47.49	1.15	31.59	66.52	11.00	166.00	1.09	1.21

Kurt: Kurtosis; Skew: Skewedness

#### 4.1.2. Reproductive traits

The overall mean, standard error, standard deviation, coefficient of variations, minimum and maximum values for AFS, AFC, WFC, FLNSPC, FLPP, FLSP and FCI are presented in table 35.

#### **4.1.2.1. Age at first service (AFS)**

The averages AFS along with CV value was  $712.05 \pm 9.24$  days and 35.52%, respectively. The average AFS observed in the present study had been longer than those reported by (Kumari, 2015) for HF  $\times$  Sahiwal cattle ( $604.79 \pm 13.24$ ) but shorter than those reported by Islam *et al.* (2004), Azizunnesa *et al.* (2010) and Hasanuzzaman *et al.* (2012) for Indigenous cattle, Red Chittagong cows, and crossbred cows, in that order.

#### **4.1.2.2. Age at first calving (AFC)**

AFC in our study averaged  $1008.01 \pm 9.52$  days and its CV value was 25.87%. This mean was observed to be within the range of means noted for *Bos indicus* and *Bos taurus* and *Bos indicus*  $\times$  *Bos taurus* crosses (34-44 months) in the tropics (Divya, 2012; Parveen, 2017), but shorter than those reported for the same trait by Garima (2006) for crossbred cattle and Kumar (1969) for 3/4 Jersey and longer than those given by Dash *et al.* (2014) for Karan Fries, Kumari (2015) for HF $\times$ Sahiwal and Singh *et al.* (2015) for HF $\times$ Sahiwal.

#### **4.1.2.3. Body weight at age at first calving (WFC)**

Mean and coefficient of variation of WFC in the present study were  $404.55 \pm 2.09$  kg and 13.97%, correspondingly. This mean was in line with previous reports given by Kumari (2015) for HF $\times$ Sahiwal; but it was higher than  $374.81 \pm 5.41$  kg obtained by Singh *et al.* (2015) for HF $\times$ Sahiwal cattle.

#### **4.1.2.4. First lactation number of service per conception (FLNSPC)**

The mean FLNSPC obtained in the present study was  $2.34 \pm 0.06$  with CV of 70.88%. This mean was higher than those of  $1.76 \pm 0.01$  (Lāsma *et al.*, 2017) for Holstein dairy cattle and 1.71 AM Wicaksono *et al.* 2018 for Holstein Friesian; but lower than the finding of Choudhuri *et al.* (1984) for Haryana cattle (2.8). In line with the present result for the same trait, finding was obtained by (Swensson *et al.*, 1981) for Arsi Cattle.

#### **4.1.2.5. First lactation pregnancy period (FLPP)**

Gestation period is calculated as the period between date of conception and date of parturition. Optimum gestation period would be of economic importance in normal parturition and maintaining short calving interval. This trait is least variable. It provides a protected environment to the off- spring in early stage of their development inside the body of the mother supplying nutrients and favorable environment. The

average pregnancy period along with coefficient of variation in crossbred cattle was  $276.96 \pm 0.27$  kg and 2.66%, respectively

#### **4.1.2.6. First lactation service period (FLSP)**

The mean and CV of crossbred cattle for FLSP were  $177.52 \pm 5.18$  days and 66.33%, in that order. The estimated average FLSP was found to be comparable with previous results reported by Mukharjee (2005) for HF  $\times$  Sahiwal and Jain *et al.* (1995) for HF (Red Dane  $\times$  Sahiwal). However it was higher than service period reports of Saha (2001) for Karan Fries and Sharama (2010) for Karan Fries and lower than previous findings reported by Bharti (2004) for HF  $\times$  Sahiwal, and Dubey and Singh (2005) for crossbred cattle.

#### **4.1.2.7. First calving interval (FCI)**

It is the parameter used to assess bovine reproductive efficiency which effects the production. Farm manager likes to keep the calving interval and dry period as short as possible, so that the animal remains productive for longer period in its life time. The average and coefficient of variation of FCI were  $454.21 \pm 5.22$  days and 26.11%, respectively. The average FCI observed in this study was in agreement with those findings reported by Safaa (2006) for Egypt HF and Singh *et al.* (2015) for HF  $\times$  Sahiwal.

Nevertheless, it was shorter than those reported by Dubey and Singh (2005) for crossbred cattle and Garima (2006) for crossbred cattle and longer than those reported by Parveen (2017).

#### **4.1.3. Milk production traits**

The overall mean, standard error, standard deviation, coefficient of variations, minimum and maximum values for FL305\_DMY, FLMY, FLL, FLDP, FLPY, and FLDPY are presented in table 35.

##### **4.1.3.1. First lactation 305 days milk yield (FL305\_DMY)**

The mean FL305\_DMY and CV of crossbred cattle were  $3646.92 \pm 48.38$  kg and 36.33%, correspondingly. Similar results were reported by Kumari (2015) for HF  $\times$  Sahiwal cattle. Saha *et al.* (2010) for Karan fries, Manoj *et al.* (2012) for Sahiwal cattle, Wondifraw *et al.* (2013) for HF  $\times$  Deoni, Singh *et al.* (2015) for HF  $\times$  Sahiwal and Sharma (2016) for HF  $\times$  Sahiwal found low 305 days milk yield as compared as the present finding. On the contrary, Safaa (2006) for HF (Egypt) reported higher value for the same trait than the present result.

#### **4.1.3.2. First lactation milk yield (FLMY)**

The average FLMY along with CV for crossbred cattle was  $4323.53 \pm 73.83$  kg and 46.77%, in that order. The average FLMY found in the present study were comparable with the previous findings of Kumari (2015) for HF  $\times$  Sahiwal cattle but higher than the reports of Saha *et al.* (2010) for Karan Fries, Wondifraw *et al.* (2013) for HF  $\times$  Deoni and Parveen (2017) for Sahiwal.

#### **4.1.3.3. First lactation length (FLL)**

FLL of crossbred cattle averaged  $370.74 \pm 4.41$  kg with coefficient variation of 32.61%. In line with the present result, many findings were given by various previous authors [Garima (2006) for crossbred cattle, Saha *et al.* (2010) for Karan Fries and Parveen (2017) for Sahiwal whereas Kumari (2015) for HF  $\times$  Sahiwal cattle reported higher average value for the same trait as compared as the current result. However lower findings as compared as the finding in our study were observed by Das *et al.* (2003) for Sahiwal  $\times$  Friesian, Manoj *et al.* (2012) for Sahiwal cattle and Wondifraw *et al.* (2013) for HF  $\times$  Deoni, Al-Samarai *et al.* (2015) for HF and Poonam *et al.* (2016) for Jersey crossbred cattle.

#### **4.1.3.4. First lactation dry period (FLDP)**

The average FLDP and CV of crossbred cattle were  $93.32 \pm 1.53$  days and 44.85%, respectively. The average FLDP observed in the current study was higher than those reported by Safaa (2006) for Egypt HF and Singh *et al.* (2015) for Sahiwal  $\times$  HF. However Garima (2006) found higher finding for the same trait in the crossbred cattle.

#### **4.1.3.5. First lactation peak yield (FLPY)**

The average with CV of crossbred cattle reported for FLPY  $20.70 \pm 0.29$  kg and 38.03%, respectively. This average value was higher than those reported by Singh *et al.* (2015) for HF  $\times$  Sahiwal cattle.

#### **4.1.3.6. First lactation days to attend peak yield (FLDPY)**

FLDPY in our study averaged  $47.49 \pm 1.15$  days with CV of 66.52%. This mean was observed to be similar with report of Singh *et al.*, 2015 who obtained  $51.30 \pm 2.13$  days for the same trait.

## **4.2. Descriptive Statistics and All Lactation Reproduction and Production Traits**

### **4.2.1. Reproduction traits**

The overall mean, standard error, standard deviation, coefficient of variations, minimum and maximum values for ALNSPC, ALPP, ALSP and ALCI are presented in table 36.

#### **4.2.1.1. All lactation number of service per conception (ALNSPC)**

The mean ALNSPC with coefficient of variation (CV) obtained in the present study were  $2.37 \pm 0.04$  and 69.24%, respectively. In line with the present result for the same trait, many findings were obtained by various former investigators [Alberro (1983) for East African Zebu, Jumat *et al.* (1998) for Friesian and its crosses and Muller *et al.* (2018) for Holstein dairy cattle]; but higher than those of Azage *et al.* (1998) for Zebu but lower than the finding of Choudhuri *et al.* (1984) for Haryana cattle.

#### **4.2.1.2. All lactation pregnancy period (ALPP)**

The average value and CV of crossbred cattle for ALPP was  $276.98 \pm 0.18$  kg and 2.71%, respectively. The estimated average ALPP observed in our study was comparable with those previously reported by Mishra (1987) in Jersey x Hariana cattle, Vij *et al.* (1992) and Kachwaha *et al.* (1993) in Tharparkar cattle and Dhaka (2013) in the Rathi cattle.

#### **4.2.1.3. All lactation service period (ALSP)**

The mean and Coefficient of variation for ALSP in crossbred cattle were  $173.91 \pm 3.17$  days and 64.29%, in that order. This mean was found to be comparable with previous results reported by various authors [Kumar & Kumar (2003) for Jersey  $\times$  Sahiwal and Gaur (2001) for HF  $\times$  Sahiwal]. However it was higher than service period reports of Singh and Gurnani (2004), Singh and Gurnani (2004), Divya (2012), Dash *et al.* (2014) and Muller *et al.* (2018) for F $\times$ T, BS $\times$ S, Karan Fries, Karan Fries and Holstein dairy cattle, respectively.

**Table 36. Descriptive statistics of datasets of reproduction and milk production traits from all lactations in crossbred cattle**

Traits	N	Mean	SE	SD	CV (%)	Min	Max	Kurt	Skew
ALNSPC (no.)	1735	2.37	0.04	1.64	69.24	1.00	8.00	1.29	1.35
ALPP (day)	1735	276.98	0.18	7.50	2.71	249.00	304.00	2.19	-0.83
ALSP (day)	1256	173.91	3.17	111.81	64.29	21.00	565.00	0.51	1.00
ALCI (day)	1256	451.44	3.24	114.20	25.30	371.45	859.00	0.53	1.00
ALMY (kg)	1735	4478.64	47.99	1998.97	44.63	1004.70	17510.90	2.22	1.06
AL305_DMY (kg)	1735	3813.69	32.43	1350.91	35.42	1004.70	10493.10	0.02	0.38
ALL (day)	1735	370.12	2.91	121.18	32.74	205.00	928.00	2.52	1.26
ALDP (day)	1735	91.36	0.97	40.58	44.42	19.00	264.00	2.76	1.48
ALPY (kg)	1735	21.72	0.20	8.31	38.25	7.00	54.30	9.38	2.15
ALDPY (day)	1735	47.48	0.74	30.54	64.32	11.00	167.00	1.04	1.16
Fat (%)	579	4.12	0.02	0.48	11.66	2.91	6.57	3.77	1.33
SNF (%)	579	8.14	0.02	0.41	4.98	7.01	9.42	-0.22	-0.36

Kurt: kurtosis; Skew: Skewedness

#### 4.2.1.4. All lactation calving interval (ALCI)

The average of ALCI with coefficient of variation was  $451.44 \pm 3.24$  days and 25.30%, correspondingly. The average ALCI observed in the study was in agreement with those CI reported by Kumar (1982), Duarte *et al.* (1983), Kishore (2012) and Dhaka (2013) for Zebu, Nellore, Tharparkar and Rathi cattle respectively. However it was shorter than those reported by Butterworth and McNitt (1984), Wagenaar *et al.* (1986) and Yadav *et al.* (2004) for Zebu, Highland zebu, and crossbred cattle, in that order and longer than those reported by Oyedipe *et al.* (1982) for White Fulani and Singh and Gurnani (2004) for Karan Fries & Karan Swiss cattle. The extended calving interval (928 days) observed might be related to the high yielding capacity of the herd which commonly might encounter negative energy balance experienced especially during the early stages of lactation. In order to maintain regular oestrus, higher producers would require more nutrients. Moreover, selection for milk production for several generations might likely be the other reasons because reproduction efficiency and production have unfavorable correlation after certain stage.

#### 4.2.2. Milk production traits

The overall mean, standard error, standard deviation, coefficient of variations, minimum and maximum values for AL305\_DMY, ALMY, ALL, ALDP, ALPY, and ALDPY are presented in table 36.

#### **4.2.2.1. All lactation 305 days milk yield (AL305\_DMY)**

The mean AL305\_DMY and CV of crossbred cattle were  $3813.69 \pm 32.43$  kg and 35.42%, respectively. Lakshmi *et al.* (2009) for HF  $\times$  Sahiwal, Thomas and Kumar (2009) for crossbred cattle, Dandapat *et al.* (2010) for HF  $\times$  Jersey  $\times$  Sahiwal, Poonam *et al.* (2016) for Jersey crossbred cattle and Dash *et al.* (2016) for Karan Fries reported lower average 305\_DMY as compared as the present finding. On the contrary, M'hamdi *et al.* (2012) for Tunisian Holstein and Japheth *et al.* (2015) for Karan Fries cattle reported higher values for the trait.

#### **4.2.2.2. All lactation all lactation milk yield (ALMY)**

The average ALMY with CV ( $4478.64 \pm 47.99$  kg; 44.63%) for crossbred cattle found in the present study were higher than the reports of Usman *et al.* (2011) for HF cattle, Gorbani *et al.* (2011) for HF Cross, Mandal *et al.* (2013) for Jersey crossbred cattle, Al-Samarai *et al.* (2015) for HF and Poonam *et al.* (2016) for Jersey crossbred cattle and as compared as the present finding, higher means for the same trait was given by Tekereli and Gundogan (2005) for Holstein, Hashemi *et al.* (2009) for Iranian Holstein and Japheth *et al.* (2015) for Karan Fries cattle.

#### **4.2.2.3. All lactation length (ALL)**

ALL of crossbred cattle averaged  $370.12 \pm 2.91$  kg with CV of 32.74%. In line with the present result, many findings were given by various previous authors Singh *et al.* (2006) for Crossbred Cattle, Usman *et al.* (2011) for HF cattle, Mandal *et al.* (2013) for Jersey crossbred cattle and Japheth *et al.* (2015) for Karan Fries cattle]. Lower findings as compared as the finding in our study were observed by Lakshmi *et al.* (2009) for HF  $\times$  Sahiwal, M'hamdi *et al.* (2012) for Tunisian Holstein, Al-Samarai *et al.* (2015) for HF, Wondifraw *et al.* (2013) for HF  $\times$  Deoni, and Poonam *et al.* (2016) for Jersey crossbred cattle.

#### **4.2.2.4. All lactation dry period (ALDP)**

The average ALDP with CV value in crossbred dairy cattle was  $91.36 \pm 0.97$  days and 44.42%, respectively. This average ALDP observed in the study was in comparable with mean FLDP reported by Shitta *et al.* (2002) for Egypt HF cattle. Whilst Kumar (1994), El-Arian *et al.* (2003), and Mukharjee (2005) found higher finding for the same trait in the F (Red Dane  $\times$  Sahiwal), Egypt HF, cattle HF  $\times$  Sahiwal and Crossbred cattle, respectively. Kumar (1994) for Jersey  $\times$  Sahiwal and Salem *et al.* (2006) for Egypt HF cattle obtained lower result for the trait.

#### **4.2.2.5. All lactation peak yield (ALPY)**

The average ALPY of crossbred dairy cattle was  $21.72 \pm 0.20$  kg with CV of 38.25%. This average value was higher than those reported by Lakshmi *et al.* (2009) for HF  $\times$  Sahiwal, Thomas and Kumar (2009) for crossbred cattle, and Poonam *et al.* (2015<sup>a</sup>, 2016<sup>b</sup>) for Jersey crossbred cattle.

#### **4.2.2.6. All lactation days to attend peak yield (ALDPY)**

ALDPY in our study averaged  $47.48 \pm 0.74$  days with coefficient of variation of 64.32%. In contrast to the present results, low average ALDPY was reported by Vij *et al.* (1992) who reported  $33.002 \pm 39.15$  days to attain peak yield in different breeds of cattle and Dhaka (2013) who reported overall least-squares mean of days to attain peak yield as  $30.95 \pm 0.036$  days for Rathi cattle. If peak yield is achieved earlier within reliable limits then it is expected that milk yield shall be more.

### **4.3. Influences of Fixed and Random Factors on First Lactation Performance**

#### **Traits**

#### **4.3.1. Influences of fixed and random factors on growth traits**

The mean sum squares of analysis of variance and least square means along with standard error for BW0, BW90, BW180, BW270, BW365, BW450 and BW540 of crossbred cattle across genetic and non-genetic factors are presented in Table 37 and Annex-table 1 and Fig. 2.

#### **4.3.1.1. The influences of season of birth**

The influences of season of birth on BW0, BW270, BW365, BW450, and BW540 were found to be significant ( $P < 0.01$ ) in both analysis of variance and least square analysis. Season of birth had also significant effect on BW90 at  $P < 0.05$ . According to the least square analysis, crossbred cows born in SOB3 (April-June) had heavier birth weight (BW0) as compared as cows born in other season. Lower BW90 was observed in crossbred cows born in SOB5 (September to October) than in other seasons. Crossbred cows born in SOB3 and SOB5 had better ( $P < 0.01$ ) BW270, BW365 and BW450 than cows born in other seasons of the whole 32 years of the study periods. However there were no significant ( $P > 0.05$ ) differences among SOB1, SOB2 and SOB4 for BW270, BW365 and BW450. Higher BW540 was found in crossbred cows born in the SOB3 followed by SOB5 and SOB2 as compared as cows born in SOB1 and SOB4.

In line with the present results, several previous workers had reported the significant influences of season of birth (SOB) on different growth performance traits

(Demeke *et al.*, 2003 for HF×Boran crosses; Mohamed, 2004, Sagar *et al.*, 2017 for Vrindavani cattle).

#### **4.3.1.2. The influences of period of birth**

The analyses of least square analysis of variance evidenced that average BW0, BW270, BW365, BW450, and BW540 varied highly and significantly ( $P<0.01$ ) across periods of birth. Average BW270 and BW90 were also significantly influenced by period of birth at ( $P<0.05$ ). The variation in the growth traits of calves over periods of birth might be associated with the prepartum management of the cows and variation in management across the different periods. And also be related to nutritional and climatic conditions particularly rainfall patterns. The coefficient of variation has shown slight increase with increases in age. This may indicate increased role of the environment in causing the variation. However no significant effect ( $P>0.05$ ) of periods of birth on BW180 was found in crossbred cattle. Crossbred cows born in the POB6 had better BW0 followed by those born in the POB1, POB3, and POB8 whereas lower BW0 was seen in crossbred cows born in POB2. BW0 did not significantly vary among crossbred cows born in the POB4, POB5, and POB6. Significantly higher BW90 was found in crossbred cows born in the POB8 whereas those born in POB3 were lower for BW90. Crossbred cows born in POB8 were heavier for BW270 and BW365 than those born in the other periods of birth. The lower average BW270 and BW365 were observed in cows born in the POB3 and POB4. Crossbred cows born in POB7 followed by POB6 were higher for BW450 and BW540 than those born in the other periods. For both traits, crossbred cows born in the POB2 had lower body weight measurements.

The significant influence of period of birth on BW0 and BW90 found in the present study was supported by similar findings of Rahman *et al.* (2015) for high yielding dairy seed calves. In consistent with the present findings, the significant influences of period of birth were observed by Abera *et al.* (2012) in Horro (Zebu) and their crosses with Holstein Friesian and Jersey cattle in Ethiopia and Demeke *et al.* (2003) in the HF×Boran crosses. Also significant ( $P<0.05$ ) influences of period of birth on birth weight, 3 month weight, 6 month weight, 9 month weight, 12 month weight and 24 month weight were obtained by Sagar *et al.* (2017) for Vrindavani cattle.

#### **4.3.1.3. The influences of genetic group**

Genetic group exerted significant ( $P < 0.01$ ) influences on BW180. However BW0, BW90, BW270, BW450 and BW540 were not significantly ( $P > 0.05$ ) affected by genetic group. The underlined reasons for insignificant effects of sire in all growth traits except BW180 might be close genetic link across the genetic groups due to common sires (HF and HF crossbred bulls) were used in all genetic group for breeding. Crossbred cows in the genetic group two and four weighed higher for BW180 than those in the genetic group three, but there were no significant variations among crossbred cows in the genetic group one, two and four. Similar to the present results, Rahman *et al.* (2015) found insignificant ( $P > 0.05$ ) influence of genetic group on BW0, BW90 and BW270 for Rahman *et al.* (2015) for high yielding dairy seed calves. Manzi (2011) and Rahman *et al.* (2003) had also reported non-significant influences of genetic group on BW0; but Nweze *et al.* (2011) and Kabir and Islam (2009) had found significant influence of genetic group on BW0 and Abera *et al.* (2012) reported that the influence of genetic group on different growth traits were observed to be significant ( $P < 0.05$ ) in Horro (Zebu) and their crosses with Holstein Friesian and Jersey cattle in Ethiopia.

#### **4.3.1.4. The random influences of sire**

The random effects of sire on all growth traits were found to be highly significant ( $P < 0.01$ ). So, sire selection should be kept on giving due attention.

**Table 37. Least squares means ( $\pm$ SE) for different growth traits (kg) in crossbred cattle**

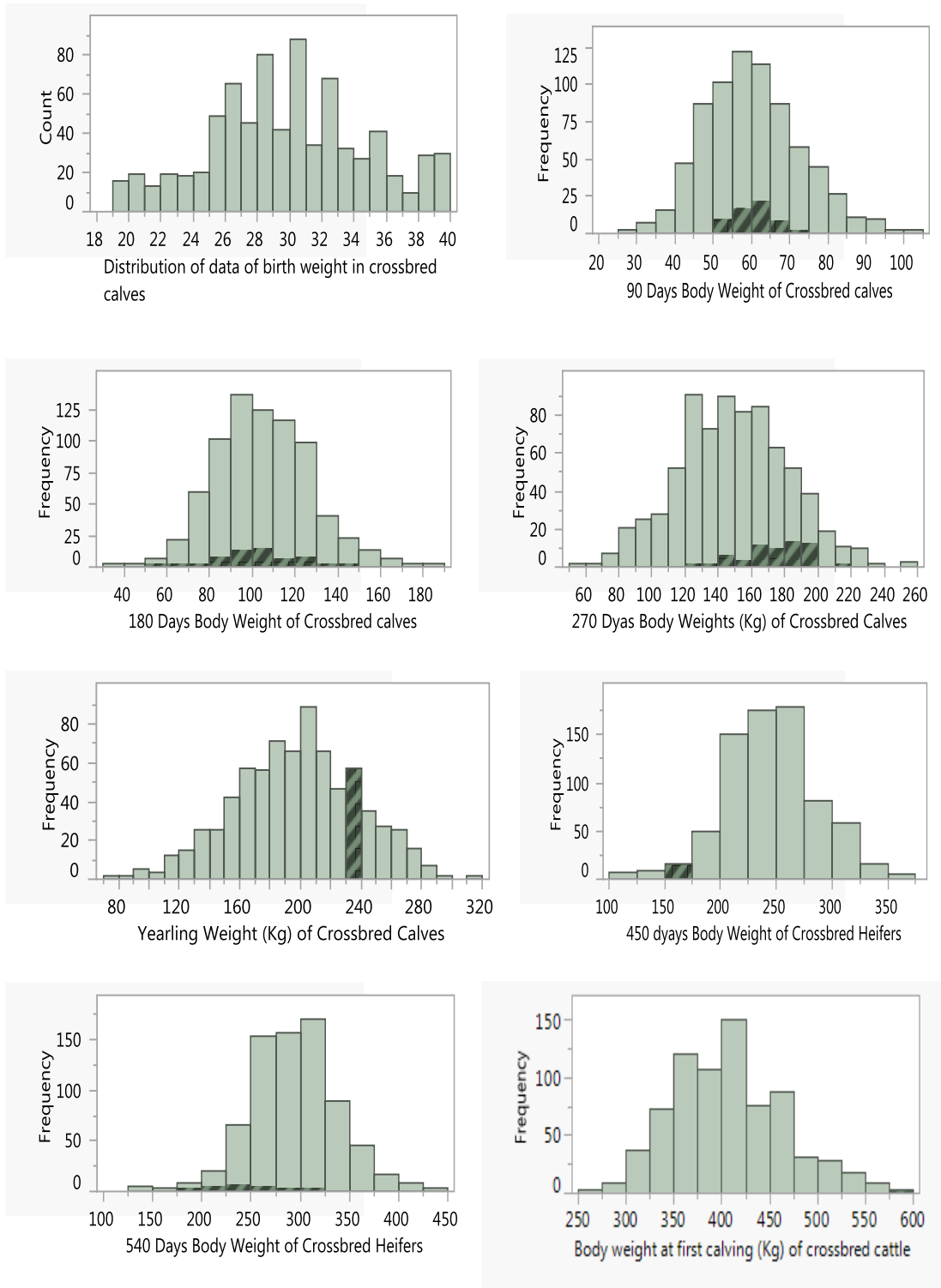
Source of variance	BW0	BW90	BW180	BW270
Overall mean	29.40 $\pm$ 0.18 (765)	59.42 $\pm$ 0.45 (760)	102.77 $\pm$ 0.76 (752)	146.80 $\pm$ 1.17 (752)
Season of birth	**	*	Ns	**
SOB1	29.85 $\pm$ 0.49 <sup>b</sup> (216)	60.16 $\pm$ .20 <sup>a</sup> (215)	102.45 $\pm$ 2.01 (215)	141.48 $\pm$ 2.86 <sup>c</sup> (214)
SOB2	28.94 $\pm$ 0.61 <sup>b</sup> (119)	59.37 $\pm$ 1.47 <sup>a</sup> (122)	99.71 $\pm$ 2.5 (116)	140.22 $\pm$ 3.55 <sup>c</sup> (117)
SOB3	30.77 $\pm$ 0.54 <sup>a</sup> (168)	59.37 $\pm$ 1.32 <sup>a</sup> (170)	101.75 $\pm$ 2.24 (165)	152.61 $\pm$ 3.20 <sup>a</sup> (164)
SOB4	29.54 $\pm$ 0.59 <sup>b</sup> (119)	56.50 $\pm$ 1.46 <sup>b</sup> (117)	103.29 $\pm$ 2.5 (116)	144.88 $\pm$ 3.49 <sup>bc</sup> (117)
SOB5	29.19 $\pm$ 0.55 <sup>b</sup> (143)	59.91 $\pm$ 1.34 <sup>a</sup> (136)	105.88 $\pm$ 2.25 (140)	151.92 $\pm$ 3.21 <sup>a</sup> (141)
Period of birth	**	*	Ns	*
POB1	29.41 $\pm$ 1.46 <sup>b</sup> (58)	57.94 $\pm$ 3.61 <sup>dc</sup> (58)	104.22 $\pm$ 6.01 (55)	146.91 $\pm$ 8.55 <sup>c</sup> (56)
POB2	28.88 $\pm$ 1.12 <sup>c</sup> (99)	54.21 $\pm$ 2.74 <sup>dc</sup> (84)	99.95 $\pm$ 4.60 (98)	134.19 $\pm$ 6.58 <sup>d</sup> (95)
POB3	29.27 $\pm$ 1.03 <sup>b</sup> (148)	54.87 $\pm$ 2.49 <sup>c</sup> (150)	98.89 $\pm$ 4.26 (147)	134.54 $\pm$ 6.05 <sup>d</sup> (147)
POB4	30.43 $\pm$ 0.87 <sup>ba</sup> (116)	60.23 $\pm$ 2.12 <sup>ba</sup> (144)	98.56 $\pm$ 3.58 (142)	134.99 $\pm$ 5.09 <sup>d</sup> (142)
POB5	30.45 $\pm$ 1.04 <sup>ba</sup> (101)	55.33 $\pm$ 2.52 <sup>c</sup> (103)	99.68 $\pm$ 4.27 (100)	142.75 $\pm$ 6.07 <sup>c</sup> (100)
POB6	31.12 $\pm$ 1.46 <sup>a</sup> (79)	63.82 $\pm$ 3.51 <sup>ba</sup> (81)	103.5 $\pm$ 6.0 (78)	144.68 $\pm$ 8.51 <sup>c</sup> (79)
POB7	28.45 $\pm$ 1.45 <sup>c</sup> (79)	61.53 $\pm$ 3.49 <sup>ba</sup> (81)	111.24 $\pm$ 5.96 (78)	160.19 $\pm$ 8.46 <sup>b</sup> (79)
POB8	29.25 $\pm$ 1.96 <sup>b</sup> (56)	64.87 $\pm$ 4.71 <sup>a</sup> (55)	104.87 $\pm$ 8.09 (53)	171.54 $\pm$ 11.48 <sup>a</sup> (54)
Genetic group	ns	ns	*	ns
GG1	29.75 $\pm$ 0.72(108)	58.18 $\pm$ 1.75 (105)	101.99 $\pm$ 2.95 <sup>ba</sup> (108)	143.89 $\pm$ 4.26(105)
GG2	28.87 $\pm$ 0.50(333)	60.11 $\pm$ 1.25 (326)	105.86 $\pm$ 2.08 <sup>a</sup> (333)	154.12 $\pm$ 2.95(331)
GG3	29.90 $\pm$ 0.83(79)	58.23 $\pm$ 2.08 (92)	97.64 $\pm$ 3.43 <sup>c</sup> (66)	141.22 $\pm$ 4.86 (71)
GG4	30.11 $\pm$ 0.67(245)	59.89 $\pm$ 1.65 (237)	104.97 $\pm$ 2.76 <sup>a</sup> (245)	145.66 $\pm$ 3.94(245)

*Table 37 continued*

Source of variance	BW365	BW450	BW540
Overall mean	195.49 $\pm$ 1.44 (751)	243.88 $\pm$ 1.49 (750)	291.57 $\pm$ 1.57 (750)
Season of birth	**	**	**
SOB1	189.91 $\pm$ 3.27 <sup>b</sup> (213)	241.72 $\pm$ 3.44 <sup>b</sup> (209)	289.40 $\pm$ 3.70 <sup>bc</sup> (208)
SOB2	194.81 $\pm$ 4.06 <sup>b</sup> (117)	242.60 $\pm$ 4.8 <sup>b</sup> (117)	293.00 $\pm$ 4.50 <sup>a</sup> (117)
SOB3	201.72 $\pm$ 3.66 <sup>a</sup> (164)	248.42 $\pm$ 3.75 <sup>a</sup> (166)	298.16 $\pm$ 4.04 <sup>a</sup> (166)
SOB4	194.97 $\pm$ 3.99 <sup>b</sup> (117)	239.37 $\pm$ 4.09 <sup>b</sup> (118)	291.60 $\pm$ 4.40 <sup>b</sup> (118)
SOB5	201.98 $\pm$ 3.66 <sup>a</sup> (140)	247.82 $\pm$ 3.76 <sup>a</sup> (140)	296.27 $\pm$ 4.04 <sup>a</sup> (141)

Period of birth	**	**	**
POB1	189.99±9.76 <sup>d</sup> (55)	241.88±9.91 <sup>d</sup> (55)	298.15±10.70 <sup>b</sup> (56)
POB2	166.29±7.53 <sup>g</sup> (96)	215.72±7.60 <sup>g</sup> (99)	272.75±8.20 <sup>c</sup> (98)
POB3	176.48±6.96 <sup>f</sup> (147)	225.68±7.05 <sup>f</sup> (147)	275.01±7.58 <sup>c</sup> (147)
POB4	181.51±5.87 <sup>e</sup> (143)	228.23±5.94 <sup>f</sup> (143)	278.70±6.35 <sup>c</sup> (143)
POB5	191.89±7.03 <sup>d</sup> (100)	233.48±7.14 <sup>e</sup> (100)	281.85±7.67 <sup>c</sup> (99)
POB6	214.98±10.07 <sup>c</sup> (79)	270.32±10.54 <sup>b</sup> (79)	322.20±11.27 <sup>a</sup> (79)
POB7	224.49±9.74 <sup>b</sup> (79)	280.30±9.95 <sup>a</sup> (79)	322.94±10.65 <sup>a</sup> (79)
POB8	227.79±13.19 <sup>a</sup> (52)	256.29±14.70 <sup>c</sup> (48)	297.88±15.73 <sup>b</sup> (49)
Genetic group	<b>ns</b>	<b>ns</b>	<b>ns</b>
GG1	193.71±4.86 (106)	243.59±4.89(108)	297.47±5.27(108)
GG2	204.48±3.37 (329)	253.42±3.52(320)	298.22±3.79(318)
GG3	193.14±5.58 (72)	236.62±5.72 (77)	286.12±6.15 (80)
GG4	195.39±4.50 (244)	242.31±4.58(245)	292.93±4.96(244)

\*P<0.05; \*\*P<0.01; Numbers in the parenthesis is number of observations



**Fig. 2. Distributions of data for different growth traits in crossbred dairy cattle**

#### 4.4. Multiple Linear Regressions

**Table 38. Multiple linear regression of body weight at 540 days on other body weight at 1, 90, 180 and 270 days of ages for crossbred female cattle**

Variables	Parameter estimates	R <sup>2</sup>
Intercept	113.87±8.52	80.43
BW0	0.96±0.24**	
BW90	0.23±0.13**	
BW180	0.25±0.10**	
BW270	0.76±0.06**	

\*\*P<0.01;

#### Developed Regression Equation:

$$Y = 113.87 + 0.96 * x_1 + 0.23 * x_2 + 0.25 * x_3 + 0.76 * x_4$$

#### Where,

Y= Body weight at 540 day of age; X<sub>1</sub>= Body weight at 0 day of age; X<sub>2</sub>= Body weight at 90 day of age; X<sub>3</sub>= Body weight at 180 day of age; X<sub>4</sub>= Body weight at 270 day of age

The regression analysis to predict body weight at 540 days of age from other body weight at 1, 90, 180 and 270 days of ages indicated that body weight at 540 days of age could be predicted with a high level of accuracy using body weight measurements at lower age. This help to select the animals for BW540 based on lower age body measurements and reduce the generation interval and farm management and maintenance costs.

#### 4.5. Influences of Fixed and Random Factors on First Lactation Reproduction

##### Traits (AFS, AFC and WFC)

The mean sum squares of analysis of variance and least square means along with standard error for first lactation reproduction traits of crossbred cattle across fixed and random factors are presented in Tables 39 and Annex-table 2 and Fig. 3.

##### 4.5.1. The influences of season of birth

Season of birth exerted highly significant (P<0.01) influences on WFC but it did not have significant influences on AFS and AFC. Female crossbred cattle born in the SOB1, SOB4, and SOB5 weighed significantly higher than those born in SOB2 and SOB3. Similar to the present finding, Kumari (2015) observed non-significant (P>0.05) effects of season of birth on AFS and AFC. Garima (2006), Dash (2014), and Singh *et al.* (2015) had also found insignificant (P>0.05) effects of season of birth on age at first calving. In contrast to the present findings, several previous authors

reported significant effects of season of birth on age at first calving (Mansour, 1992a; El-Khashab, 1993; Safaa, 2002). Oliveira (1974) reported that Nellore cows in Brazil that calved first in the dry season were younger than those that calved first in the rainy season. The underlined reason for insignificant influences of season on AFS and AFC but not WFC might be due to availability of cultivated green fodder round the year.

#### **4.5.2. The influences of period of birth**

Period of birth had highly significant ( $P < 0.01$ ) influences on AFS, and AFC but its effect on WFC was observed to be non-significant ( $P > 0.05$ ). Crossbred cows born in POB1 had higher mean of AFS and AFC as compared as crossbred cows born in the other period of birth. Crossbred cows born in the other POB apart from POB1 had similar AFS. Crossbred born in the POB1 attained AFS lately but other cows in the other POB reached AFS early. In line with our results, Garima, 2006 for crossbred cattle and Sentitula *et al.*, 2008 and Parveen, 2017 for Sahiwal cattle indicated that the effect of period of birth ( $P < 0.05$ ) on age at first calving was significant. However Bharti (2004), Singh *et al.* (2015) and Kumari (2015) for HF  $\times$  Sahiwal crossbred cattle could not found significant effects of the factor on AFC.

#### **4.5.3. The influences of genetic group**

Insignificant ( $P > 0.05$ ) differences were seen among crossbred cows for AFS, AFC and WFC across genetic groups. Similar results were reported by different researchers (Garima, 2006; Kumari, 2015; Singh *et al.* (2015). In contrary to the current result, Kumari (2015) reported that the genetic group of cow had significant ( $P < 0.05$ ) effect on AFS and AFC. For AFC alone, significant effects of genetic group on AFC were also observed by Kumar (1992) and Mukharjee (2005) in various crossbreds. The effects due to genetic groups were not significant for AFS, AFC and WFC which indicated that there is no larger difference between genetic groups.

#### **4.5.4. The random influences of sire**

Highly significant ( $P < 0.01$ ) influences of sire on AFS, AFC and WFC were found. The significant influence of sire on AFS and AFC observed in the present study was supported by Kumari (2015) who found similar result in the HF $\times$ Sahiwal crossbred cattle. Sire of the cow was also proved to have significant effect on AFC in dairy cattle by different research workers (Garima, 2006; Kumari, 2015; Singh *et al.*, 2015; Parveen, 2017). So, selection should be carefully made to select breeding sire for improving of AFS, AFC and WFC and thereby consecutively reproduction and production in the crossbred dairy cattle population.

**Table 39. Least squares means ( $\pm$ SE) for different first lactation reproductive traits in crossbred cattle**

Source	AFS (days)	AFC (days)	WFC (kg)
Overall mean	712.05 $\pm$ 9.24 (750)	1008.05 $\pm$ 9.52 (750)	404.55 $\pm$ 2.09 (750)
Season of birth	Ns	Ns	**
SOB1	728.84 $\pm$ 22.21 (212)	1026.10 $\pm$ 23.47 (212)	411.15 $\pm$ 5.39 <sup>a</sup> (210)
SOB2	723.71 $\pm$ 26.84 (114)	1007.45 $\pm$ 28.36 (114)	399.63 $\pm$ 6.58 <sup>b</sup> (113)
SOB3	706.35 $\pm$ 24.40 (165)	1008.03 $\pm$ 25.78 (165)	398.96 $\pm$ 5.86 <sup>b</sup> (167)
SOB4	706.09 $\pm$ 26.55 (119)	1011.99 $\pm$ 28.05 (119)	414.98 $\pm$ 6.43 <sup>a</sup> (120)
SOB5	687.31 $\pm$ 24.93 (140)	988.19 $\pm$ 26.34 (140)	417.58 $\pm$ 6.01 <sup>a</sup> (140)
Period of birth	**	**	*
POB1	1028.80 $\pm$ 68.29 <sup>a</sup> (68)	1308.67 $\pm$ 72.16 <sup>a</sup> (68)	390.35 $\pm$ 16.47 <sup>c</sup> (68)
POB2	624.45 $\pm$ 54.05 <sup>b</sup> (120)	918.61 $\pm$ 57.11 <sup>b</sup> (120)	389.08 $\pm$ 13.05 <sup>c</sup> (120)
POB3	588.75 $\pm$ 50.63 <sup>cb</sup> (140)	895.44 $\pm$ 53.50 <sup>cb</sup> (140)	394.04 $\pm$ 12.23 <sup>c</sup> (140)
POB4	676.49 $\pm$ 40.14 <sup>b</sup> (139)	990.40 $\pm$ 42.41 <sup>b</sup> (139)	416.88 $\pm$ 9.81 <sup>b</sup> (139)
POB5	714.08 $\pm$ 47.80 <sup>b</sup> (91)	1027.80 $\pm$ 50.51 <sup>b</sup> (91)	409.17 $\pm$ 11.64 <sup>b</sup> (91)
POB6	749.22 $\pm$ 71.81 <sup>ba</sup> (72)	1049.30 $\pm$ 75.89 <sup>ba</sup> (72)	406.75 $\pm$ 17.09 <sup>b</sup> (72)
POB7	638.37 $\pm$ 70.94 <sup>b</sup> (72)	922.39 $\pm$ 74.97 <sup>b</sup> (72)	411.82 $\pm$ 17.40 <sup>b</sup> (72)
POB8	663.51 $\pm$ 105.03 <sup>b</sup> (48)	954.21 $\pm$ 110.99 <sup>b</sup> (48)	449.58 $\pm$ 32.77 <sup>a</sup> (48)
Genetic group	ns	ns	ns
GG1	721.38 $\pm$ 30.96 (129)	1013.04 $\pm$ 32.72 (129)	403.60 $\pm$ 7.44 (129)
GG2	688.20 $\pm$ 22.17 (300)	977.22 $\pm$ 23.43 (300)	412.91 $\pm$ 5.38 (300)
GG3	742.60 $\pm$ 37.57 (72)	1046.48 $\pm$ 39.70 (72)	415.52 $\pm$ 9.03 (72)
GG4	689.67 $\pm$ 30.96 (249)	996.67 $\pm$ 32.72 (249)	401.81 $\pm$ 7.43 (249)

\*P<0.05; \*\*P<0.01; ns= non-significant; Number in the parenthesis is number of observations

#### 4.6. Influences of Fixed and Random Factors on First Lactation Reproduction

##### Traits (FLNSPC, FLPP, FLSP and FCI)

The mean sum squares of analysis of variance and least square means along with standard error for first lactation reproduction traits of crossbred cattle across fixed and random factors are presented in Tables 40 and Annex-table 3 and Fig. 3. The results in table 53 revealed that genetic group and period of calving for FLNSPC; genetic group, period of birth and sire for FLPP; period of calving and sire for FLSP and FCI were the most important fixed factors relative to all effects included in the model of analysis. The underlined reasons were the mean square values of these fixed factors were observed to be higher.

##### 4.6.1. The influences of period of birth

Except for FLPP, period of birth did not significantly influence FLNSPC, FLSP and FCI. Relatively longer average FLPP was observed in cows born in the

POB1, POB2 and POB3. However, crossbred cows in the POB6, POB7 and POB8 had relatively shorter average FLPP.

#### **4.6.2. The influences of season of calving**

There were no significant variations among crossbred cows for FLNSPC, FLPP, FLSP and FCI over season of calving. However the significant effect of season of calving on CI were observed by Singh *et al.* (2015) in different crossbred cattle while non-significant effect of season of calving on CI were reported by Garima (2006) and Safaa (2006) in different crossbred cattle. The significant effects of season of calving on FLSP were observed by Mukharjee (2005) while non-significant effects of season of calving were reported by Bharti (2004) and Dubey and Singh (2005) in crossbred cattle.

#### **4.6.3. The influences of period of calving**

Significant effects of period of calving were observed on FLNSPC, FLSP and FCI but average FLPP did not vary significantly ( $P>0.05$ ) among crossbred cows over period of calving. Crossbred cows calved in the POC5, 6 and 7 required higher average FLNSPC for conceiving than those calved in the other period of calving subclasses. However crossbred cows calved in the POC1 and POC2 needed smaller average FLNSPC. The higher and lower average FLSP were verified in crossbred cows calved in the period of calving 7 and 2, respectively as compared as crossbred cows calved in the other period of calving subclasses. Average FCI was very longer for crossbred cows calved in the period of calving 7 followed by POC6 and POC4 but those calved in POC2 had shorter average FCI. In agreement with the present findings, the significant effect of period of calving on FCI were observed by Dubey and Singh (2005) and Garima (2006) while non-significant effect period of calving were observed by Singh *et al.* (2015) and Parveen (2017) in various crossbred cattle. The significant effects of period of calving on FLSP were observed by Mukharjee (2005) and Dubey and Singh (2005) while non-significant effects of period of calving were observed by Bharti (2004) in different crossbred.

#### **4.6.4. The influences of genetic group**

Genetic group had significantly ( $P<0.05$ ) and highly significantly ( $P<0.01$ ) effects on FLNSPC and FLPP, in that order. However it had insignificant ( $P>0.05$ ) influences on FLSP and FCI. Crossbred cows under genetic group two and four were higher in average FLNSPC but crossbred cows under genetic group one conceived with small average NSPC. The longer average FLPP was found in crossbred cows in

the genetic group 2 and 3 whereas in crossbred cows in the genetic group 1 and 4, average length pregnancy period was relatively short. The non-significant effects of Genetic group on CI were observed by Dubey and Singh (2005), Mukharjee (2005) and Singh *et al.* (2015) in various crossbred cattle whereas Garima (2006) had reported significant effect ( $P < 0.05$ ) of animal genetic group on CI (Garima, 2006). The non-significant effects of genetic group on FLSP were observed by Mukharjee (2005) and Dubey and Singh (2005) in different crossbred cattle.

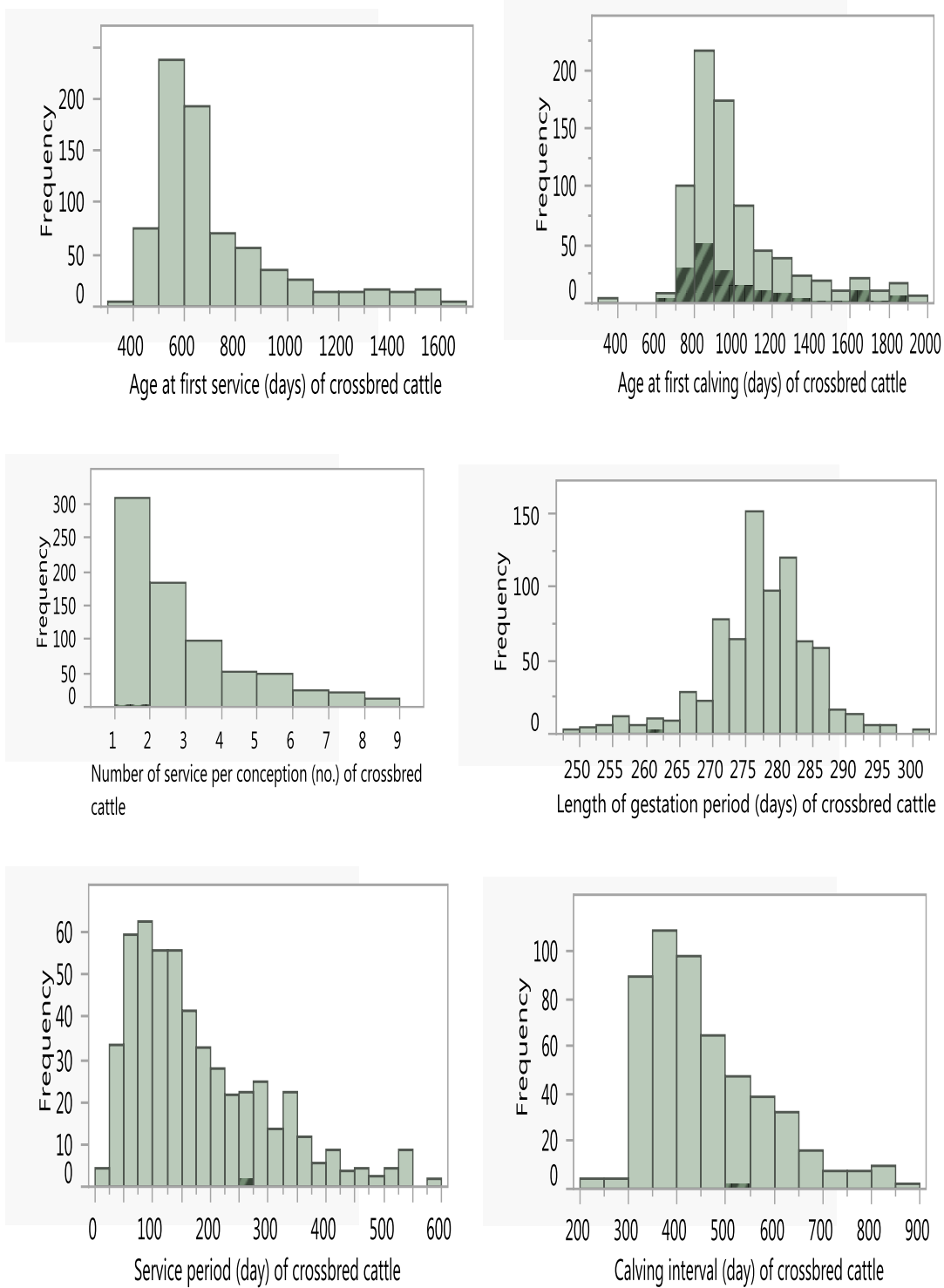
#### **4.6.5. The random influences of sire of cow**

Average FLPP, FLSP and FCI were significantly ( $P < 0.05$ ) affected by sire but non-significant ( $P > 0.05$ ) effect of sire was found on FLNSPC. Calving interval length was found to be influenced significantly by the effect of sire of the cow by different investigators (Singh *et al.*, 2015; Parveen, 2017). However Safaa (2006) reported that sire had exerted insignificant ( $P > 0.05$ ) effect on calving interval.

**Table 40. Least squares means ( $\pm$ SE) of first lactation various reproductive traits in crossbred cattle**

Source of Variance	FLNSPC (no.)	FLPP (day)	FLSP (day)	FCI (day)
Overall mean	2.34 $\pm$ 0.06 (750)	276.97 $\pm$ 0.27 (750)	117.91 $\pm$ 5.18 (526)	454.63 $\pm$ 5.22 (526)
Period of birth	<b>ns</b>	**	<b>Ns</b>	<b>ns</b>
POB1	3.19 $\pm$ 0.63 (75)	282.64 $\pm$ 2.68 <sup>a</sup> (71)	208.45 $\pm$ 49.87 (54)	492.36 $\pm$ 50.25 (54)
POB2	2.53 $\pm$ 0.46 (111)	281.99 $\pm$ 2.03 <sup>a</sup> (115)	190.68 $\pm$ 38.48 (92)	472.22 $\pm$ 38.77 (92)
POB3	3.20 $\pm$ 0.43 (133)	283.53 $\pm$ 1.88 <sup>a</sup> (140)	186.69 $\pm$ 35.38 (98)	472.28 $\pm$ 35.64 (98)
POB4	2.59 $\pm$ 0.38 (132)	280.01 $\pm$ 1.69 <sup>ba</sup> (134)	196.65 $\pm$ 34.51 (79)	479.33 $\pm$ 34.77 (79)
POB5	2.09 $\pm$ 0.41 (99)	276.34 $\pm$ 1.82 <sup>ba</sup> (102)	247.52 $\pm$ 36.00 (73)	523.93 $\pm$ 36.27 (73)
POB6	1.87 $\pm$ 0.53 (70)	266.77 $\pm$ 2.34 <sup>b</sup> (70)	154.59 $\pm$ 46.70 (48)	418.27 $\pm$ 47.05 (48)
POB7	1.36 $\pm$ 0.68 (69)	271.30 $\pm$ 3.01 <sup>b</sup> (70)	83.77 $\pm$ 63.62 (50)	350.54 $\pm$ 64.10 (50)
POB8	1.25 $\pm$ 0.97 (61)	264.93 $\pm$ 4.17 <sup>b</sup> (48)	269.83 $\pm$ 80.47 (32)	533.32 $\pm$ 81.07 (32)
Genetic group	*	**	<b>ns</b>	<b>ns</b>
GG1	1.81 $\pm$ 0.25 <sup>b</sup> (122)	273.60 $\pm$ 1.09 <sup>b</sup> (130)	193.93 $\pm$ 19.92 (105)	466.43 $\pm$ 20.07 (105)
GG2	2.50 $\pm$ 0.18 <sup>a</sup> (301)	277.57 $\pm$ 0.81 <sup>a</sup> (307)	165.59 $\pm$ 15.16 (216)	443.49 $\pm$ 15.28 (216)
GG3	2.32 $\pm$ 0.29 <sup>ba</sup> (89)	278.25 $\pm$ 1.29 <sup>a</sup> (66)	210.98 $\pm$ 25.65 (55)	489.00 $\pm$ 25.85 (55)
GG4	2.41 $\pm$ 0.24 <sup>a</sup> (238)	274.34 $\pm$ 1.07 <sup>b</sup> (247)	198.59 $\pm$ 20.21 (150)	472.21 $\pm$ 20.36 (150)
Seasons of calving	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
SOC1	2.33 $\pm$ 0.17 (225)	276.53 $\pm$ 0.75 (230)	173.09 $\pm$ 14.42 (77)	448.83 $\pm$ 14.53 (77)
SOC2	2.12 $\pm$ 0.20 (116)	276.00 $\pm$ 0.89 (115)	203.77 $\pm$ 17.59 (97)	481.17 $\pm$ 17.72 (97)
SOC3	2.31 $\pm$ 0.21 (143)	275.36 $\pm$ 0.90 (140)	206.84 $\pm$ 17.63 (92)	481.32 $\pm$ 17.76 (92)
SOC4	2.30 $\pm$ 0.20 (132)	275.08 $\pm$ 0.86 (131)	190.04 $\pm$ 16.88 (97)	464.36 $\pm$ 17.01 (97)
SOC5	2.24 $\pm$ 0.19 (134)	276.72 $\pm$ 0.83 (134)	187.63 $\pm$ 16.72 (73)	463.22 $\pm$ 16.84 (73)
Period of calving	*	<b>ns</b>	*	*
POC1	1.13 $\pm$ 0.43 <sup>c</sup> (103)	274.96 $\pm$ 1.87 (105)	152.21 $\pm$ 37.28 <sup>b</sup> (69)	427.03 $\pm$ 37.56 <sup>ba</sup> (69)
POC2	1.04 $\pm$ 0.37 <sup>c</sup> (139)	275.52 $\pm$ 1.63 (149)	122.19 $\pm$ 32.83 <sup>b</sup> (109)	397.08 $\pm$ 33.08 <sup>b</sup> (109)
POC3	1.74 $\pm$ 0.34 <sup>b</sup> (145)	274.47 $\pm$ 1.48 (150)	199.85 $\pm$ 29.44 <sup>ba</sup> (100)	473.97 $\pm$ 29.67 <sup>ba</sup> (100)
POC4	2.49 $\pm$ 0.31 <sup>ba</sup> (117)	275.79 $\pm$ 1.37 (117)	216.20 $\pm$ 27.20 <sup>ba</sup> (80)	491.14 $\pm$ 27.40 <sup>ba</sup> (80)
POC5	3.03 $\pm$ 0.38 <sup>a</sup> (79)	277.34 $\pm$ 1.62 (81)	190.82 $\pm$ 31.2 <sup>b</sup> (60)	468.83 $\pm$ 31.76 <sup>ba</sup> (60)
POC6	3.02 $\pm$ 0.50 <sup>a</sup> (84)	277.34 $\pm$ 2.16 (65)	226.23 $\pm$ 44.49 <sup>ba</sup> (50)	503.22 $\pm$ 44.83 <sup>a</sup> (50)
POC7	3.38 $\pm$ 0.56 <sup>a</sup> (83)	276.17 $\pm$ 2.42 (83)	238.41 $\pm$ 48.62 <sup>a</sup> (58)	513.19 $\pm$ 48.99 <sup>a</sup> (58)

\*P<0.05; \*\*P<0.01; ns= non-significant; Numbers in the parenthesis are number of observations



**Fig. 3. Distributions of data for different first lactation reproduction traits in crossbred cattle**

#### **4.7. Influences of Fixed and Random Factors on Reproduction Traits from All Lactation**

The mean sum squares of analysis of variance and least square means along with standard error for reproduction traits from all lactation of crossbred cattle across fixed and random factors are presented in Table 41 and Annex-table 4 and Fig. 4.

##### **4.7.1. The influences of period of birth**

The effects of period of birth on ALSP and ALCI were found to be significant ( $P < 0.05$ ) and highly significant ( $P < 0.01$ ), correspondingly but non-significant ( $P > 0.05$ ) on ALNSPC and ALPP. Longer average ALSP was seen in crossbred cows born in the POB8 than those born in the other POB subclasses. There were no significant variations among crossbred cows for ALCI born in all POB subclasses except POB8. Crossbred cows born in the POB8 had higher average ALCI followed by those born in the POB5 whereas lower average ALCI was observed for crossbred cows born in the POB4. Cows in the other POB subclasses, they did not show significant differences for the average value of the same trait.

##### **4.7.2. The influences of season of calving**

Both analysis of variance and least square analysis showed that season of calving did not significantly ( $P > 0.05$ ) influenced ALLNSPC, ALSP, ALPP and ALCI. However the significant effect of season of calving on ALCI were observed by Raheja (1997), Sahana and Gurnani (2000), Gaur *et al.* (2001) and Dahiya *et al.* (2003) in different crossbred cattle while non-significant effect of season of calving on CI were reported by Nayak *et al.* (1996) and Singh *et al.* (2000) in different crossbred cattle. Similar to the present study, Dhaka (2013) observed non-significant effect of period of calving on ALPP, ALCI and ALSP. The very slight variations in ALPP, ALCI and ALSP across season of calving could be due to variation in environmental and management conditions.

##### **4.7.3. The influences of period of calving**

The period of calving significantly ( $p < 0.05$ ) influenced the ALNSPC and ALSP in crossbred cattle but it did have insignificant influence on ALPP and ALCI. The results of present study indicates good environmental control, better feeding and reproductive management of the farm and regular culling pattern on the basis of reproductive fitness that helps in reducing calving interval and pregnancy period.

ALNSPC varied significantly among crossbred cattle across period of calving which meant average ALNSPC was higher for crossbred cows calved in POC5 and POC6

but those calved in the POC1 and 2 had smaller NSPC than those calved in the other POC subclasses. Average ALSP was significantly longer for crossbred cows calved in POC4. However crossbred cows calved in the POC2 showed shorter average ALSP as compared as those calved in the other POC subclasses. The significant effect of period of calving on ALCI were observed by Sahana and Gurnani (2000), Singh *et al.* (2000), Gaur *et al.* (2001), and Dahiya *et al.* (2003) while non-significant effect of calving were observed by Reddy and Basu (1985), and Raheja (1997) in various crossbred cattle. The difference in ALNSPC might be due to annual changes in climate conditions, quantity and quality of feeds available and differential management practices followed over the years. Similar findings were reported by Koul *et al.* (1979), Rajan *et al.* (1981), and Jajo (1984). Similar to the present study, Dhaka (2013) observed non-significant effect of period of calving on ALPP, and ALCI. The significant variation of ALSP across period of calving might be due to variation in environmental and management conditions.

#### **4.7.4. The influences of genetic group**

Genetic group had highly significant ( $P < 0.01$ ) influences on average ALNSPC and ALPP. However it did not have significant ( $P > 0.05$ ) effect on ALSP and ALCI. The average NSPC for crossbred cows in the G1 was lower whilst the average NSPC of crossbred cows in G2, G3 and G4 were similar. There were significant ( $P < 0.05$ ) differences between G3 and G1, G3 and G2, G3 and G4 but no differences among G1, G2 and G4 for PP. Genetic group had highly significant ( $P < 0.01$ ) influences on average ALNSPC and ALPP. However it did not have significant ( $P > 0.05$ ) effect on ALSP and ALCI.

#### **4.7.5. The random influences of sire**

The random influences of sire were highly significant ( $P < 0.01$ ) on ALPP and ALCI, significant on ALSP but non-significant on ALNSPC. Similar to the present finding, Jumat *et al.* (1988) reported non-significant effects of Sire on ALNSPC. The study clearly indicated that improvement of ALNSPC could be attained through means other than genetic. ALCI was found to be influenced significantly by the effect of sire of the cow by different investigators (Singh *et al.*, 1987; Afifi *et al.*, 1992b; Shereen, 1998). However Saafa (2006) reported that sire had exerted insignificant ( $P > 0.05$ ) effect on calving interval. Sharma and Prabhu (1968) did their study on variation in gestation period due to sires in eight breeds of zebu cattle and found that males were carried for a longer period (2-8 days more) than females in all the breeds

and herds considered, which fact corroborated the general findings of earlier workers. Significant variation in gestation lengths due to sire used was found in the case of female births in Gir and Kangayam breeds. In all other breeds, the differences were not statistically significant. In the case of dams, significant differences in gestation lengths due to dams were found in mate births in Ongole, Hallikar and Sindhi (Kirkee herd) only. In all other cases, the differences were not statistically significant.

#### **4.7.6. The influences of age at calving**

Age at calving exerted highly significant ( $P < 0.01$ ) influences on ALNSPC and ALCI; but significant ( $P < 0.05$ ) and non-significant influences of the same factor were found on ALPP and ALSP, respectively. Higher average ALNSPC was found for crossbred cows under AAC8 whereas those under AAC1 had lower average ALNSPC. Average ALSP was obtained to be longer in crossbred cows under AAC8 than crossbred cows in the other AAC subclasses. Short average ALSP was observed for crossbred cows under AAC2 as compared as crossbred cows in the other age at calving. Crossbred cows under AAC8 had higher average ALCI than crossbred cows in other AAC sub groups, but lower average ALCI was found in crossbred cows under AAC2.

#### **4.7.7. The influences of weight at calving**

The effects of WAC on ALNSPC, ALSP and ALCI were found to be highly significant ( $P < 0.01$ ) but ALPP was not significantly ( $p > 0.05$ ) influenced by WFC. Crossbred cows with WAC8 followed by WAC9 and WAC7 was higher in ALNSPC as compared as crossbred cows with in the other WAC subclasses. Crossbred cows with WAC1 required less NSPC for getting pregnancy preceded by WAC2. Higher average ALSP was observed in crossbred cows with WAC8 followed by WAC whereas lower was found in crossbred cows with WAC4 next to WAC1. ALCI was found to be higher for crossbred cows with WAC8 followed by WAC7 and WAC9 than those in the other WAC subclasses. Crossbred cows with WAC2 and WAC1 had shorter average ALCI than crossbred cows with in the other WAC subclasses.

### **4.8. Influences of Fixed and Random Factors on First Lactation Milk Production Traits**

The mean sum squares of analysis of variance and least square means along with standard error for first lactation reproduction traits of crossbred cattle across fixed and random factors are presented in Table 42 and Annex-table 5 and Fig. 5.

#### **4.8.1. The influences of period of birth**

The effects of period of birth was significant ( $P < 0.05$ ) only on FLDP; but other milk production traits (FLMY, FL305\_DMY, FLL, FLPY and FLDPY) were not significantly affected by it. Significantly longer average FLDP was found in crossbred cows born in the POB6 while shorter average FLDP was seen for crossbreed cattle born in the POB8 as compared as those born in the other POB subclasses.

#### **4.8.2. The influences of seasons of calving**

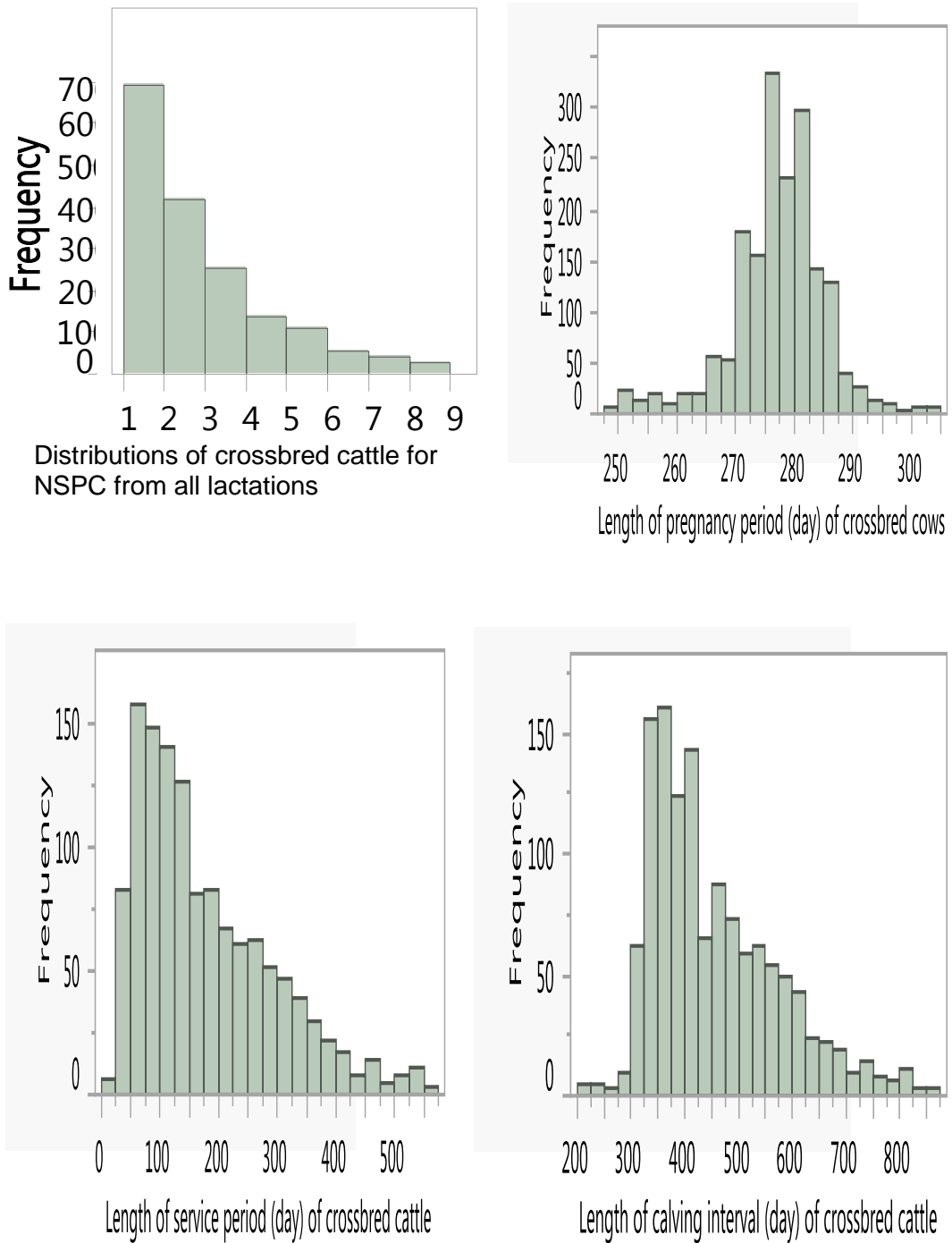
Only FLDPY was significantly ( $P < 0.05$ ) affected by season of calving out of all first lactation milk production traits indicating poor contribution of season of calving to the total variability of FLMY, FL305\_DMY, FLL, FLDP and FLPY. In line with the present study, season of calving had non-significant ( $P > 0.05$ ) influences on: FL305\_DMY (Safaa, 2006; Manoj *et al.*, 2012; Wondifraw *et al.*, 2013), FLMY (Garima, 2006; Verma *et al.*, 2015), FLL (Garima, 2006, Manoj *et al.*, 2012; Wondifraw *et al.*, 2013; Kumari, 2015), FLDP (Bharti, 2004; Dubey and Singh, 2005; Garima, 2006; Singh *et al.*, 2015). However significant effects ( $P < 0.01$ ) of season of calving were reported by Kumari (2015) on 305 days milk yield; Safaa (2006), Wondifraw *et al.* (2013) and Kumari (2015) on FLMY; Singh and Gurnani (2004) and Safaa (2006) on FLL; Mukharjee (2005) and Safaa (2006) on FLDP; Poonam *et al.* (2016) and Singh *et al.* (2015) on FLPY and Singh *et al.* (2015) on FLDPY. Cows calving in dry season were milked significantly ( $P < 0.05$ ) longer than those calving in rainy season.

**Table 41. Least squares means ( $\pm$ SE) of different reproductive traits from all lactations in crossbred cattle**

Source of variance	ALNSPC (no.)	ALPP(day)	ALSP (day)	ALCI (day)
Overall mean	2.37 $\pm$ 0.04 (1735)	276.98 $\pm$ 0.18 (1735)	173.93 $\pm$ 3.17 (1256)	451.47 $\pm$ 3.24 (1256)
Period of birth	<b>ns</b>	<b>ns</b>	*	**
POB1	3.04 $\pm$ 0.36 (198)	279.35 $\pm$ 1.66 (207)	172.56 $\pm$ 27.96 <sup>b</sup> (179)	435.48 $\pm$ 28.38 <sup>b</sup> (179)
POB2	2.65 $\pm$ 0.27 (340)	279.05 $\pm$ 1.25 (350)	176.97 $\pm$ 21.31 <sup>b</sup> (280)	448.10 $\pm$ 21.63 <sup>b</sup> (280)
POB3	2.81 $\pm$ 0.25 (297)	279.25 $\pm$ 1.18 (310)	166.01 $\pm$ 20.17 <sup>b</sup> (219)	434.03 $\pm$ 20.48 <sup>b</sup> (219)
POB4	2.52 $\pm$ 0.24 (246)	277.81 $\pm$ 1.12 (254)	131.92 $\pm$ 20.04 <sup>b</sup> (155)	425.03 $\pm$ 20.34 <sup>c</sup> (155)
POB5	2.27 $\pm$ 0.28 (187)	276.74 $\pm$ 1.30 (191)	189.36 $\pm$ 24.34 <sup>b</sup> (136)	505.95 $\pm$ 24.73 <sup>ba</sup> (136)
POB6	2.51 $\pm$ 0.34 (187)	272.98 $\pm$ 1.55 (161)	184.21 $\pm$ 26.21 <sup>b</sup> (114)	470.33 $\pm$ 26.61 <sup>b</sup> (114)
POB7	1.71 $\pm$ 0.40 (180)	275.06 $\pm$ 1.87 (182)	136.27 $\pm$ 32.95 <sup>b</sup> (123)	415.55 $\pm$ 33.46 <sup>b</sup> (123)
POB8	1.97 $\pm$ 0.61 (100)	273.28 $\pm$ 2.82 (80)	252.07 $\pm$ 52.57 <sup>a</sup> (50)	556.43 $\pm$ 53.37 <sup>a</sup> (50)
Seasons of calving	<b>ns</b>	<b>ns</b>	<b>ns</b>	<b>ns</b>
SOC1	2.47 $\pm$ 0.12 (512)	277.12 $\pm$ 0.58 (525)	172.35 $\pm$ 9.70 (380)	456.83 $\pm$ 9.86 (380)
SOC2	2.36 $\pm$ 0.14 (297)	276.65 $\pm$ 0.66 (265)	169.48 $\pm$ 11.55 (191)	453.26 $\pm$ 11.73 (191)
SOC3	2.40 $\pm$ 0.14 (325)	276.99 $\pm$ 0.65 (335)	185.91 $\pm$ 11.08 (244)	467.26 $\pm$ 11.25 (244)
SOC4	2.51 $\pm$ 0.14 (296)	276.18 $\pm$ 0.64 (293)	180.36 $\pm$ 11.03 (210)	469.68 $\pm$ 11.20 (210)
SOC5	2.45 $\pm$ 0.14 (305)	276.52 $\pm$ 0.63 (317)	172.76 $\pm$ 10.73 (230)	459.77 $\pm$ 10.94 (230)
Period of calving	*	<b>ns</b>	*	<b>ns</b>
POC1	2.10 $\pm$ 0.34 <sup>d</sup> (276)	277.45 $\pm$ 1.56 (282)	176.42 $\pm$ 26.95 <sup>ba</sup> (201)	467.81 $\pm$ 27.37 (201)
POC2	2.11 $\pm$ 0.27 <sup>dc</sup> (376)	277.00 $\pm$ 1.23 (396)	154.38 $\pm$ 21.47 <sup>b</sup> (305)	448.91 $\pm$ 21.81 (304)
POC3	2.49 $\pm$ 0.22 <sup>bac</sup> (330)	276.15 $\pm$ 1.03 (344)	189.94 $\pm$ 18.24 <sup>ba</sup> (246)	465.52 $\pm$ 18.52 (246)
POC4	2.57 $\pm$ 0.21 <sup>ba</sup> (224)	276.53 $\pm$ 0.96 (225)	192.76 $\pm$ 16.42 <sup>a</sup> (160)	461.70 $\pm$ 16.67 (160)
POC5	2.63 $\pm$ 0.24 <sup>a</sup> (182)	277.77 $\pm$ 1.10 (157)	159.72 $\pm$ 19.29 <sup>ba</sup> (114)	436.40 $\pm$ 19.58 (114)
POC6	2.88 $\pm$ 0.28 <sup>a</sup> (185)	276.83 $\pm$ 1.30 (177)	184.15 $\pm$ 23.08 <sup>ba</sup> (115)	480.81 $\pm$ 23.43 (115)
POC7	2.28 $\pm$ 0.35 <sup>bdc</sup> (162)	275.09 $\pm$ 1.63 (154)	175.82 $\pm$ 28.49 <sup>ba</sup> (114)	468.38 $\pm$ 28.92 (114)
Genetic group	**	**	<b>ns</b>	<b>ns</b>
GG1	2.06 $\pm$ 0.16 <sup>b</sup> (305)	275.07 $\pm$ 0.74 <sup>b</sup> (320)	173.07 $\pm$ 12.07 (259)	464.70 $\pm$ 12.26 (259)
GG2	2.73 $\pm$ 0.13 <sup>a</sup> (723)	276.62 $\pm$ 0.58 <sup>b</sup> (738)	178.62 $\pm$ 9.61 (540)	445.01 $\pm$ 9.76 (540)
GG3	2.36 $\pm$ 0.19 <sup>a</sup> (209)	279.07 $\pm$ 0.88 <sup>a</sup> (159)	182.91 $\pm$ 16.19 (114)	474.81 $\pm$ 16.44 (114)
GG4	2.59 $\pm$ 0.16 <sup>a</sup> (498)	276.01 $\pm$ 0.75 <sup>b</sup> (518)	170.08 $\pm$ 12.46 (342)	460.93 $\pm$ 12.70 (342)
Age at calving	**	<b>ns</b>	*	**
AAC1	1.79 $\pm$ 0.14 <sup>d</sup> (332)	275.76 $\pm$ 0.64 (336)	192.99 $\pm$ 14.47 <sup>ba</sup> (109)	486.15 $\pm$ 14.76 <sup>ba</sup> (109)

AAC2	2.65±0.14 <sup>bac</sup> (315)	276.35±0.65 (323)	149.75±12.86 <sup>c</sup> (140)	438.78±13.06 <sup>c</sup> (140)
AAC3	2.68±0.14 <sup>ba</sup> (267)	275.95±0.63 (275)	188.87±10.24 <sup>ba</sup> (247)	476.55±10.40 <sup>ba</sup> (247)
AAC4	2.45±0.15 <sup>bac</sup> (194)	277.63±0.69 (197)	182.66±10.86 <sup>ba</sup> (189)	460.96±11.03 <sup>ba</sup> (189)
AAC5	2.66±0.16 <sup>bac</sup> (164)	276.12±0.73 (173)	176.59±11.61 <sup>ba</sup> (167)	457.74±11.79 <sup>ba</sup> (167)
AAC6	2.29±0.18 <sup>bc</sup> (112)	276.10±0.84 (117)	162.81±13.47 <sup>ba</sup> (111)	435.72±13.68 <sup>c</sup> (111)
AAC7	2.36±0.21 <sup>bc</sup> (90)	278.51±0.98 (80)	174.27±15.32 <sup>ba</sup> (79)	460.50±15.56 <sup>ba</sup> (79)
AAC8	2.80±0.23 <sup>a</sup> (87)	276.34±1.04 (77)	196.47±16.60 <sup>a</sup> (70)	489.89±16.86 <sup>a</sup> (70)
AAC9	2.24±0.27 <sup>c</sup> (88)	276.88±1.25 (77)	168.42±19.70 <sup>ba</sup> (64)	457.81±20.00 <sup>ba</sup> (64)
AAC10	2.45±0.26 <sup>bac</sup> (86)	277.26±1.21 (80)	168.85±19.41 <sup>ba</sup> (79)	449.51±19.72 <sup>b</sup> (79)
Weight at calving	**	<b>ns</b>	**	**
WAC1	1.56±0.25 <sup>l</sup> (83)	276.04±1.16 (67)	136.22±22.10 <sup>d</sup> (39)	435.45±22.69 <sup>bc</sup> (38)
WAC2	1.93±0.18 <sup>lc</sup> (174)	275.45±0.84 (180)	165.41±16.06 <sup>bc</sup> (91)	432.44±16.31 <sup>c</sup> (91)
WAC3	2.05±0.15 <sup>dc</sup> (328)	276.42±0.69 (336)	161.13±12.21 <sup>bc</sup> (195)	444.33±12.40 <sup>bc</sup> (195)
WAC4	2.26±0.14 <sup>dc</sup> (312)	276.91±0.66 (324)	158.71±11.21 <sup>c</sup> (236)	442.11±11.38 <sup>bc</sup> (236)
WAC5	2.36±0.13 <sup>bc</sup> (342)	277.30±0.61 (349)	172.31±10.34 <sup>bc</sup> (271)	452.96±10.49 <sup>bc</sup> (271)
WAC6	2.69±0.15 <sup>b</sup> (195)	277.19±0.69 (198)	168.63±11.64 <sup>bc</sup> (161)	465.05±11.82 <sup>bac</sup> (161)
WAC7	2.85±0.17 <sup>ba</sup> (129)	277.02±0.80 (136)	206.38±13.13 <sup>ba</sup> (122)	498.16±13.33 <sup>ba</sup> (122)
WAC8	3.15±0.21 <sup>a</sup> (98)	277.20±0.98 (80)	223.73±15.78 <sup>a</sup> (73)	503.42±16.02 <sup>a</sup> (73)
WAC9	3.08±0.25 <sup>ba</sup> (74)	276.68±1.17 (64)	193.02±18.34 <sup>bac</sup> (55)	478.35±18.62 <sup>ba</sup> (55)

\*P<0.05; \*\*P<0.05; ns: nonsignificant; Numbers in the parenthesis are number of observations



**Fig. 4. Distributions of data for different reproduction traits from all lactations in crossbred cattle**

#### **4.8.3. The influences of period of calving**

Period of calving was found to have significant ( $P < 0.05$ ) effects on FLMY, FL305\_DMY and FLL in the crossbred cattle. The higher FLMY and FL305\_DMY were observed in crossbred cows calved in the POC5. It seems that selection and culling of cows was very effective in fifth period. Management practices could also be good in fifth period due to availability of ample green fodder was available in most part of the year. However the lower FLMY and 305\_DMY were found in crossbred cows calved in the POC7 and crossbred cows calved in the POC6 had longer average FLL than those calved in the other POC subclasses. This might be due to favorable climatic conditions and good management practices at the farm in during the 6<sup>th</sup> periods. Similar with the present findings, Safaa (2006), Manoj *et al.* (2012), Kumari (2015) and Poonam *et al.* (2016) for FL305\_DMY; Lakshmi *et al.* (2010), Wondifraw *et al.* (2013), Kumari, (2015) and Parveen, 2017 for FLMY; Manoj *et al.* (2012, Wondifraw *et al.* (2013 and Parveen (2017) for LL had observed the significant influences of period of calving. In contrast to the present results, the period of calving influenced significantly FLDP (Mukharjee, 2005; Safaa, 2006), FLPY (Poonam *et al.*, 2016) and FLDPY (Singh *et al.*, 2015).

However period of calving had non-significant influences on FL305-DMY (Verma, 2015; Singh *et al.* (2015); on FLMY (Verma *et al.*, 2015; Das *et al.*, 2006); on FLL (Banda, 1996; Kumari, 2015); on FLDP (Bharti, 2004; Dubey and Singh, 2005; Garima, 2006; Singh *et al.*, 2015); on FLPY and FLDPY (Singh *et al.*, 2015).

#### **4.8.4. The influences of genetic groups**

Genetic groups had highly significant influences ( $P < 0.01$ ) on FLMY, and FL305\_DMY and significant one ( $P < 0.05$ ) FLPY; but its influences were insignificant ( $P > 0.05$ ) on FLL, FLDP, and FLDPY in crossbred cattle. Crossbred cattle in the G3 and G4 had higher FLMY and FLPY than those in the other genetic group subclasses. Higher FL305\_DMY was found in crossbred cows in the genetic group of 2 and 3 as compared as crossbred cows in the other genetic groups. In agreement with the present results, genetic group of animals exerted significant influences on ( $P < 0.05$ ) on FL305\_DMY (Poonam *et al.*, 2016; Lakshmi *et al.*, 2010); on FLMY (Garima, 2006; Lakshmi *et al.*, 2010; Kumar *et al.* 2014); on FLPY (Lakshmi *et al.*, 2010; Singh *et al.*, 2015; Poonam *et al.* (2016). In contrary to the present study, the influences of genetic group of the animals were found to be significant on FLL (Dubey and Singh, 2005; Kumari, 2015), on FLDP (Kumar (1994)

and Dubey and Singh (2005) and on FLDPY (Singh *et al.*, 2015). The non-significant effects of animal genetic group were reported by Singh *et al.* (2015), and Kumari (2015) on FL305\_DMY; by Garima (2006), and Kumari (2015) on FLMY; by Bharti (2004) and Garima (2006) on the LL and by Mukharjee (2005) on FLDP.

#### **4.8.5. The influences of sire**

FLMY and FL305\_DMY was highly significantly ( $p < 0.01$ ) influenced by sire but no significant influence of the sire on FLL, FLDP, FLPY and FLDPY was observed in crossbred cattle. In line with the current results, Kumari (2015), Verma *et al.* (2015), Poonam *et al.* (2016) and Parveen (2017) for FL305\_DMY and Garima (2006), Kumari (2015) and Parveen (2017) for FLMY had observed significant influences of sire of cows. However, sire exerted non-significant effect on FL305-DMY (Safaa, 2006; Verma 2015) and on FLMY (Safaa, 2006; Verma 2015). In the contrary to the present findings, sire of the cows had significant influences on FLPY (Poonam *et al.*, 2016; Singh *et al.*, 2015), on FLDPY Singh *et al.*, 2015); on FLL (Garima (2006), Kumari, 2015, Parveen, 2017) and on FLDP (Garima, 2006) but the non-significant influences of sire of cow was reported by Safaa (2006) on FLL and by Singh *et al.* (2015) and Safaa (2006) on FLDP.

#### **4.8.6. The influences of age at calving**

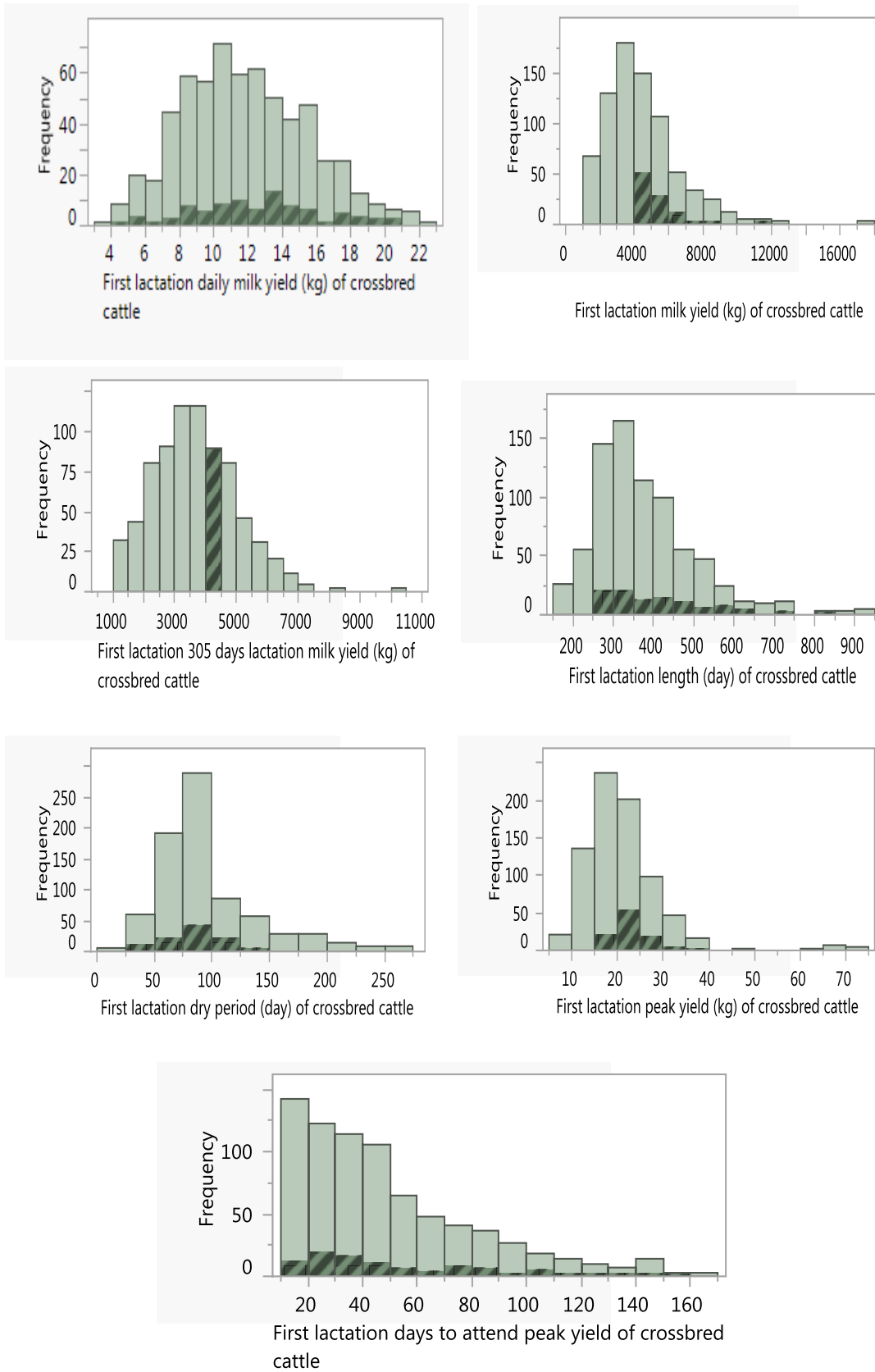
Age at calving was able to constitute significant ( $P < 0.05$ ) sources of variation in FLDP and FLPY but not in FLMY, 305\_DMY, FLL, AND FLDPY in crossbred cattle. Significantly higher average FLDP were obtained in the crossbred cows in the AAC3 and 7 but crossbred cows under AAC5 had lower average FLDP than those in the other AAC subclasses. Significant differences were seen among crossbred cows for FLPY over age at calving sub-classes. To this end, crossbred cows under AAC4 were higher in FLPY as compared as those in the other AAC subclasses. On the contrast, the effects of age at calving were significant on FL305-DMY (Kumari, 2015; Safaa, 2006); on FLMY (Manoj *et al.*, 2010); on FLL (Safaa, 2006; Parveen, 2017); and on FLDP (Safaa, 2006). The non-significant influences were found by Verma (2015) on FL305\_DMY; Verma (2015) and Parveen (2017) on LMY; Kumari (2015) on FLL and Alhammad (2005) on FLDP.

**Table 42. Least squares means ( $\pm$ SE) of various first lactation milk production traits in crossbred cattle**

Source of Variance	N	FLMY (Kg)	FL305_DMY (Kg)	FLL (day)	FLDP (day)	FLPY (Kg)	FLDPY (day)
Overall mean	750	4323.53 $\pm$ 73.83	3646.92 $\pm$ 48.38	370.74 $\pm$ 4.41	93.32 $\pm$ 1.53	20.70 $\pm$ 0.29	47.49 $\pm$ 1.15
Period of birth		ns	ns	ns	*	ns	ns
POB1	65	4921.76 $\pm$ 807.84	4065.36 $\pm$ 509.46	438.10 $\pm$ 53.39	91.57 $\pm$ 18.27 <sup>bac</sup>	23.62 $\pm$ 3.40	34.54 $\pm$ 13.67
POB2	116	4638.68 $\pm$ 652.48	3823.11 $\pm$ 411.48	395.76 $\pm$ 43.13	74.05 $\pm$ 14.75 <sup>cd</sup>	24.23 $\pm$ 2.74	40.39 $\pm$ 11.04
POB3	144	4663.14 $\pm$ 571.43	3808.27 $\pm$ 360.37	396.24 $\pm$ 37.77	99.15 $\pm$ 12.92 <sup>ba</sup>	22.90 $\pm$ 2.40	43.14 $\pm$ 9.67
POB4	141	4078.30 $\pm$ 488.41	3311.34 $\pm$ 308.01	375.09 $\pm$ 32.28	91.99 $\pm$ 11.04 <sup>bac</sup>	19.10 $\pm$ 2.05	40.29 $\pm$ 8.26
POB5	98	4308.92 $\pm$ 554.15	3458.21 $\pm$ 349.47	378.18 $\pm$ 36.63	77.51 $\pm$ 12.53 <sup>bdc</sup>	18.17 $\pm$ 2.33	49.25 $\pm$ 9.38
POB6	69	3520.46 $\pm$ 719.23	3432.19 $\pm$ 453.58	304.22 $\pm$ 47.54	106.89 $\pm$ 16.26 <sup>a</sup>	18.90 $\pm$ 3.02	45.03 $\pm$ 12.17
POB7	70	4843.38 $\pm$ 868.71	4312.50 $\pm$ 547.84	304.60 $\pm$ 57.42	74.23 $\pm$ 19.64 <sup>cdc</sup>	24.07 $\pm$ 3.65	67.01 $\pm$ 14.70
POB8	47	4532.88 $\pm$ 1337.00	4252.20 $\pm$ 843.17	294.86 $\pm$ 88.37	73.43 $\pm$ 30.23 <sup>e</sup>	24.11 $\pm$ 5.62	72.39 $\pm$ 22.62
Seasons of calving		ns	ns	ns	ns	ns	*
SOC1	207	4550.35 $\pm$ 268.36	3865.37 $\pm$ 169.24	365.24 $\pm$ 17.74	83.24 $\pm$ 6.07	22.50 $\pm$ 1.13	47.64 $\pm$ 4.54 <sup>ba</sup>
SOC2	140	4342.18 $\pm$ 288.11	3739.53 $\pm$ 181.69	359.46 $\pm$ 19.04	82.69 $\pm$ 6.51	22.11 $\pm$ 1.21	43.36 $\pm$ 4.87 <sup>b</sup>
SOC3	178	4462.47 $\pm$ 282.32	3756.21 $\pm$ 178.04	366.87 $\pm$ 18.66	88.85 $\pm$ 6.38	21.30 $\pm$ 1.19	45.11 $\pm$ 4.78 <sup>b</sup>
SOC4	110	4356.52 $\pm$ 288.74	3849.06 $\pm$ 182.09	362.97 $\pm$ 19.08	88.34 $\pm$ 6.53	22.25 $\pm$ 1.21	54.21 $\pm$ 4.89 <sup>a</sup>
SOC5	115	4480.66 $\pm$ 302.54	3829.31 $\pm$ 190.79	349.86 $\pm$ 20.00	87.38 $\pm$ 6.84	21.28 $\pm$ 1.27	54.70 $\pm$ 5.12 <sup>a</sup>
Period of calving		*	*	*	ns	ns	ns
POC1	156	4187.73 $\pm$ 689.36 <sup>cb</sup>	3513.43 $\pm$ 434.74 <sup>c</sup>	329.71 $\pm$ 45.56 <sup>b</sup>	89.41 $\pm$ 15.59	17.99 $\pm$ 2.90	63.90 $\pm$ 11.66
POC2	149	4007.52 $\pm$ 579.00 <sup>c</sup>	3587.79 $\pm$ 365.14 <sup>cb</sup>	310.88 $\pm$ 38.27 <sup>b</sup>	74.81 $\pm$ 13.09	20.18 $\pm$ 2.43	51.41 $\pm$ 9.80
POC3	134	4565.31 $\pm$ 532.72 <sup>b</sup>	4047.53 $\pm$ 335.96 <sup>b</sup>	352.52 $\pm$ 35.21 <sup>b</sup>	73.21 $\pm$ 12.05	21.97 $\pm$ 2.24	60.88 $\pm$ 9.01
POC4	112	5242.88 $\pm$ 566.31 <sup>a</sup>	4486.88 $\pm$ 357.14 <sup>a</sup>	367.14 $\pm$ 37.43 <sup>b</sup>	87.74 $\pm$ 12.80	26.09 $\pm$ 2.38	66.77 $\pm$ 9.58
POC5	65	5344.05 $\pm$ 707.02 <sup>a</sup>	4549.66 $\pm$ 445.87 <sup>a</sup>	388.63 $\pm$ 46.73 <sup>b</sup>	89.92 $\pm$ 15.99	26.75 $\pm$ 2.97	39.87 $\pm$ 11.96
POC6	79	4542.73 $\pm$ 759.00 <sup>b</sup>	3437.83 $\pm$ 478.65 <sup>d</sup>	441.44 $\pm$ 50.17 <sup>a</sup>	79.11 $\pm$ 17.16	21.63 $\pm$ 3.19	43.32 $\pm$ 12.84
POC7	156	3178.85 $\pm$ 1056.11 <sup>c</sup>	3032.14 $\pm$ 666.03 <sup>d</sup>	335.85 $\pm$ 69.80 <sup>b</sup>	108.51 $\pm$ 23.88	18.60 $\pm$ 4.44	16.88 $\pm$ 17.87
Genetic group		**	**	ns	ns	*	ns
GG1	131	3907.11 $\pm$ 331.64 <sup>b</sup>	3348.42 $\pm$ 209.15 <sup>c</sup>	359.50 $\pm$ 21.92	91.89 $\pm$ 7.50	20.24 $\pm$ 1.39 <sup>c</sup>	49.48 $\pm$ 5.61
GG2	311	4278.95 $\pm$ 288.71 <sup>b</sup>	3826.75 $\pm$ 182.07 <sup>a</sup>	340.69 $\pm$ 19.08	81.95 $\pm$ 6.53	21.27 $\pm$ 1.21 <sup>bc</sup>	47.12 $\pm$ 4.88
GG3	56	5221.88 $\pm$ 380.94 <sup>a</sup>	4402.04 $\pm$ 240.24 <sup>a</sup>	377.80 $\pm$ 25.18	82.75 $\pm$ 8.61	23.96 $\pm$ 1.60 <sup>a</sup>	48.44 $\pm$ 6.45
GG4	252	4345.82 $\pm$ 329.26 <sup>a</sup>	3654.38 $\pm$ 207.65 <sup>b</sup>	365.53 $\pm$ 21.76	87.81 $\pm$ 7.44	22.09 $\pm$ 1.38 <sup>ba</sup>	50.98 $\pm$ 5.57
Age at calving		ns	ns	ns	*	*	ns
AAC1	205	4758.12 $\pm$ 229.96	3932.23 $\pm$ 145.02	384.25 $\pm$ 15.20	89.07 $\pm$ 5.20 <sup>ba</sup>	21.75 $\pm$ 0.97 <sup>b</sup>	50.60 $\pm$ 3.89

AAC2	270	4589.60±301.40	3824.13±190.08	375.55±19.92	88.36±6.81 <sup>bc</sup>	21.37±1.27 <sup>b</sup>	44.05±5.10
AAC3	75	3828.87±454.33	3521.03±286.52	323.61±30.03	99.77±10.27 <sup>a</sup>	21.65±1.91 <sup>b</sup>	40.71±7.69
AAC4	57	4681.40±546.61	4063.62±344.72	350.59±36.13	72.06±12.36 <sup>bc</sup>	27.26±2.30 <sup>a</sup>	51.81±9.25
AAC5	50	4201.30±566.84	3648.37±357.47	348.30±37.47	67.64±12.82 <sup>c</sup>	17.99±2.38 <sup>b</sup>	56.90±9.59
AAC6	48	4758.12±229.96	3932.23±145.02	384.25±15.20	89.07±5.20 <sup>ba</sup>	21.75±0.97 <sup>b</sup>	50.60±3.89
AAC7	45	4571.35±239.03	3858.01±150.74	382.98±15.80	99.72±5.40 <sup>a</sup>	21.30±1.01 <sup>b</sup>	49.96±4.04
Weight at calving		*	*	<b>ns</b>	**	*	<b>ns</b>
WAC1	50	3960.10±384.63 <sup>cd</sup>	3433.30±242.57 <sup>d</sup>	362.06±25.42	104.01±8.70 <sup>a</sup>	19.71±1.62 <sup>dc</sup>	47.58±6.51
WAC2	132	4042.61±315.23 <sup>dc</sup>	3553.67±198.80 <sup>dc</sup>	352.91±20.84	86.04±7.13 <sup>b</sup>	21.25±1.33 <sup>bdc</sup>	39.70±5.33
WAC3	160	4361.74±286.53 <sup>bdc</sup>	3819.39±180.70 <sup>bc</sup>	356.08±18.94	82.27±6.48 <sup>b</sup>	23.12±1.20 <sup>ba</sup>	46.31±4.85
WAC4	130	4578.75±286.15 <sup>bac</sup>	3871.34±180.46 <sup>ba</sup>	361.20±18.91	84.82±6.47 <sup>b</sup>	22.67±1.20 <sup>bac</sup>	50.72±4.84
WAC5	123	4797.58±279.56 <sup>ba</sup>	4058.18±176.30 <sup>ba</sup>	368.34±18.48	80.25±6.32 <sup>b</sup>	23.07±1.18 <sup>bac</sup>	51.40±4.73
WAC6	52	4883.71±353.20 <sup>ba</sup>	4030.72±222.74 <sup>ba</sup>	388.89±23.34	91.49±7.99 <sup>ba</sup>	22.98±1.49 <sup>bac</sup>	44.60±5.98
WAC7	30	5126.38±454.71 <sup>a</sup>	4223.79±286.76 <sup>a</sup>	417.30±30.05	80.98±10.28 <sup>b</sup>	23.73±1.91 <sup>a</sup>	55.58±7.69
WAC8	36	4406.59±523.74 <sup>bac</sup>	3385.38±330.29 <sup>d</sup>	357.77±34.62	77.60±11.84 <sup>b</sup>	19.17±2.20 <sup>d</sup>	49.96±8.86
WAC9	37	3788.50±595.53 <sup>e</sup>	3895.29±375.57 <sup>ba</sup>	283.37±39.36	87.47±13.47 <sup>ba</sup>	21.31±2.50 <sup>bac</sup>	55.18±10.08

\*P<0.05; \*\*P<0.01; ns= nonsignificant; Numbers in the parenthesis are number of observations



**Fig. 5. Distributions of data for different first lactation milk production traits in crossbred cattle**

#### **4.8.7. The influences of weight at calving**

FLMY, FL305\_DMY, FLDP and FLPY were significantly ( $P < 0.05$ ) influenced by WAC. However there were no significant influences of WAC on FLL and FLDPY. Crossbred cows with WAC7 had significantly higher FLMY and FL305\_DMY than those crossbred cows with other WAC subclasses. Similar with the present results, Clark and Touchberry (1962) found significant effects of body weight at calving on FL305-DMY, FLMY, and FLDP for HF cattle. Ghoraishy and Rokouei (2013) reported that low birth weight calves produced less milk later in life. However the same author observed significant effects of body weight at calving on FLL for HF cattle.

#### **4.9. Influences of Fixed and Random Factors on Milk Production Traits from All Lactations**

The mean sum squares of analysis of variance and least square means along with standard error for all lactation milk production traits of crossbred cattle across fixed and random factors are presented in Table 43 and Annex-table 6 and Fig. 6 & 7.

##### **4.9.1. The influences of period of birth**

The influence of period of birth were found to be highly significant ( $P < 0.01$ ) on ALMY, AL305\_DMY and ALPY but significant ( $p < 0.05$ ) for ALL. Crossbred cows born in the POB4 and POB5 were found to have higher ALMY and AL305\_DMY as compared as those born in the other POB subclasses. Whilst lower ALMY and 305\_DMY were observed in crossbred cows born in the POB1 than crossbred cows born in the other POB subclasses.

##### **4.9.2. The influences of season of calving**

Season of calving exerted highly significant influences on ALPY and ALDPY, however the effects of SOC on ALMY, AL305\_DMY, ALL, and ALDP were non-significant ( $P > 0.05$ ) in crossbred cattle. Crossbred cows calved in the season of calving 1 and 2 had higher ALPY and ALDPY than crossbred cows calved in the SOC3, 4 and 5. Longer ADPY was observed in crossbred cows calved in the SOC5 followed by SOC4 and SOC1 as compared as crossbred cows in the SOC 2 and 3. However crossbred cows in the SOC3 had shorter ALDPY as compared as those calved in the other SOC subclasses. Similar with the present results, the significant influences of season of calving was observed by Japheth *et al.* (2015) on ALPY whereas Manoj *et al.* (2012) and Wondifraw *et al.* (2013) for AL305DMY; Kothekar (2004) Varaprasad *et al.* (2013), and Al-Samarai *et al.* (2015) for ALMY; Chavan

(2001), Jadhav *et al.* (2010) and Wondifraw *et al.* (2013) for ALL reported non-significant ( $P>0.05$ ) effect of season of calving.

In contrary with the current results, season of calving had significant influences on AL305-DMY (Atil *et al.*, 2001; Katok and Yanar, 2012; M'hamdi *et al.*, 2012); on ALMY (Mishra and Joshi, 2009; Wondifraw *et al.*, 2013, Japheth *et al.*, 2016); on ALL (Auradkar, 1999; Komatwar *et al.*, 2010); and on ALDP (Mukharjee, 2005). Cows calving in dry season were milked significantly ( $P<0.05$ ) longer than those calving in rainy season.

#### **4.9.3. The influences of period of calving**

Period of calving highly and significantly ( $p<0.01$ ) influenced ALDPY in the crossbred cattle. However insignificant ( $P>0.05$ ) influences of POC were found on ALMY, AL305\_DMY, ALL, ALDP and ALPY in those cattle. Longer ALDPY was seen in crossbred cows significantly calved in the POC 1, 2 and 3 than those calved in the POC4, 5, 6 and 7. On the other hand, crossbred cows calved in the POC7 followed by POC6 shorter average ALDPY as compared as those calved in the other POC subclasses.

In agreement with these results, non-significant influences of period of calving were reported by Banik (2004) and Mundhe *et al.* (2015) on AL305\_DMY; by Gadmade (1999), and Pundir *et al.* (2007) on ALMY; by Jadhav *et al.* (2010), Singh *et al.* (2013), Mandal *et al.* (2013) and Bhutkar *et al.* (2014) on ALL and by Singh *et al.* (1993) and Bharti (2004) on ALDP. In contrary with these results, significant influences of period of calving were reported on AL305-DMY (Singh and Gurnani, 2004; M'hamdi *et al.*, 2012; Wondifraw *et al.*, 2013) ; on ALMY (Wondifraw *et al.*, 2013; Bhutkar *et al.*, 2014; Japheth *et al.*, 2015); on ALL (Pantelici *et al.*, 2014; Al-Samarai *et al.*, 2015 and Japheth *et al.*, 2015) ; on ALDP (Garcha and Dev, 1994, Nayak and Raheja, 1996) and on ALPY (Dhaka *et al.*, 2002; Bhutkar *et al.*, 2014; Anarase *et al.*, 2015).

#### **4.9.4. The influences of genetic group**

ALMY and AL305\_DMY varied highly and significantly ( $p<0.01$ ) among crossbred cows across the different genetic groups. However ALPY varied only significantly ( $p<0.05$ ). ALL, ALDP, and ALDPY were not significantly ( $p>0.05$ ) influenced by the genetic group. Crossbred cows in the genetic group 2 and 3 were significantly higher in the ALMY and AL305\_DMY than those in the other genetic groups. ALPY was significantly higher in crossbred cows under G3 as compared as those in the other

genetic group subclasses. There were no significant differences among G1, G and G for ALPY. In agreement with these results, significant effects of genetic group of animals were observed on AL305\_DMY (Sahana and Gurnani (2000), Mandal *et al.* (2013); on ALMY (Elemam *et al.*, 2012; Singh *et al.*, 2013; Mandal *et al.*, 2013, Kumar *et al.* 2014) and on ALPY (Belayneh *et al.*, 2001, Kumar *et al.*, 2014). Non-significant effects due to genetic group were observed on the ALL (Banda, 1996; Bharti, 2004, Mandal *et al.*, 2013) and on the ALDP (Garcha and Dev, 1994). However the influences due to genetic group of animal on the ALL (Nehra *et al.*, 1987; Kumar *et al.*, 2014) and on the ALDP (Nagarcenkar and Rao, 1982) and Kumar, 1994) were obtained to be significant.

#### **4.9.5. The influences of sire**

Sires had highly significant ( $P < 0.01$ ) influences on all milk production traits from all lactation except ALDP. These findings are in consistent with those of different studies on AL305\_DMY (Atil *et al.*, 2001; Mundhe *et al.*, 2015); on ALMY (Ayied *et al.*, 2011; Nawaz *et al.*, 2013; Pantelici *et al.*, 2014; Al-Samarai *et al.* 2015); ALL (Pantelici *et al.*, 2014) and ALPY (Poonam *et al.* (2016). On the contrary, sire exerted non-significant effect on AL305\_DMY and ALMY (Safaa, 2006; Verma 2015) and ALL (Safaa, 2006) and Al-Samarai *et al.*, 2015).

#### **4.9.6. The influences of age at calving**

ALMY, AL305\_DMY and ALPY were highly and significantly ( $P < 0.01$ ) affected by age at calving but effects of AAC was non-significant ( $P > 0.05$ ) on ALL, ALDP and ALDPY. No significant differences were seen among crossbred cows n the AAC6, 7, 8, 9 and 10. Lower average ALMY and 305\_DMY were seen in the crossbred cows under the AAC2. The higher and lower average ALPY were found in crossbred cows in the age group of AAC10 and AAC1, respectively than those in the other AAC subclasses.

In line with these results, Manoj *et al.* (2010) and Monalisa *et al.* (2010) for AL305\_DMY and ALMY had observed the significant effects of age at calving, whereas non-significant influences were reported by Mandal *et al.* (2013), Gupta (2013), Prakash *et al.* 2015 and Shingare *et al.* (2015) for AL305-DMY and ALMY and Mandal *et al.* (2013) for ALL. In contrary with this finding, significant influence of weight at calving on ALL was obtained by Safaa (2006).

#### **4.9.7. The influences of weight at calving**

The influences of WAC on AL305\_DMY and ALPY were highly significant ( $P < 0.01$ ) but on ALDPY, it was significant ( $P < 0.05$ ). ALTMY, ALL, and ALDP were not significantly ( $P > 0.05$ ) influenced by WAC. Crossbred cows with WAC5 and 6 yielded higher average AL305\_DMY whereas those cows with WAC1 produced lower average AL305\_DMY as compared as crossbred cows with in the other WAC subclasses. Crossbred dairy cows calved in August had the lowest daily milk yield. Higher daily milk yield was observed for cows calved in POC5 followed by POC4 and POC7; but dairy cows calved within POC1 and POC2 had significantly ( $P > 0.05$ ) lower daily milk yield.

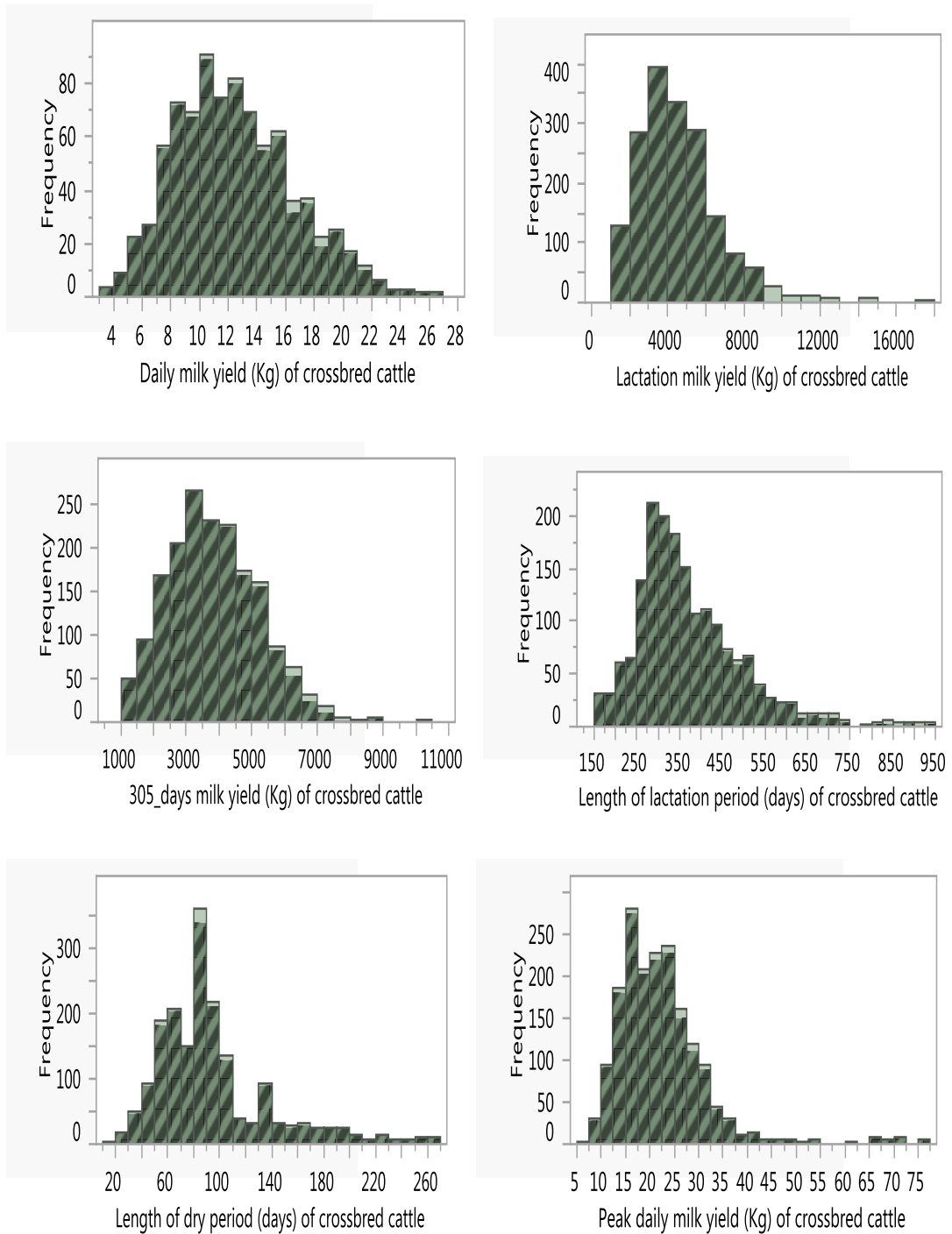
Similar with these results, Miller and McGilliard (1959) and Clark, R.D. and Touchberry, R.W. (1962) found significant effects of body weight at calving on AL305\_DMY. In contrary to the present study, the same workers found significant influences of weight at calving on ALMY and LL for HF cattle. Ghoraihy and Rokouei (2013) reported that low birth weight calves produced less milk later in life.

**Table 43. Least squares means ( $\pm$ SE) of different milk production traits from all lactations in crossbred cattle**

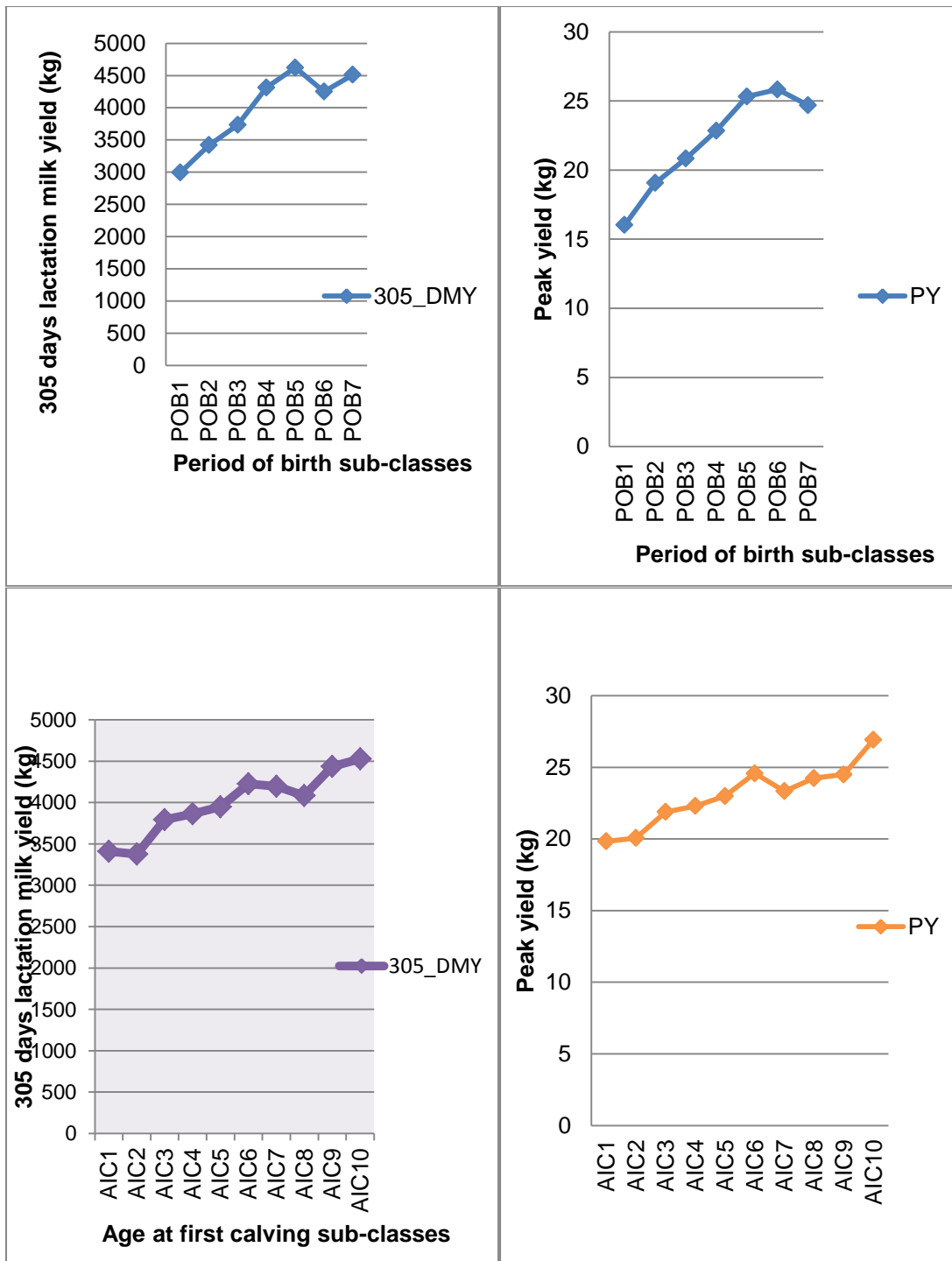
Sources of variance	ALMY (kg)	AL305_DMY (kg)	ALL (days)
Overall mean	4478.64 $\pm$ 47.99 (1735)	3813.69 $\pm$ 32.43 (1735)	370.12 $\pm$ 2.91 (1735)
Period of birth	**	**	*
POB1	3392.84 $\pm$ 393.75 <sup>c</sup> (208)	2993.13 $\pm$ 256.70 <sup>d</sup> (208)	341.77 $\pm$ 26.41 <sup>b</sup> (208)
POB2	4024.67 $\pm$ 314.11 <sup>bc</sup> (355)	3419.71 $\pm$ 204.78 <sup>c</sup> (355)	347.87 $\pm$ 21.07 <sup>b</sup> (355)
POB3	4340.94 $\pm$ 295.55 <sup>b</sup> (312)	3732.69 $\pm$ 192.68 <sup>bc</sup> (312)	344.27 $\pm$ 19.82 <sup>b</sup> (312)
POB4	5270.03 $\pm$ 271.79 <sup>a</sup> (253)	4314.46 $\pm$ 177.19 <sup>a</sup> (253)	401.86 $\pm$ 18.23 <sup>a</sup> (253)
POB5	5935.17 $\pm$ 303.29 <sup>a</sup> (193)	4622.72 $\pm$ 197.73 <sup>a</sup> (193)	432.75 $\pm$ 20.34 <sup>a</sup> (193)
POB6	4989.83 $\pm$ 367.11 <sup>abc</sup> (163)	4250.38 $\pm$ 239.33 <sup>a</sup> (163)	374.19 $\pm$ 24.62 <sup>ba</sup> (163)
POB7	5294.48 $\pm$ 443.89 <sup>abc</sup> (182)	4511.47 $\pm$ 289.39 <sup>a</sup> (182)	382.31 $\pm$ 29.77 <sup>ba</sup> (182)
POB8	4941.59 $\pm$ 688.94 <sup>abc</sup> (69)	4045.15 $\pm$ 449.14 <sup>a</sup> (69)	403.88 $\pm$ 46.21 <sup>a</sup> (69)
Genetic group	**	**	ns
GG1	4446.25 $\pm$ 178.52 <sup>b</sup> (322)	3768.91 $\pm$ 116.38 <sup>b</sup> (322)	371.88 $\pm$ 11.97 (322)
GG2	4818.82 $\pm$ 136.08 <sup>ab</sup> (742)	4128.53 $\pm$ 88.72 <sup>a</sup> (742)	366.38 $\pm$ 9.13 (742)
GG3	5308.10 $\pm$ 212.45 <sup>a</sup> (150)	4298.22 $\pm$ 138.51 <sup>a</sup> (150)	399.18 $\pm$ 14.25 (150)
GG4	4521.61 $\pm$ 183.08 <sup>b</sup> (521)	3749.20 $\pm$ 119.35 <sup>b</sup> (521)	377.01 $\pm$ 12.28 (521)
Season of calving	Ns	ns	ns
SOC1	4841.70 $\pm$ 138.16 (513)	4069.32 $\pm$ 90.07 (513)	373.29 $\pm$ 9.27 (513)
SOC2	4834.15 $\pm$ 158.51 (270)	4017.88 $\pm$ 103.34 (270)	385.95 $\pm$ 10.63 (270)
SOC3	4864.43 $\pm$ 156.79 (342)	3970.84 $\pm$ 102.21 (342)	387.90 $\pm$ 10.52 (342)
SOC4	4596.15 $\pm$ 156.54 (283)	3911.83 $\pm$ 102.05 (283)	376.50 $\pm$ 10.50 (283)
SOC5	4732.06 $\pm$ 147.99 (327)	3961.19 $\pm$ 96.48 (327)	369.43 $\pm$ 9.93 (327)
Period of Calving	Ns	ns	ns
POC1	5183.98 $\pm$ 306.71 (288)	4388.91 $\pm$ 199.96 (288)	378.61 $\pm$ 20.57 (288)
POC2	5044.83 $\pm$ 265.77 (397)	4312.99 $\pm$ 173.26 (397)	379.27 $\pm$ 17.83 (397)
POC3	5092.50 $\pm$ 238.41 (343)	4350.03 $\pm$ 155.43 (343)	380.07 $\pm$ 15.99 (343)
POC4	4699.42 $\pm$ 231.51 (225)	4113.57 $\pm$ 150.93 (225)	356.34 $\pm$ 15.53 (225)
POC5	4491.85 $\pm$ 272.42 (150)	3774.00 $\pm$ 177.60 (150)	368.78 $\pm$ 18.27 (150)
POC6	4532.22 $\pm$ 323.09 (178)	3588.05 $\pm$ 210.63 (178)	398.79 $\pm$ 21.67 (178)
POC7	4371.07 $\pm$ 399.73 (154)	3375.94 $\pm$ 260.60 (154)	388.43 $\pm$ 26.81 (154)
Age at calving	**	**	ns
AAC1	4131.77 $\pm$ 140.17 <sup>c</sup> (334)	3410.56 $\pm$ 91.38 <sup>d</sup> (334)	369.55 $\pm$ 9.40 (334)
AAC2	4010.79 $\pm$ 147.63 <sup>d</sup> (318)	3374.61 $\pm$ 96.24 <sup>e</sup> (318)	368.92 $\pm$ 9.90 (318)
AAC3	4552.37 $\pm$ 149.98 <sup>bc</sup> (275)	3791.18 $\pm$ 97.77 <sup>c</sup> (275)	377.64 $\pm$ 10.06 (275)
AAC4	4580.62 $\pm$ 166.66 <sup>ac</sup> (197)	3863.92 $\pm$ 108.65 <sup>b</sup> (197)	370.27 $\pm$ 11.18 (197)
AAC5	4821.79 $\pm$ 173.63 <sup>ac</sup> (175)	3949.94 $\pm$ 113.20 <sup>ab</sup> (175)	386.64 $\pm$ 11.65 (175)
AAC6	5151.68 $\pm$ 200.12 <sup>a</sup> (117)	4225.11 $\pm$ 130.47 <sup>a</sup> (117)	392.02 $\pm$ 13.42 (117)
AAC7	4953.16 $\pm$ 231.59 <sup>a</sup> (81)	4195.60 $\pm$ 150.98 <sup>a</sup> (81)	375.03 $\pm$ 15.53 (81)
AAC8	4838.68 $\pm$ 243.17 <sup>a</sup> (80)	4084.69 $\pm$ 158.53 <sup>ab</sup> (80)	371.43 $\pm$ 16.31 (80)
AIC9	5335.71 $\pm$ 276.74 <sup>a</sup> (79)	4437.86 $\pm$ 180.42 <sup>a</sup> (79)	388.27 $\pm$ 18.56 (79)
AAC10	5360.37 $\pm$ 254.91 <sup>a</sup> (79)	4528.67 $\pm$ 166.19 <sup>a</sup> (79)	386.35 $\pm$ 17.10 (79)
Weight at calving	Ns	**	ns
WAC1	4346.95 $\pm$ 263.38 <sup>c</sup> (68)	3693.39 $\pm$ 171.71 <sup>e</sup> (68)	366.90 $\pm$ 17.67 (68)
WAC2	4583.88 $\pm$ 186.79 <sup>b</sup> (183)	3854.43 $\pm$ 121.78 <sup>bac</sup> (183)	373.94 $\pm$ 12.53 (183)
WAC3	4794.58 $\pm$ 151.41 (337)	4008.19 $\pm$ 98.71 (337) <sup>c</sup>	380.68 $\pm$ 10.16 (337)
WAC4	4879.89 $\pm$ 151.51 (325)	4066.88 $\pm$ 98.78 (325) <sup>ba</sup>	383.36 $\pm$ 10.16 (325)
WAC5	5026.06 $\pm$ 146.76 <sup>a</sup> (343)	4248.76 $\pm$ 95.68 (343) <sup>a</sup>	378.79 $\pm$ 9.84 (343)
WAC6	4903.56 $\pm$ 167.49 <sup>a</sup> (199)	4141.92 $\pm$ 109.19 (199) <sup>a</sup>	382.62 $\pm$ 11.23 (199)
WAC7	4873.78 $\pm$ 194.09 <sup>a</sup> (137)	4005.46 $\pm$ 126.53 (137) <sup>c</sup>	385.65 $\pm$ 13.02 (137)
WAC8	4558.98 $\pm$ 243.34 <sup>a</sup> (78)	3816.41 $\pm$ 158.64 (78) <sup>d</sup>	375.19 $\pm$ 16.32 (78)
WAC9	4995.56 $\pm$ 281.89 <sup>a</sup> (65)	4040.48 $\pm$ 183.77 (65) <sup>c</sup>	380.38 $\pm$ 18.91 (65)

Source of variance	ALDP (days)	ALPY (kg)	ALDPY (days)
Overall mean	91.36±0.97 (1735)	21.72±0.20 (1735)	47.48±0.74 (1735)
Period of birth	<b>Ns</b>	**	<b>ns</b>
POB1	87.26±8.79 (208)	16.03±1.71 <sup>d</sup> (207)	38.90±6.43 (204)
POB2	91.34±7.01 (355)	19.07±1.36 <sup>dc</sup> (354)	41.69±5.11 (353)
POB3	101.21±6.60 (312)	20.83±1.28 <sup>c</sup> (312)	41.31±4.81 (312)
POB4	89.85±6.07 (253)	22.85±1.17 <sup>bc</sup> 252)	47.63±4.43 (249)
POB5	83.00±6.77 (193)	25.32±1.31 <sup>a</sup> (193)	53.13±4.96 (193)
POB6	99.25±8.19 (163)	25.83±1.59 <sup>a</sup> (162)	58.16±6.01 (159)
POB7	86.12±9.91 (182)	24.69±1.92 <sup>ba</sup> (182)	64.78±7.37 (167)
POB8	94.35±15.3 (69)	29.90±2.98 <sup>a</sup> (73)	63.39±11.46 (98)
Genetic group	<b>Ns</b>	*	<b>ns</b>
GG1	91.24±3.98 (322)	22.41±0.77 <sup>b</sup> (321)	51.32±2.91 (319)
GG2	89.14±3.04 (742)	22.79±0.59 <sup>b</sup> (739)	53.05±2.22 (719)
GG3	91.50±4.74 (150)	24.90±0.92 <sup>a</sup> (155)	47.99±3.45 (181)
GG4	94.31±4.09 (521)	22.16±0.79 <sup>b</sup> (520)	52.13±2.98 (516)
Seasons of calving	<b>Ns</b>	**	**
SOC1	89.25±3.08 (513)	23.94±0.60 <sup>a</sup> (512)	52.59±2.26 <sup>b</sup> (507)
SOC2	89.09±3.54 (270)	23.76±0.68 <sup>a</sup> (275)	48.56±2.59 <sup>cb</sup> (265)
SOC3	92.90±3.50 (342)	22.71±0.68 <sup>b</sup> (340)	47.41±2.56 <sup>c</sup> (337)
SOC4	91.95±3.49 (283)	22.84±0.68 <sup>b</sup> (282)	52.44±2.56 <sup>b</sup> (275)
SOC5	94.55±3.30 (327)	22.08±0.64 <sup>b</sup> (326)	54.62±2.42 <sup>a</sup> (320)
Period of calving	<b>Ns</b>	<b>ns</b>	**
POC1	85.98±6.84 (288)	23.64±1.33 (286)	63.46±5.00 <sup>a</sup> (284)
POC2	87.24±5.93 (397)	23.29±1.15 (397)	56.23±4.33 <sup>a</sup> (395)
POC3	84.98±5.32 (343)	23.35±1.03 (342)	57.98±3.89 <sup>a</sup> (340)
POC4	86.47±5.17 (225)	23.46±1.00 (225)	52.61±3.78 <sup>b</sup> (224)
POC5	96.30±6.08 (150)	23.47±1.18 (155)	47.44±4.45 <sup>cb</sup> (166)
POC6	93.75±7.21 (178)	22.19±1.40 (177)	41.60±5.30 <sup>c</sup> (165)
POC7	106.1±8.92 (154)	22.05±1.73 (153)	38.53±6.57 <sup>d</sup> (161)
Age at calving	<b>Ns</b>	**	<b>ns</b>
AAC1	91.91±3.13 (334)	19.83±0.61 <sup>cb</sup> (337)	51.06±2.29 (349)
AAC2	97.84±3.29 (318)	20.07±0.64 <sup>cb</sup> (320)	49.52±2.41 (322)
AAC3	91.69±3.35 (275)	21.89±0.65 <sup>ba</sup> (275)	48.27±2.46 (271)
AAC4	92.26±3.72 (197)	22.30±0.72 <sup>ba</sup> (197)	51.76±2.73 (194)
AAC5	90.10±3.87 (175)	22.99±0.75 <sup>ba</sup> (175)	50.30±2.84 (172)
AAC6	93.78±4.47 (117)	24.58±0.87 <sup>ba</sup> (116)	53.62±3.30 (113)
AAC7	88.94±5.17 (81)	23.33±1.00 <sup>ba</sup> (81)	57.21±3.78 (80)
AAC8	85.19±5.43 (80)	24.24±1.05 <sup>ba</sup> (77)	49.33±3.99 (88)
AAC9	86.69±6.18 (79)	24.50±1.20 <sup>ba</sup> (79)	47.65±4.49 (87)
AAC10	97.09±5.69 (79)	26.92±1.11 <sup>a</sup> (78)	52.50±4.16 (78)
Weight at calving	<b>Ns</b>	**	*
WAC1	103.01±5.88 (68)	21.38±1.14 <sup>c</sup> (68)	53.18±4.28 <sup>b</sup> (68)
WAC2	90.36±4.17 (183)	22.65±0.81 <sup>bc</sup> (183)	45.65±3.05 <sup>c</sup> (181)
WAC3	88.04±3.38 (337)	23.46±0.65 <sup>ba</sup> (335)	49.52±2.48 <sup>cb</sup> (330)
WAC4	86.99±3.38 (325)	22.90±0.66 <sup>bc</sup> (324)	50.92±2.47 <sup>cb</sup> (322)
WAC5	88.24±3.28 (343)	24.58±0.63 <sup>a</sup> (342)	54.20±2.40 <sup>b</sup> (335)
WAC6	91.93±3.74 (199)	24.32±0.72 <sup>a</sup> (199)	49.09±2.75 <sup>cb</sup> (194)
WAC7	92.29±4.33 (137)	23.18±0.84 <sup>ab</sup> (137)	48.01±3.18 <sup>cb</sup> (134)
WAC8	90.64±5.43 (78)	22.37±1.06 <sup>bc</sup> (77)	51.19±3.97 <sup>cb</sup> (91)
WAC9	92.43±6.29 (65)	22.72±1.22 <sup>bc</sup> (70)	58.34±4.65 <sup>a</sup> (80)

\*P<0.05; \*\*P<0.01; ns= non-significant; Numbers in the parenthesis are number of observations



**Fig. 6. Distributions of data for different milk production traits from all lactations in crossbred cattle**



**Fig. 7. Trends of 305\_DMY and PY over period of birth and age at calving sub-classes in crossbred cattle**

## 4.10. Genetic Parameters

### 4.10.1. Genetic parameter for first lactation performance traits

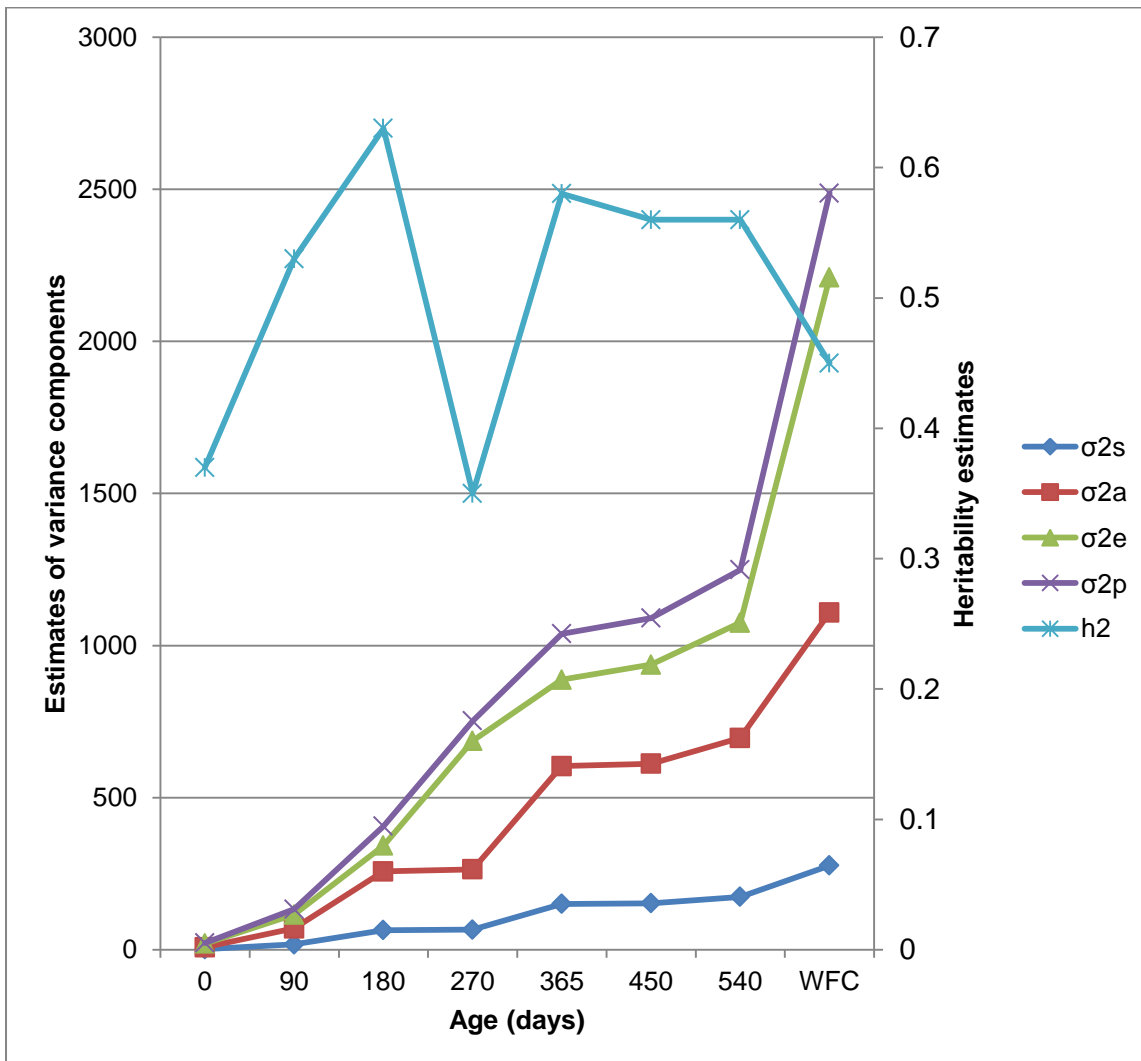
#### 4.10.1.1. Heritability estimates of growth traits

The estimates of sire ( $\sigma^2_s$ ), additive, ( $\sigma^2_a$ ), permanent environmental variance ( $\sigma^2_{PE}$ ), residual variance ( $\sigma^2_e$ ), phenotypic variance ( $\sigma^2_p$ ), and heritability ( $h^2$ ) of crossbred cattle for first lactation performance traits are presented in Table 44. The heritability estimates of crossbred cattle for growth traits were intermediate to high (Fig. 8) with reasonably low to intermediate standard error estimates. They varied from  $0.35\pm 0.12$  for body weight at 270 days of age (BW270) to  $0.63\pm 0.08$  for body weight at 180 days of age (BW180). The estimates of heritability for BW90, BW365, BW450 and BW540 and WFC were high with corresponding values of  $0.53\pm 0.10$ ,  $0.58\pm 0.09$ ,  $0.56\pm 0.09$ ,  $0.56\pm 0.09$  and  $0.45\pm 0.10$ , respectively, whereas the heritability estimates of BW0 ( $0.37\pm 0.11$ ) was intermediate. In agreement with these the present result for BW0, intermediate  $h^2$  estimates were reported by Islam *et al.* (2004), El-Saied *et al.* (2006), Rahman *et al.* (2015) and Nobre *et al.* (2003), However Abera (2011), Brotherstone *et al.* (2007) and Rabeya *et al.* (2009) for BW0 and BW270 were found high heritability estimates whilst similar to the present findings, high  $h^2$  estimates were observed by Brotherstone *et al.* (2007), Prathap *et al.* (2017) and Rabeya *et al.* (2009) for BW180, Rahman *et al.* (2015) and Brotherstone *et al.* (2007) for BW90 and BW270, Rabeya *et al.* (2009) for BW90 and BW365 found high  $h^2$  estimates. However Kumari (2015) for BW0 and Nesar *et al.* (2012) for BW0, BW365 and BW540 reported lower heritability values than the present findings. In general, the present results indicated that there are good additive genetic variances in all growth traits which can give high opportunities to the breeder for undertaking genetic improvement through individual selection.

#### 4.10.1.2. Heritability estimates of first lactation reproduction traits

The estimates of sire ( $\sigma^2_s$ ), additive variance ( $\sigma^2_a$ ), permanent environmental variance ( $\sigma^2_{PE}$ ), residual variance ( $\sigma^2_e$ ), phenotypic variance ( $\sigma^2_p$ ), and heritability ( $h^2$ ) of crossbred cattle for first lactation performance traits are presented in Table 44. The heritability estimates of crossbred cattle for first lactation reproduction traits were very low to intermediate with relatively low to intermediate high standard errors. The estimates ranged from  $0.03\pm 0.14$  for FLNSPC to  $0.37\pm 0.11$  for AFC. Low heritability estimates of crossbred cattle were found for FLPP with corresponding values of

0.13±0.13 whereas the heritability estimates of AFS (0.33±0.12), and FLSP (0.28±0.13) and FCI (0.28±0.13) were intermediate.



**Fig. 8. Sire variance ( $\sigma^2_s$ ), additive variance ( $\sigma^2_a$ ), residual variance ( $\sigma^2_e$ ), phenotypic variance ( $\sigma^2_p$ ) and heritability ( $h^2$ ) for growth traits in crossbred cattle over ages (days)**

Similar with the present results, low  $h^2$  estimates were obtained by Dhaka (2013) for FLNSPC and FLPP whereas intermediate  $h^2$  estimates were found by Garima (2006) for AFC, Singh *et al.* (2015) for FCI and FLSP. In the contrary to the present results, high  $h^2$  estimates were observed by Safaa (2006), Singh *et al.* (2015), and Parveen (2017) for AFC and lower  $h^2$  values were reported by Garima (2006) and Parveen (2017) for FCI. The heritability obtained for FLNSPC and FLPP clearly showed that there were small variations among crossbred cows for these traits and thereby genetic improvement of the traits via selection are not advantageous rather good husbandry management and good control over of climate condition should be used for their

improvement, whilst the intermediate heritability estimates observed in the AFC, and CI could mean that the traits would be improved using mass selection supported by either pedigree or progeny informations.

#### **4.10.1.3. Heritability estimates of first lactation milk production traits**

The estimates of sire ( $\sigma^2_s$ ), additive ( $\sigma^2_a$ ), permanent environmental ( $\sigma^2_{PE}$ ), residual error variance ( $\sigma^2_e$ ), and phenotypic (total) variances ( $\sigma^2_p$ ), and heritability ( $h^2$ ) of crossbred cattle for first lactation milk production traits are presented in Table 44. The heritability estimates for first lactation milk production traits were low to intermediate high with relatively low to intermediate high standard error estimates. The estimates varied from  $0.12 \pm 0.14$  for FLDPY to  $0.40 \pm 0.10$  for FL305\_DMY. Low heritability estimates of crossbred cattle were found for FLL, FLDP, FLPY, and FLDPY with corresponding values of  $0.17 \pm 0.13$ ,  $0.15 \pm 0.13$ ,  $0.13 \pm 0.14$  and  $0.12 \pm 0.14$  whereas intermediate estimates of heritability were observed for FLMY ( $0.35 \pm 0.12$ ) and FL305\_DMY ( $0.40 \pm 0.10$ ).

Similar with the present results, low  $h^2$  estimates were obtained by Parveen (2017) for FLL, Garima (2006), Safaa (2006) and Singh *et al.* (2015) for FLDP and Singh *et al.* (2015) for FLDPY whilst intermediate  $h^2$  estimates were found by Kumari (2015) for FLMY. In contrast to the present findings, higher  $h^2$  estimates were reported by Das *et al.* (2003) for FLL and Kumari (2015) for FL305\_DMY and  $h^2$  values of FLPY estimated by Singh *et al.* (2015) was also intermediate. The heritability obtained for FLL, FLDP, FLPY, and FLDPY showed that there were small variations among crossbred cows for these traits and thereby genetic improvement of them via selection are not advantageous rather good husbandry management should be used for their improvement. However the results estimated for FLMY and FL305\_DMY indicated that considerable variation are found which can give good room to the breeder for exploiting the animals via selection.

**Table 44. Estimates of sire variance, additive variance ( $\sigma^2_a$ ), permanent environmental variance ( $\sigma^2_{PE}$ ), residual variance ( $\sigma^2_e$ ), phenotypic variance ( $\sigma^2_p$ ) and heritability ( $h^2$ ) for first lactation performance traits of crossbred cattle**

Performance traits	$\sigma^2_s$	$\sigma^2_a$	$\sigma^2_e$	$\sigma^2_p$	$h^2$
BW0	2.05	8.21	20.13	22.18	0.37±0.11
BW90	17.60	70.38	115.59	133.19	0.53±0.10
BW180	64.35	257.41	342.21	406.56	0.63±0.08
BW270	66.10	264.38	686.64	752.74	0.35±0.12
BW365	150.97	603.88	887.99	1038.96	0.58±0.09
BW450	152.87	611.48	937.28	1090.15	0.56±0.09
BW540	174.05	696.20	1075.09	1249.14	0.56±0.09
WFC	277.17	1108.68	2209.80	2486.97	0.45±0.10
AFC	4594.76	18379.04	44867.00	49461.76	0.37±0.11
AFS	3660.93	14643.72	40490.00	44150.93	0.33±0.12
FLNSPC	0.02	0.07	2.62	2.71	0.03±0.14
FLPP	1.73	6.90	51.17	59.79	0.13±0.13
FLSP	1003.06	4012.24	13089.00	14092.06	0.28±0.13
FCI	999.70	3998.80	13301.00	14300.70	0.28±0.13
FLMY	296507.00	1186028.00	3133623.00	3430130.00	0.35±0.12
FL305_DMY	138338.00	553352.00	1239321.00	1377659.00	0.40±0.10
FLL	613.56	2454.24	13548.00	14161.56	0.17±0.13
FLDP	62.52	250.09	1573.96	1636.48	0.15±0.13
FLPY	1.85	7.40	55.59	57.44	0.13±0.14
FLDPY	89.17	356.69	3000.32	3089.49	0.12±0.14

#### **4.10.2. Genetic parameter for milk production and reproduction traits from all lactations**

##### **4.10.2.1. Heritability estimates of reproduction traits from all lactations**

The heritability estimates of crossbred cattle for all lactation reproduction traits were in general low with reasonably low standard errors (table 45). The estimates ranged from 0.08±0.11 for ALNSPC to 0.12±0.10 for ALSP. The heritability estimates of ALPP and ALCI were found to be 0.05±0.11 and 0.11±0.11, respectively. In line with these results, Aziz *et al.* (2014), Parineeta *et al.* (2017), and Wondossen *et al.* (2017) for ALCI, Bharti (2004), Mukharjee (2005) and Wondossen *et al.* (2017) for ALSP and Wondossen *et al.* (2017) for ALPP found low  $h^2$  estimates; however high  $h^2$  estimates for ALCI and intermediate  $h^2$  for ALSP were reported by Dubey and Singh (2005). The low heritability estimates obtained in the present study meant that the additive genetic variances of the traits are very small and thereby genetic improvements of the traits via selection are not recommended rather good husbandry management should be used for their improvement.

#### 4.10.2.2. Heritability estimates of milk production traits from all lactations

The heritability estimates of crossbred cattle for all lactation milk production traits were low to intermediate with reasonably intermediate low standard error estimates. The estimates varied from  $0.02 \pm 0.09$  for ALDPY to  $0.23 \pm 0.10$  for ALMY.

**Table 45. Estimates of sire ( $\sigma^2_s$ ), additive variance ( $\sigma^2_a$ ), permanent environmental variance ( $\sigma^2_{PE}$ ), residual variance ( $\sigma^2_e$ ), phenotypic variance ( $\sigma^2_p$ ), heritability ( $h^2$ ) and repeatability ( $r$ ) for milk production and reproduction traits from all lactations in crossbred cattle**

Traits	$\sigma^2_a$	$\sigma^2_a$	$\sigma^2_{PE}$	$\sigma^2_e$	$\sigma^2_p$	$h^2$	R
ALNSPC	0.05	0.20	0.10	2.26	2.41	$0.08 \pm 0.10$	0.12
ALPP	141.40	565.60	2219.92	9725.81	12087.13	$0.05 \pm 0.11$	0.22
ALSP	1.66	6.64	5.61	48.19	55.46	$0.12 \pm 0.10$	0.20
ALCI	350.57	1402.28	1730.75	10677.00	12758.32	$0.11 \pm 0.11$	0.23
ALMY	194158.25	776633.00	366635.00	2853822.00	3414615.25	$0.23 \pm 0.10$	0.30
AL305_DMY	77128.36	308513.45	150867.00	1202480.00	1430475.36	$0.22 \pm 0.11$	0.28
ALL	241.23	964.92	1046.28	13349.00	14636.51	$0.07 \pm 0.09$	0.13
ALDP	74.09	296.37	90.23	1476.52	1640.84	$0.18 \pm 0.11$	0.21
ALPY	0.94	3.75	6.25	52.61	59.80	$0.06 \pm 0.09$	0.16
ALDPY	4.19	16.76	2.48	832.24	838.91	$0.02 \pm 0.09$	0.02

Low heritability estimates of crossbred cattle were found for ALL, ALDP, ALPY and ALDPY with corresponding estimates of  $0.07 \pm 0.09$ ,  $0.18 \pm 0.11$ ,  $0.06 \pm 0.09$ , and  $0.02 \pm 0.09$  whereas intermediate estimate of heritability ( $0.22 \pm 0.11$ ) was observed for AL305\_DMY. Similar with these results, low  $h^2$  estimates were observed by Aziz *et al.* (2014), Al-Samarai *et al.* (2015) and Ratwari *et al.* (2016) for ALL, Rehman *et al.* (2008) and Aziz *et al.* (2014) for ALDP whereas Aziz *et al.* (2014), Zavadilova and Zink (2013) and Al-Samarai *et al.* (2015) for ALMY and Lee and Han (2004), Amimo *et al.* (2007) and Aziz *et al.* (2014) for AL305\_DMY found intermediate  $h^2$  value which are comparable with the present finding. In contrary to the present results, intermediate  $h^2$  estimates were reported by Singh *et al.* (2005), and Singh *et al.* (2007) for ALL, Rekaya *et al.* (2000) and Dhaka *et al.* (2002) for ALPY whereas Poonam *et al.* (2016) for AL305\_DMY, Poonam *et al.* (2016) and Singh *et al.* (2005) for ALMY, and Singh and Gurnani (2004) for ALL had observed high  $h^2$  estimates. The heritability obtained for ALL, ALDP, ALPY and ALDPY showed that there were small variations among crossbred cows and thereby genetic improvement of the traits via selection are not advantageous rather good husbandry managements should be used for their improvement. However the results estimated for ALMY and 305\_DMY

indicated that considerable variation are found in these traits which give room to the breeder for exploiting the animals with selection.

The standard errors of heritability estimates are reasonable low to intermediate low inspite of intermediate high for some first lactation and few pooled lactation performance traits. The likely reasons for the relatively high SE estimates for some traits might be the different number of daughters per sire. The number of daughters per sire varied from 3 to 62. As the number of daughter per sire becomes low, precision of the estimates may be low whereas SE may increase vice versa. The second probable reasons might be the high variation between elite crossbred cows which are being used as crossbred AI bull mother and the other animals in the herd. The phenotypic performances of these elite cows are far higher which would seem to be extreme observations; they are infact real observation, than the average performance of the herd.

#### **4.10.3. Repeatability estimates for reproduction traits**

The results of the present study clearly revealed that coefficients of repeatability of crossbred cows for all lactation reproduction traits were low to intermediate. The coefficients ranged from 0.12 for ALNSPC to 0.23 for ALCI. The repeatability estimates for ALSP and ALPP were computed as 0.22, and 0.20, respectively. In line with the present results, Ilatsia *et al.* (2007) for ALNSPC and Wondossen *et al.* (2017) for ALSP reported low repeatability values. Also similar with the current findings, intermediate repeatability estimates were obtained by Wondossen *et al.* (2017) for ALCI. However Ilatsia *et al.* (2007) for ALCI and Wondossen *et al.* (2017) for ALSP found low repeatability estimates as compared as the present results. The moderate repeatability estimates observed for ALPP, ALSP and ALCI indicated that selection of dairy cattle for the traits based on early performance records is reliable. However to reduce the number of service per conception during the lifetime of the crossbred dairy cows, decision about culling on one record of NSPC attends with low accuracy.

#### **4.10.4. Repeatability estimates for milk production traits**

It was observed that the estimates of repeatability of crossbred cows for all lactation milk production traits were low to intermediate. The estimates varied from 0.02 for ALDPY to 0.30 for ALMY. The repeatability estimates for AL305\_DMY, ALL, ALDP and ALPY were computed as 0.28, 0.13, 0.21, and 0.16, correspondingly. Similar with the present results, intermediate repeatability estimates

were reported by Aziz *et al.* (2014) for AL305\_DMY and ALMY, and Rehman and Khan (2012) for AL305\_DMY, Aziz *et al.* (2014 and Wondossen *et al.* (2017) for ALL observed low repeatability estimates which were comparable with the present finding. However Ilatsia *et al.* (2007) for ALMY and Wondossen *et al.* (2017) for AL305\_DMY and ALMY, Verma (2015) for ALMY had obtained high repeatability values as compared as the current results. Moreover Ilatsia *et al.* (2007) for ALL reported intermediate repeatability estimates compared with our results. The moderate repeatability estimates observed for AL305\_DMY and ALMY indicated that selection of dairy cattle for the traits based on early performance records is reliable whereas the low repeatability estimate obtained for ALL, ALDP, ALPY and ALDPY implied that variations in them were more a result of variation in management and feeding in the given environment of a particular lactation rather than of factors associated genetic makeup of the cows.

#### **4.10.5. Phenotypic correlation among first lactation performance traits**

The coefficients of genetic (above diagonal) and phenotypic (below diagonal) correlations ( $r$ ) among first lactation performance traits of crossbred cattle are presented in Table 46. Generally, the phenotypic correlations between BW180 and BW90, BW270 and BW90, BW365 and BW90, BW450 and BW90, BW365 and BW180, BW450 and BW180, BW540 and BW180, BW540 and BW270, FLMY and FLPY and FL305\_DMY and FLPY were positive, moderate and significant while the phenotypic correlations between FLNSPC and FCI, FLNSPC and FLSP, BW0 and BW90, FL305\_DMY and FLL, and BW90 and BW540 were positive, low and significant. On the other hand positive, high and significant phenotypic correlations were found between BW180 and BW270, BW365 and BW270, BW450 and BW270, BW450 and BW365, BW540 and BW365, AFS and AFC, FLMY and FL305\_DMY and FLMY and FLL. The high and positive phenotypic correlations found in the current study showed that the traits are influenced by more or less same genetic and environmental factors and thereby improvement of one trait has improved the other correlated trait.

The phenotypic correlation of AFC with BW0, BW90, BW270, BW365, BW450 and BW540 was generally negative and very low with corresponding values of -0.06, -0.01, -0.01, -0.01, -0.04 and -0.01, in that order. However the correlation coefficient of AFC with WFC and AFC and BW180 were very low and positive with value of  $0.14 \pm 0.04$  and 0.01, respectively. Weak phenotypic correlations between

AFC with FLMY, FL305\_DMY, FLL, FLDP, FLPY and FLDPY were observed. Their estimates of the correlation coefficient were 0.01, -0.01, 0, -0.10, -0.01 and 0, respectively. These results were comparable with previous results obtained by Parveen (2017) for AFC×FLL; however the phenotypic correlation between AFC with AFS, FLNSPC, FLPP, FLSP and FCI varied from weak (-0.03 for AFC & FLPP) to strong (0.98 for AFC & AFS). The correlation AFC with FLNSPC, FLSP and FCI were estimated as 0.06, 0.04 and 0.04, respectively. Similar finding was observed by Parveen (2017) for AFC×FLL.

The phenotypic correlation between FL305\_DMY with BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC were weak and ranged from -0.01 (for FL305\_DMY and FLWFC) to 0.10 (for FL305\_DMY & BW0). Very low correlation coefficients were observed between FL305\_DMY with AFS, AFC, FLNSPC, FLPP, FLSP and FCI. The corresponding values were -0.01, -0.01, -0.04, 0.28, 0.01 and 0.02, respectively. Similar result was reported by Safaa (2006) for FCI and FL305\_DMY and Ahmad *et al* (2001) for FL305\_DMY and AFC (-0.02). Conversely, positive and a bit high phenotypic correlation was reported for Jersey cattle in Ethiopia (Yosef, 2006) and Wondossen *et al.* (2017) for crossbred cattle in Ethiopia. The phenotypic correlation between FL305\_DMY with FLMY, FLL, FLDP, FLPY and FLDPY varied from -0.23 (FL305\_DMY & FLDP) to 0.87 (for FL305\_DMY & FLMY). The estimates of correlation between FL305\_DMY with FLL, FLPY and FLDPY were found to be  $0.42\pm 0.03$ ,  $0.64\pm 0.03$  and  $0.25\pm 0.04$ , correspondingly. Similar with the present findings, Safaa (2006) obtained high and negative phenotypic correlation estimate between FL305\_DMY and FLDP. The highest phenotypic correlation among LMY and 305\_DMY and FLPY and FL305\_DMY were in agreement with the estimate reported by Shalaby *et al.* (2001) and Ahmad *et al.* (2001) for crossbred dairy cattle in Egypt and Wondossen *et al.* (2017) for crossbred cattle in Ethiopia.

#### **4.10.6. Genetic correlation among first lactation performance traits**

Generally, the genetic correlations among BW270 and BW365, BW270 and BW450, BW365 and BW450, BW365 and BW540, BW450 and BW540, FCI and FLSP and FL305\_DMY and FLMY were positive, higher and significant while the genetic correlations among BW0 and BW450, BW270 and BW540, WFC and FLDPY, FLMY and FLPY and FL305\_DMY and FLPY were positive, intermediate and significant whereas the phenotypic correlations among BW0 and BW90, BW0

and BW540, BW90 and BW180, BW90 and BW365, BW90 and BW450, BW90 and BW540, BW180 and BW270, BW180 and BW365, BW180 and BW450, BW180 and WFC, BW0 and FLDP, BW180 and FLDPY, FLL and AFS, FLL and AFC, and FLMY and FLL were observed to be positive, low and significant. However BW0 and FLMY were negatively and significantly correlated with intermediate values and the genetic correlation between BW0 and BW365 and FLSP and FLPY were positive and intermediate.

The positive and strong genetic correlations observed in the present study indicate the evidence of common genetic and physiological mechanisms controlling those traits. This in turn indicates that improvement of one trait has positive impact on the other trait and estimates of genetic correlations between the traits under study are important to exploit the correlated response.

The genetic correlation of AFC with BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC was generally negative and very low to low with estimated values of -0.37, -0.22, -0.27, -0.22, -0.09, -0.23, -0.36 and 0.11, respectively. Very low (-0.04) for AFC and FLNSPC to highest (0.996) for AFC and AFS genetic correlations were obtained. The genetic correlations between AFC with FLPP, FLSP and FCI were 0.185, 0.251 and 0.238, respectively. Estimates of genetic correlation of AFC with FLMY, FL305\_DMY, FLL, FLDP, FLPY and FLDPY ranged from -0.01 (for AFC and FLDPY) to 0.35 (for FLL and AFC). Its correlations with FLMY, FL305\_DMY, FLDP, FLPY were 0.28, 0.31, -0.03 and 0.21, respectively. On the contrary, an intermediate and positive genetic correlation (0.54) was reported for Holstein Friesian dairy cattle in Kenya (Ojango and Pollott, 2001). The positive genetic correlation between 305\_DMY and AFC indicates that genes which affect the 305\_DMY trait positively will also be responsible for an early onset of puberty among the current population at DLF of GADVASU.

The genetic correlation of FL305\_DMY with BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC was generally negative and very low to low with estimated values of -0.47, -0.25, -0.09, 0.16, -0.06, -0.17, -0.21 and -0.08, respectively. Very low genetic correlations were obtained between FL305\_DMY with AFS, FLNSPC, FLPP, and FLSP. The estimated corresponding values were found to be 0.10, -0.05, 0.25, 0.24 and 0.29, in that order. Estimates of genetic correlation of FL305\_DMY with FLMY, FLL, FLDP, FLPY and FLDPY were ranged from -0.22 (for FL305\_DMY and FLDP) to 0.96 (for FL305\_DMY and FLMY). Its correlations

with FLL, FLPY and FLDPY were 0.18, 0.69 and 0.01, respectively. The genetic correlations between FL305\_DMY with other milk yield traits were comparable with Ahmad *et al.* (2001) and Wondossen *et al.* (2017). Generally the highest genetic correlation between FL305\_DMY and FLMY and intermediate correlation between FL305\_DMY and FLPY is indicative of the fact that using 305\_DMY can be sufficient to meet selection for lactation milk yield and lactation length.

#### **4.10.7. Phenotypic correlation among milk production and reproduction traits from all lactations**

The coefficients of genetic (above diagonal) and phenotypic (below diagonal) correlations ( $r$ ) among performance traits from all lactation in crossbred cattle are presented in Table 47. The phenotypic correlation between ALCI with ALNSPC, ALPP, and FLSP were positive and varied from low to highest with corresponding values of 0.36, 0.03 and 0.99, respectively. The strong and positive phenotypic correlation between ALCI and ALSP was in agreement with results of Ghiasi *et al.* (2011), Zambrano and Echeverri (2014) who reported 0.95 and 1.0, respectively for Holstein Friesian cattle and Wondossen *et al.* (2017) for crossbred cattle in Ethiopia (0.98). Weak and negative phenotypic correlation between ALCI with ALMY, AL305\_DMY, ALL, ALDP, ALPY and ALDPY were observed. The corresponding estimated values were -0.03, -0.05, -0.01, -0.03, -0.05 and -0.01, respectively. Very low correlation coefficients were observed between AL305\_DMY with ALNSPC, ALPP, and ALSP. The corresponding values were, 0.01, 0.04 and -0.05, respectively. Conversely, positive and a bit high phenotypic correlation was reported for Jersey cattle in Ethiopia (Yosef, 2006) and Wondossen *et al.* (2017) for crossbred cattle in Ethiopia. The phenotypic correlation between AL305\_DMY with ALMY, ALL, ALDP, ALPY and ALDPY varied from -0.21 (AL305\_DMY & ALDP) to 0.87 (for AL305DMY & ALMY). The estimates of correlation between AL305\_DMY with ALL, ALPY and ALDPY were found to be 0.37, 0.69 and 0.26, correspondingly. These results were comparable with previous reports found by Wondossen *et al.* (2017) for AL305\_DMY and ALCI, Singh and Gurnani (2004) for CI and LL; but Dubey and Singh (2005) and Wondossen *et al.* (2017) for LL×CI reported intermediate and high phenotypic correlation values, respectively. These results were comparable with previous findings found by Wondossen *et al.* (2017) for 305\_DMY and LMY but lower phenotypic correlation estimates between LL and 305\_DMY by Safaa (2006) and Wondossen *et al.* (2017) whereas higher phenotypic correlation

values were obtained by Parveen (2017). Moreover the phenotypic correlations among ALMY and ALDPY was positive, intermediate and significant while the phenotypic correlations among ALNSPC and ALSP, ALNSPC and ALCI were positive, low and significant. On the other hand, positive, higher and significant phenotypic correlations were found among ALL and ALMY and ALPY and ALMY.

#### **4.10.8. Genetic correlation among milk production and reproduction traits from all lactations**

Generally the genetic correlation between ALSP and ALCI, ALMY and AL305\_DMY, ALMY and ALL, ALMY and ALPY and AL305\_DMY and ALPY were positive, high and significant whereas the genetic correlation between ALCI and ALPY, AL305-DMY and ALL and ALL and ALPY were positive, intermediate and significant. Low, negative and significant correlation were observed in ALSP and ALL, and ALSP and ALPY but the genetic correlation between ALNSPC and ALDP was negative, low and significant.

The genetic correlation between ALCI with ALNSPC, ALPP, and FLSP were positive and varied from very low to high with corresponding values of 0.083, 0.041 and 0.837, respectively. The strong and positive genetic correlation between ALCI and ALSP was in agreement with results of Ghiasi *et al.* (2011), Zambrano and Echeverri (2014) who reported 0.95 and 1.0, respectively for Holstein Friesian cattle and Wondossen *et al.* (2017) for crossbred cattle in Ethiopia (0.98). Very low to moderate genetic correlation between ALCI with ALMY, AL305\_DMY, ALL, ALDP, ALPY and ALDPY were observed. The corresponding estimated values were 0.25, 0.31, 0.17, -0.01, 0.52 and 0.06, respectively. Comparable with the present study, higher and positive genetic correlations of  $0.54 \pm 0.01$  was reported by Yosef (2006) for the crossbred cattle in Ethiopia. However weak and negative genetic correlation between 305\_DMY and CI was found by Rege (1991) for Friesian cattle and Wondossen *et al.* (2017) for crossbred cattle in Ethiopia.

Very low to low correlation coefficients were observed between AL305\_DMY with ALNSPC, ALPP, ALSP and ALCI. The corresponding values were -0.05, -0.04, 0.26 and 0.31, respectively. Positive and lower estimates were reported in Turkey (Atil *et al.*, 2001) and Egypt (Hammoud and Salem, 2013); however negative and lower genetic correlation between 305\_DMY and SP was also observed by Wondossen *et al.* (2017). On the other hand, a higher and positive estimate of genetic correlation was observed for Ethiopian

Holstein (Yosef, 2006). The positive genetic correlation of 305\_DMY and fertility traits (ALSP and ALCI) indicates that improvement of fertility is possible to certain degree in this herd as milk yield increase.

The estimates of correlation between AL305DMY with ALL, ALPY and ALDPY were found to be 0.54, 0.83 and -0.22, correspondingly. The genetic correlations between FL305-DMY with other milk yield traits were comparable with Ahmad *et al.* (2001), and Wondossen *et al.* (2017). The high genetic correlation between AL305\_DMY and ALMY and AL305-DMY and ALPY traits and moderate correlation between AL305\_DMY and ALL were result from pleiotropy (Falconer and Mackay, 1996). This means that genetic improvement of milk production trait could result in a correlated response in the correlated trait.

**Table 46. Coefficients of genetic (above diagonal) and phenotypic (below diagonal) correlations (r) among 1<sup>st</sup> lactation performance traits in crossbred cattle**

Traits	BW0	BW90	BW180	BW270	BW365	BW450	BW540	AFS	AFC	WFC
BW0		0.45*	0.08	0.08	0.33	0.50**	0.44**	-0.37*	-0.37*	0.04
BW90	0.29±0.04**		0.34*	0.32	0.37*	0.42**	0.39*	-0.24	-0.22	-0.05
BW180	0.16±0.04**	0.68±0.03**		0.45**	0.37*	0.35*	0.32	-0.28	-0.27	0.36*
BW270	0.14±0.04**	0.56±0.03**	0.77±0.02**		0.85**	0.70**	0.63**	-0.23	-0.22	-0.25
BW365	0.21±0.04**	0.53±0.03**	0.67±0.03**	0.84±0.02**		0.92**	0.80**	-0.08	-0.09	-0.14
BW450	0.25±0.04**	0.52±0.03**	0.63±0.03**	0.75±0.02**	0.87±0.02**		0.91**	-0.23	-0.23	-0.11
BW540	0.23±0.04**	0.48±0.03**	0.60±0.03**	0.70±0.03**	0.78±0.02**	0.86±0.02**		-0.37*	-0.36*	-0.07
AFS	-0.04±0.04	0.01±0.04	0.02±0.04	-0.01±0.04	0.01±0.04	-0.02±0.04	0.01±0.04		0.99**	0.11
AFC	-0.06±0.04	-0.01±0.04	0.01±0.04	-0.01±0.04	-0.01±0.04	-0.04±0.04	-0.01±0.04	0.98±0.01**		0.1062
WFC	-0.07±0.04	-0.02±0.04	-0.04±0.04	-0.09±0.04**	-0.1±0.04	-0.04±0.04	-0.03±0.04	0.11±0.04**	0.14±0.04**	
FLNSPC	-0.05±0.04	0.04±0.04	0.06±0.04	0.04±0.04	0.01±0.04	0.03±0.04	0.02±0.04	0.05±0.04	0.06±0.04	0.02±0.04
FLPP	-0.05±0.04	-0.01±0.04	-0.02±0.04	0.02±0.04	0.03±0.04	0.01±0.04	0±0.04	-0.04±0.04	-0.03±0.04	0.04±0.04
FLSP	-0.08±0.04	0.03±0.04	0.01±0.04	-0.02±0.04	-0.02±0.04	0±0.04	-0.03±0.04	0.05±0.04	0.04±0.04	-0.10±0.04**
FCI	-0.08±0.04	0.03±0.04	0.01±0.04	-0.02±0.04	-0.02±0.04	0±0.04	-0.03±0.04	0.05±0.04	0.04±0.04	-0.10±0.04**
FLMY	0.08±0.04**	0.02±0.04	0.01±0.04	0.03±0.04	0±0.04	0±0.04	0±0.04	0.01±0.04	0.01±0.04	0.01±0.04
FL305_DMY	0.1±0.04	0.04±0.04	0.04±0.04	0.06±0.04	0.05±0.04	0.03±0.04	0.02±0.04	-0.01±0.04	-0.01±0.04	-0.01±0.04
FLL	0.01±0.04	0±0.04	-0.02±0.04	-0.02±0.04	-0.07±0.04	-0.06±0.04	-0.05±0.04	-0.01±0.04	0±0.04	0.06±0.04
FLDP	-0.06±	-0.01±0.04	0.01±0.04	-0.06±0.04	-0.07±0.04	-0.05±0.04	-0.03±0.04	-0.09±0.04**	-0.10±0.04**	0.08±0.04**
FLPY	0.09±0.04**	0.05±0.04	0.02±0.04	0.05±0.04	0.05±0.04	0.02±0.04	0.02±0.04	-0.01±0.04	-0.01±0.04	0.04±0.04
FLDPY	0.11±0.04**	0.03±0.04	0.01±0.04	0.04±0.04	0.05±0.04	0.06±0.04	0.04±0.04	0±0.04	0±0.04	-0.05±0.04

**Table 46 continued**

<b>Traits</b>	<b>FLNSPC</b>	<b>FLPP</b>	<b>FLSP</b>	<b>FCI</b>	<b>FLLMY</b>	<b>FL305_DMY</b>	<b>FLL</b>	<b>FLDP</b>	<b>FLPY</b>	<b>FLDPY</b>
BW0	0.01	-0.32	0.04	0.05	-0.50**	-0.47**	-0.16	0.34**	-0.29	-0.19
BW90	0.17	-0.15	0.004	0.02	-0.29	-0.25	-0.05	0.07	-0.09	-0.02
BW180	-0.34	-0.11	-0.36*	-0.32	-0.07	-0.09	-0.12	-0.01	-0.21	0.48**
BW270	-0.06	-0.15	-0.27	-0.08	0.15	0.16	-0.16	0.24	-0.07	-0.08
BW365	-0.19	-0.27	-0.20	-0.04	-0.09	-0.06	-0.03	0.24	-0.20	-0.22
BW450	-0.18	-0.31	-0.24	-0.15	-0.20	-0.17	-0.13	0.18	-0.23	-0.26
BW540	-0.21	-0.12	-0.23	-0.14	-0.26	-0.21	-0.26	0.17	-0.17	-0.24
AFS	-0.03	0.18	0.23	0.22	0.26	0.29	0.35*	-0.04	0.19	-0.03
AFC	-0.04	0.18	0.25	0.24	0.28	0.31	0.35*	-0.03	0.21	-0.01
WFC	-0.41*	0.20	0.08	0.09	-0.05	-0.08	0.07	0.07	-0.19	0.52**
FLNSPC		-0.13	-0.21	-0.19	0.09	0.10	-0.09	0.25	-0.04	-0.34
FLPP	0.01±		0.15	0.23	-0.02	-0.05	-0.002	0.06	0.03	0.16
FLSP	0.35±0.04**	-0.03±0.04		0.85**	0.21	0.25	0.32	0.13	0.33	0.02
FCI	0.35±0.04**	0.030.04	0.985		0.21	0.24	0.25	0.07	0.20	0.01
FLMY	-0.03±0.04	0.23±0.04**	0.02±0.04	0.03±0.04		0.96**	0.30	-0.21	0.61**	0.09
FL305DMY	-0.04±0.04	0.28±0.04**	0.01±0.04	0.02±0.04	0.87±0.02**		0.18	-0.22	0.69**	0.01
FLL	-0.01±0.04	0.07±0.04**	0±0.04	0.01±0.04	0.73±0.02**	0.42±0.03**		-0.22	-0.04	-0.04
FLDP	0.01±0.04	-0.18±0.04**	-0.09±0.04**	-0.10±0.04**	-0.18±0.04**	-0.23±0.04**	-0.02±0.04		-0.17	0.19
FLPY	-0.05±0.04	0.18±0.04**	0.01±0.04	0.02±0.04	0.54±0.03**	0.64±0.03**	0.20±0.04**	-0.21±0.04**		-0.01
FLDPY	-0.01±0.04	0.12±0.04**	-0.02±0.04	-0.01±0.04	0.20±0.04**	0.25±0.04**	0.06±0.04	-0.16±0.04**	0.14±0.04**	

\*P<0.05; \*\*P<0.01; ns= non-significant; Numbers in the parenthesis are number of observations

**Table 47. Coefficients of genetic (above diagonal) and penotypic (bellow diagonal) correlations (r) among milk production and reproduction traits from all lactations in crossbred cattle**

<b>Traits</b>	<b>ALNSPC</b>	<b>ALPP</b>	<b>ALSP</b>	<b>ALCI</b>	<b>ALMY</b>	<b>AL305-DMY</b>	<b>ALL</b>	<b>ALDP</b>	<b>ALPY</b>	<b>ALDPY</b>
ALNSPC		0.036	0.15	0.08	-0.06	-0.04	-0.08	-0.39*	0.13	0.32
ALPP	0.02±0.02		-0.0001	0.04	0.05	-0.04	0.11	0.13	-0.06	0.09
ALSP	0.36±0.03**	-0.03±0.03		0.84**	0.27	0.26	0.40*	-0.002	0.48**	0.26
ALCI	0.36±0.03**	0.03±0.03	0.99±0.002**		0.25	0.31	0.17	-0.002	0.52**	0.06
ALMY	-0.01±0.00	0.05±0.02	-0.03±0.0	-0.03±0.01		0.90**	0.73**	-0.33	0.85**	-0.30
AL305DMY	0.01±0.02	0.04±0.01	-0.05±0.03	-0.05±0.03	0.87±0.02**		0.54**	-0.27	0.83**	-0.22
ALL	-0.02±0.02	0.02±0.02	-0.01±0.03	-0.01±0.03	0.70±0.02**	0.37±0.02**		-0.27	0.62**	0.08
ALDP	0.02±0.02	-0.01±0.02	-0.01±0.03	-0.01±0.03	-0.17±0.02	-0.21±0.02**	-0.02±0.02		-0.29	-0.19
ALPY	0.00±0.02	0.03±0.02	-0.05±0.03	-0.05±0.03	0.57±0.01**	0.69±0.02**	0.16±0.02**	-0.18±0.02**		0.26
ALDPY	-0.04±0.02	0.05±0.02	-0.04±0.03	-0.03±0.03	0.21±0.01**	0.260±0.02	0.04±0.02	-0.12±0.02**	0.12±0.02**	

\*P<0.05; \*\*P<0.01; ns= non-significant; Numbers in the parenthesis are number of observations

## **4.11. Phenotypic, Genetic and Environmental Trends of Performance Traits**

### **4.11.1. Phenotypic trend**

The phenotypic, genetic and environmental trends of crossbred dairy cattle for performance traits are presented in Table 48 and Fig. 9-13. The phenotypic trends for growth traits were generally positive and varied from  $0.01 \pm 0.03$  (BW0) to  $2.80 \pm 0.39$  (WFC) kg per year. Fluctuating trends were found in all different growth traits for yearly averages over the entire period 1985-2016, whilst phenotypic trends for AFS, AFC, NSPC and PP were generally negative; but the phenotypic trends for SP and CI were found to be positive. These trends varied from  $-16.20 \pm 3.30$  days per year (AFC) to  $1.17 \pm 0.44$  (CI) days per year and increase annual phenotypic trends of  $56.66 \pm 13.0$  kg,  $41.55 \pm 8.34$  kg,  $0.59 \pm 0.50$  days,  $0.20 \pm 0.04$  kg and  $0.95 \pm 0.15$  days were observed for LMY, 305\_DMY, LL, PY and DPY, respectively; whereas DP declined by  $-0.51 \pm 0.19$  days/year.

### **4.11.2. Genetic and environmental trends of growth traits**

The estimates of genetic trends for growth traits varied from  $-0.076 \pm 0.101$  kg/yr (BW365) to  $1.361 \pm 0.226$  kg per year (WFC) (table 62; Fig. 9-10). The trends were negative for all growth traits except BW180 and WFC, which might be actually expectable for dairy animals which were subjected for subsequent selection for improvement of milk production. The estimates of genetic trends for BW0, BW90, BW180, BW270, BW450 and BW540 were  $0.002 \pm 0.006$ ,  $-0.001 \pm 0.015$ ,  $0.131 \pm 0.051$ ,  $-0.042 \pm 0.061$ ,  $-0.041 \pm 0.103$  and  $0.020 \pm 0.102$  kg per yr, respectively. The environmental trends were positive for all growth traits and their estimates ranged from  $0.008 \pm 0.029$  kg/yr (BW0) to  $2.311 \pm 0.369$  kg per year (BW540). Whilst the environmental trends of crossbred dairy cattle for BW90, BW180, BW270, BW365, BW450, and WFC were found to  $0.383 \pm 0.068$ ,  $0.676 \pm 0.096$ ,  $1.508 \pm 0.209$ ,  $2.046 \pm 0.308$ ,  $2.092 \pm 0.356$  and  $1.443 \pm 0.198$  kg/yr, in that order.

### **4.11.3. Genetic and environmental trends of reproduction traits**

The estimates of genetic trends for reproduction traits varied from  $-0.494 \pm 0.490$  days/yr (AFC) to 0 days per year (NSPC) (table 62; Fig. 10-12). The genetic trends were estimated as  $-0.489 \pm 0.478$ ,  $-0.018 \pm 0.008$ ,  $-0.007 \pm 0.026$  and  $-0.016 \pm 0.048$  for AFS, PP, SP and CI, respectively. The negative genetic trends observed for AFS, AFC, SP, and CI are actually desirable. The environmental trends were positive for NSPC, SP and CI; but they were negative for AFS, AFC and PP. Their estimates ranged from  $-15.703 \pm 2.987$  days/yr (AFC) to  $1.045 \pm 0.528$  days per year (CI). Whilst the environmental trends of crossbred dairy cattle for AFS, NSPC, PP and SP were found to be  $-15.685 \pm 3.033$  days/yr,  $0.006 \pm 0.010$  no./yr,  $-0.090 \pm 0.035$  days/yr, and  $0.947 \pm 0.488$  days/yr, in that order.

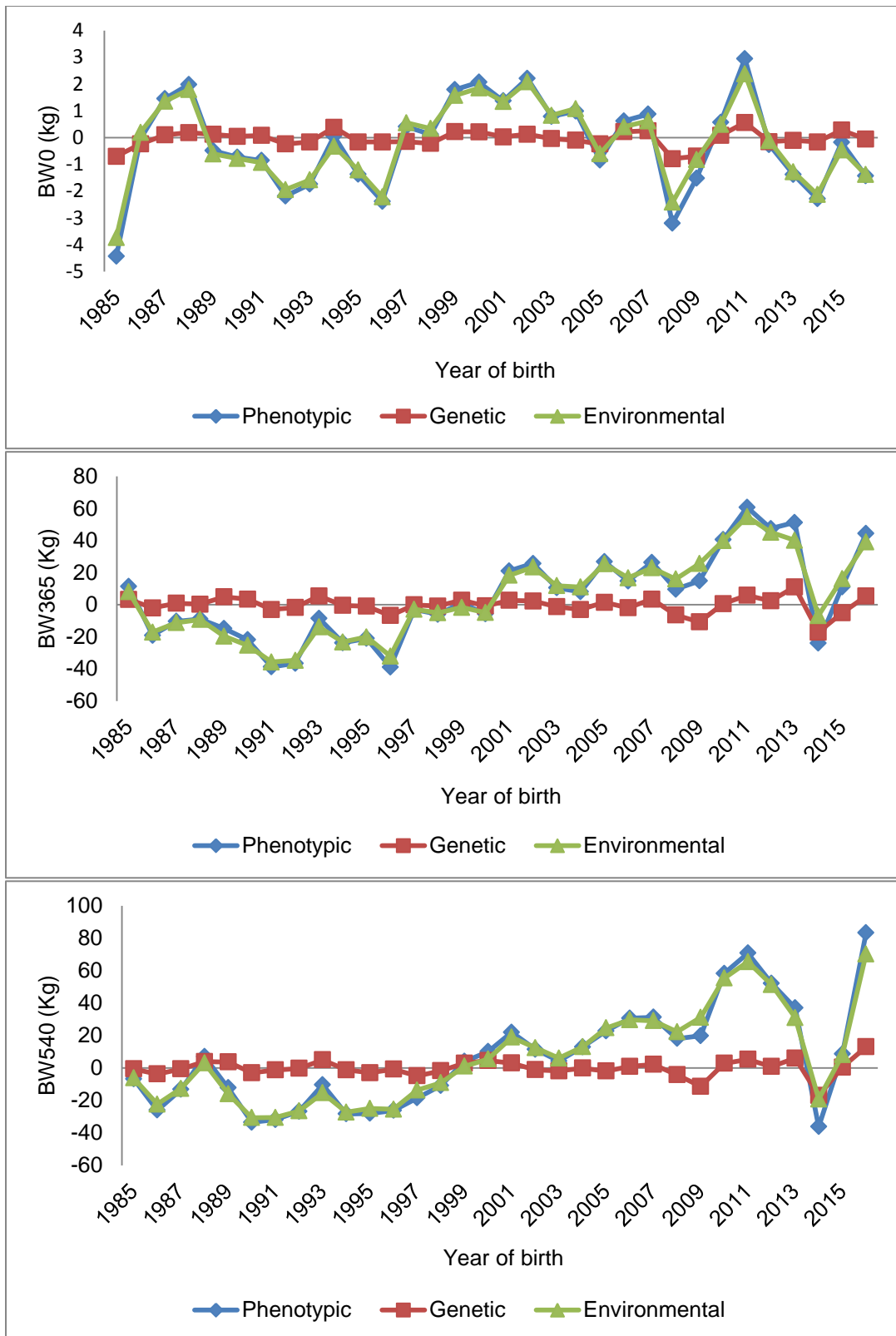
#### 4.11.4. Genetic and environmental trends of milk production traits

The annual environmental trends showed an increase for LMY (75.48±12.23 kg), 305\_DMY (62.30±6.82 kg), LL (0.84±0.56 days), PY (0.28±0.03 kg) and DPY (1.17±0.14 days); but decline for DP (0.60±.20). In general, there was an annual genetic decline of 0.68±2.91 kg , 0.89±1.94 kg, 0.12±0.05 days and 0.002±0.01 kg in LMY, 305\_DMY, DP and PY, respectively, but LL and DPY increased by 0.02±0.07 days and 0.003±0.01 days, in that order (table 48; Fig. 12-13).

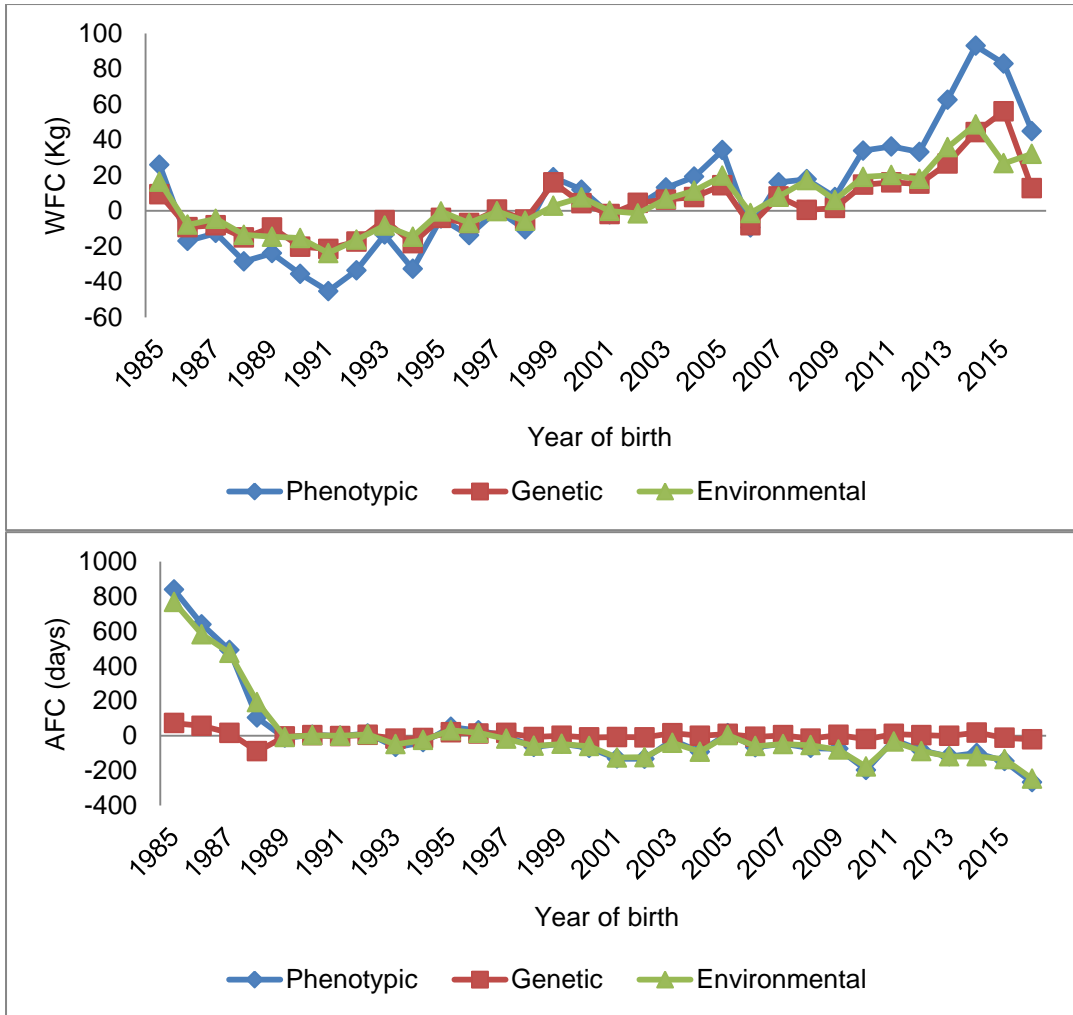
**Table 48. Phenotypic, genetic and environmental trends for performance traits in crossbred cattle**

Traits	$\Delta P$	$\Delta G$	$\Delta E$
BW0	0.01±0.03	0.002±0.01	0.01±0.03
BW90	0.38±0.08	-0.001±0.02	0.38±0.07
BW180	0.81±0.14	0.13±0.05	0.68±0.10
BW270	1.47±0.25	-0.04±0.06	1.51±0.21
BW365	1.97±0.38	-0.08±0.10	2.05±0.31
BW450	2.05±0.42	-0.04±0.10	2.09±0.36
BW540	2.33±0.44	0.02±0.10	2.31±0.37
AFS	-16.17±3.33	-0.49±0.48	-15.69±3.03
AFC	-16.20±3.30	-0.49±0.49	-15.70±2.99
WFC	2.80±0.39	1.36±0.23	1.44±0.20
NSPC	-0.002±0.01	0	0.01±0.01
PP	-0.02±0.05	-0.02±0.01	-0.09±0.04
SP	1.13±0.42	-0.01±0.03	0.95±0.49
CI	1.17±0.44	-0.02±0.05	1.05±0.53
LMY	56.66±13.00	-0.68±2.91	75.48±12.23
305_DMY	41.55±8.34	-0.89±1.94	62.30±6.82
LL	0.59±0.50	0.02±0.07	0.84±0.56
DP	-0.51±0.19	-0.12±0.05	-0.60±0.20
PY	0.20±0.04	-0.002±0.01	0.28±0.03
DPY	0.95±0.15	0.003±0.01	1.17±0.14

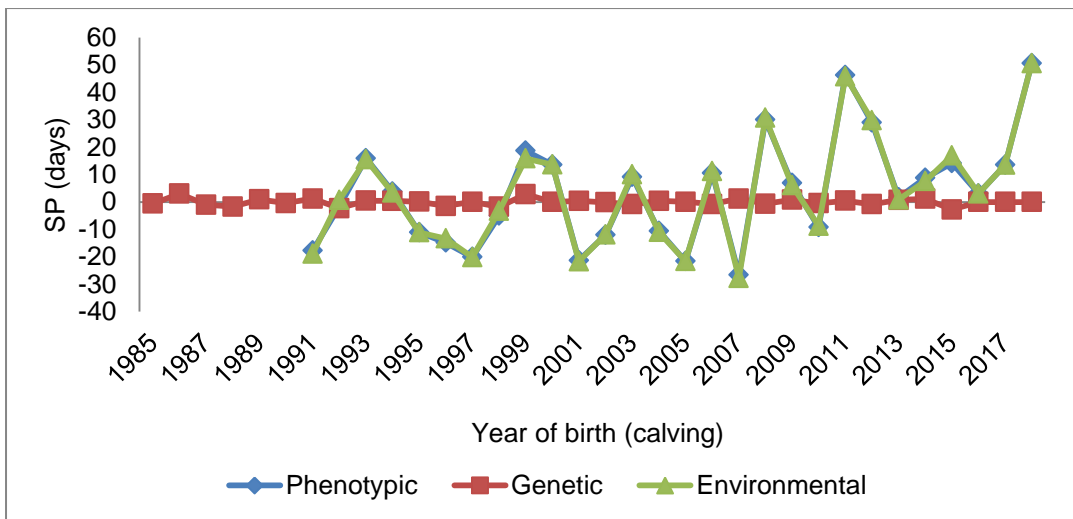
The estimates of phenotypic trends were very close to the environmental trends (Fig. 9-13), implying that the major variation in phenotypic values of milk production traits may be caused by the environment. However, the genetic trends for all the traits were close to zero or slightly above and below zero. High fluctuations were observed in the phenotypic and environmental trends over the study period (1991 to 2018). The low and static genetic trends observed on LMY, 305\_DMY and PY traits might be due to the aid of selection (phenotypic selection) used to select replacement heifers and sires or less genetic variation within the herd which might in turn be small herd size (inbreeding) and breeding system practiced (upgrading type crossbreeding). They produce milk may be because of non-additive genetic variance (dominance and epistasis which result in heterosis) or good husbandry practices. The selection criteria, the type and method of selection should be reconsidered and new breed should be introduced in the herd to increase genetic variance.



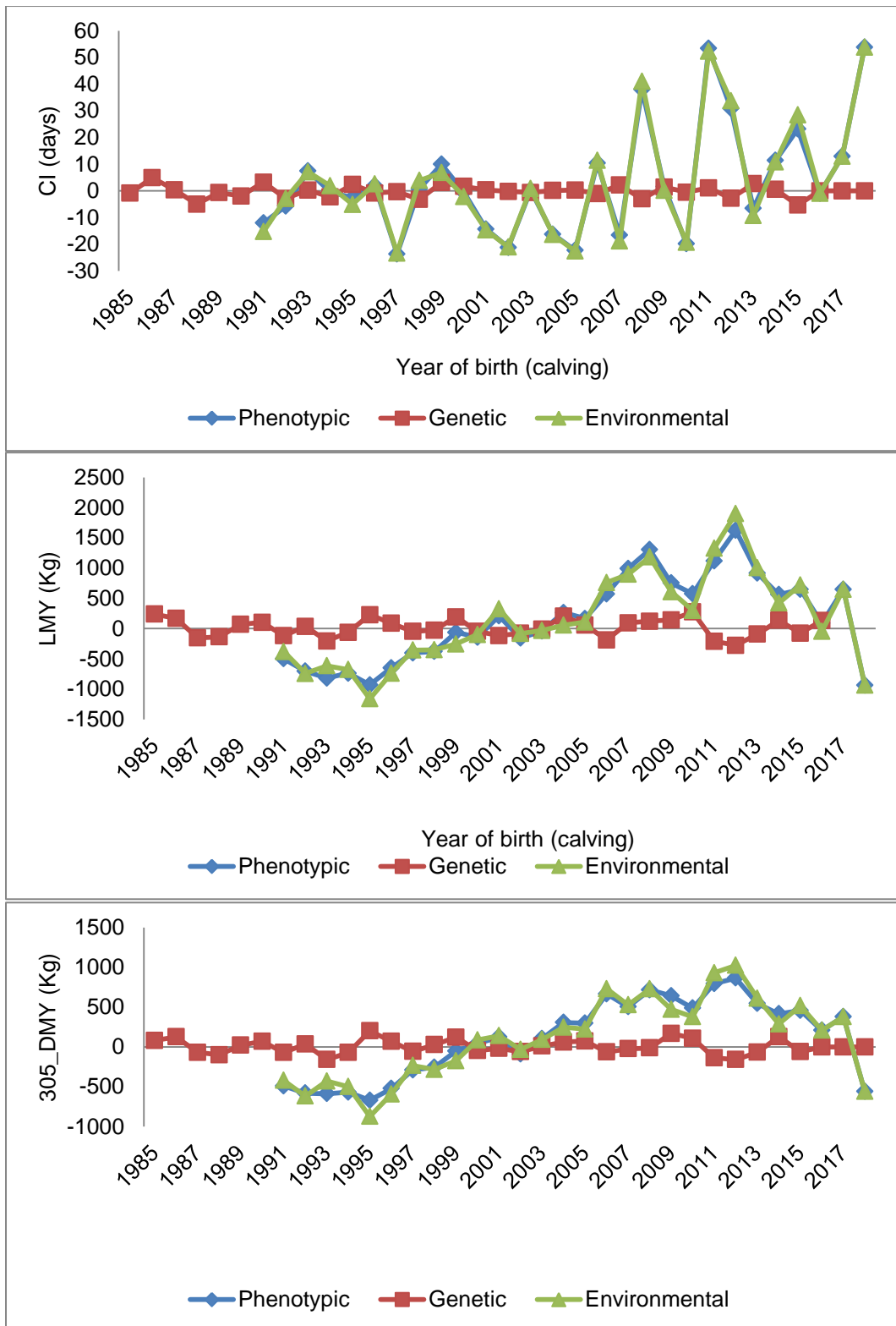
**Fig. 9. Phenotypic, genetic and environmental trends for BW0, BW365 and 540 over year of birth in crossbred cattle**



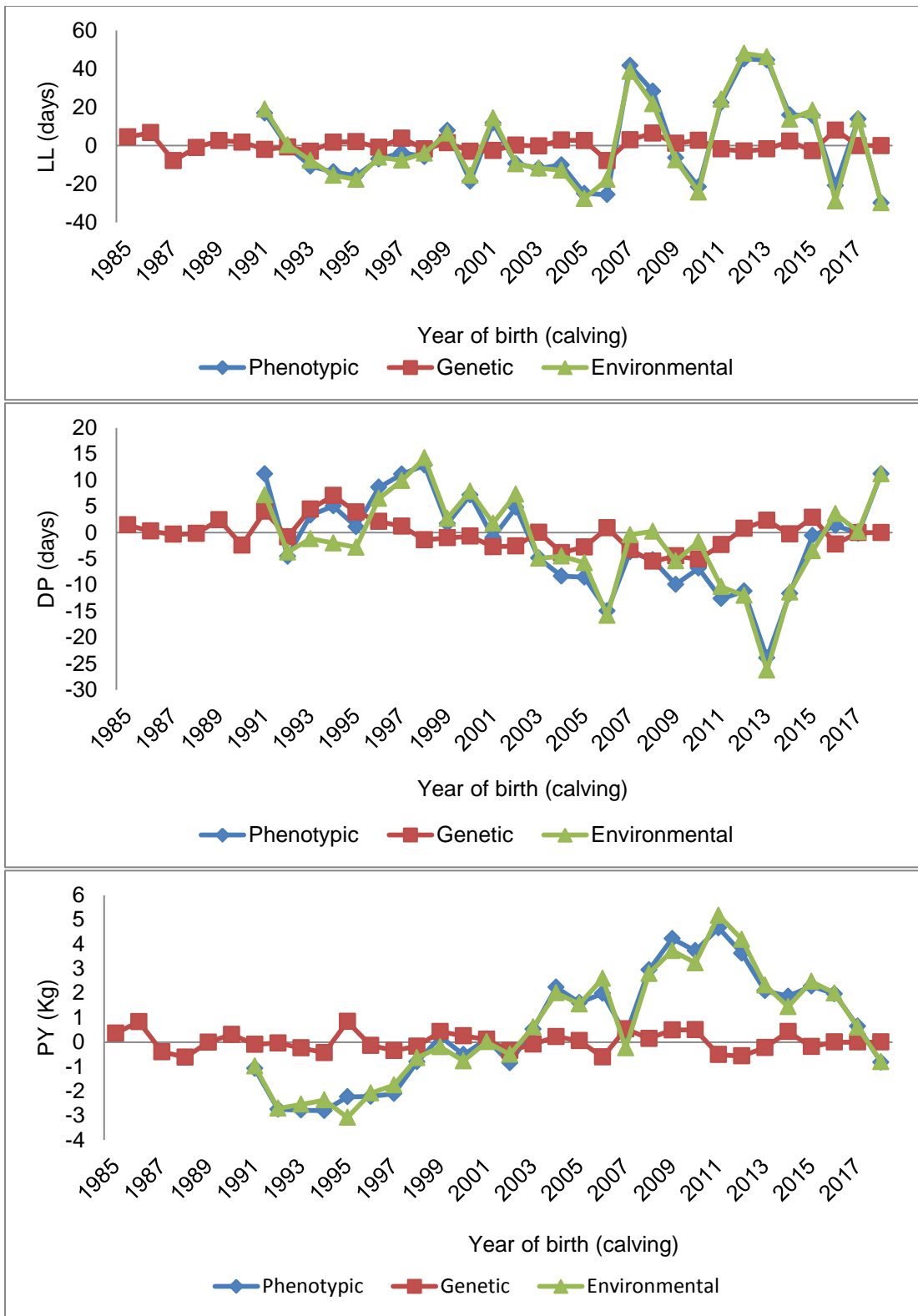
**Fig. 10. Phenotypic, genetic and environmental trends for WFC and AFC over year of birth in crossbred cattle**



**Fig. 11. Phenotypic (P), genetic (G) and environmental (E) trends for SP over year of birth for G and year of calving for P and E in crossbred cattle**



**Fig. 12. Phenotypic (P), genetic (G) and environmental (E) trends for CI, LMY and 305\_DMY over year of birth for G and year of calving for P and E in crossbred cattle**



**Fig. 13. Phenotypic (P), genetic (G) and environmental (E) trends for LL, DP and PY over year of birth for G and year of calving for P and E in crossbred cattle**

#### 4.12. Most Probable Producing Ability (MPPA) of crossbred cattle

The mean most probable producing abilities of crossbred dairy cattle for AL305\_DMY, ALMY and ALPY were  $3874.49 \pm 20.10$ ,  $4532.21 \pm 30.68$  and  $22.55 \pm 0.34$  kg, respectively and the corresponding CV were estimated as 16.93, 13.76 and 36.40%, respectively. The maximum and minimum MPPA values for AL305\_DMY, ALMY and ALPY were 2615.03, 5600.31; 2852.43, 7289.39; and 8.97, 67.33 kg, correspondingly (table 49). The values 190, 220 for AL305\_DMY, 185, 225 for ALMY and 183, 227 for ALPY were the numbers of cows whose MPPA observed above and below the average breeding values, correspondingly (table 63). The maximum and minimum MPPA estimates found in the present study for AL305\_DMY, ALMY and ALPY were comparable with previous findings of Lakshmi *et al.* (2009) whereas lower MPPA estimates based on lactation milk yield was reported by Gandhi and Gurnani (1990) in Sahiwal cows. The results for AL305\_DMY revealed that cow number FC1130 followed by FC1142 and C1278 had the highest merit but cow number FC1130 were the 8<sup>th</sup> rank based on ALMY MPPA and 3<sup>rd</sup> based on ALPY MPPA (table 64). The three top ranked cow based on MPPA of ALMY were HHS570, FC1152 and FC1142 whereas based on MPPA for APY, the first 1 viz 3 top ranked cows were 2F1017, 1F171 and FC1130.

**Table 49. Average Most Probable Producing Ability (MPPA) estimates of crossbred dairy cattle for milk production traits.**

Traits	1	2	3	4	5	6
ALMY	$4532.21 \pm 37.90$	2852.43	7289.39	185	225	40
AL305_DMY	$3874.49 \pm 26.32$	2615.03	5600.31	190	220	30
ALPY	$22.55 \pm 0.41$	8.97	67.33	183	227	44

1. Avg. MPPA ( $\pm$ SE), 2. Min MPPA (below average MPPA), 3. Max MPPA (above average MPPA), 4. Number of cows whose MPPA greater than average MPPA, 5. Number of cows whose less than average MPPA 6. Range

**Table 50. Estimated Most Probable Producing Ability (MPPA) of cows and their ranks (R) for milk production traits**

<b>Traits</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>
ALMY	HHS570	FC1142	FC1152	FC1186	HHS568	FC1282	3F721	FC1130	FC1175	FC1373
	2	2	3	3	2	3	3	3	2	4
	7342.96	7296.05	7139.09	6772.36	6587.45	6531.52	6479.38	6467.00	6427.57	6388.62
AL305_DMY	FC1130	FC1142	FC1278	HHS570	FC1152	HRS720	FC1370	FC1186	3F721	FC1373
	3	2	2	2	3	2	4	3	3	4
	5661.11	5649.24	5569.98	5501.40	5397.21	5336.15	5318.55	5314.83	5144.28	5098.64
ALPY	2F1017	FC1130	FC1370	FC1282	1F171	FC1269	1F717	3F713	HRS720	FC1338
	3	3	4	3	2	2	4	2	2	3
	34.71	31.17	30.27	29.89	29.87	29.45	29.41	28.56	28.347	28.28

### **4.13. Sire Evaluation for First Lactation Performance Traits**

In general estimated breeding value of sires for evaluation by MIVQUE and REML and Least Square Method showed large genetic variation between sires for both first and all lactation traits. The estimated breeding values of sires estimated for first and all lactation traits by all three methods revealed that EBV's of sires estimated by REML method showed small genetic variation in comparison to other three methods except for first lactation .

#### **4.13.1. Sire evaluation for growth traits**

##### **4.13.1.1. Least squares method**

The average breeding values of sires for BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC estimated by Least Squares Method were observed to be 29.39, 59.55, 102.91, 147.11, 195.51, 243.75, 291.36 and 404.35 kg, respectively. The values 42 and 33 for BW0, 40 and 35 for BW90, 37 and 38 for BW180, 54 and 21 for BW270, 53 and 22 for W365, 50 and 25 for BW450, 47 and 28 for BW540 and 44 and 30 for WFC were the numbers of sires whose breeding values found to be above and below the average breeding values, correspondingly. The highest average breeding values observed for BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC were 36.72, 76.3, 128.75, 178.9, 236.4, 286.27, 345.4 and 502.3 kg, respectively and lowest breeding values were 23.45, 44.8, 77.05, 107.11, 135.84, 187.61, 219.66, and 335.12, correspondingly. The differences between highest and lowest breeding values were 13.27, 31.5, 51.70, 71.79, 100.56, 98.66, 125.74 and 167.18 kg for BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC, in that order (table 51).

##### **4.13.1.2. Restricted Maximum Likelihood**

The average breeding values of sires for BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC estimated by Restricted Maximum Likelihood were observed to be  $28.07 \pm 0.90$ ,  $65.37 \pm 2.31$ ,  $100.76 \pm 1.80$ ,  $170.35 \pm 5.18$ ,  $223.23 \pm 6.59$ ,  $254.99 \pm 7.24$ ,  $301.86 \pm 7.65$  and  $423.21 \pm 5.96$  kg, respectively. The values 43 and 32 for BW0, 39 and 36 for BW90, 28 and 47 for BW180, 39 and 36 for BW270, 40 and 35 for BW365, 39 and 36 for BW450, 36 and 39 for BW540 and 36 and 38 for WFC were the numbers of sires whose breeding values found to be above and below the average breeding values, correspondingly. The highest average breeding values observed for BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC were 30.32, 72.82, 111.90, 182.10, 241.88, 272.77 and 325.17kg,

respectively and lowest breeding values were 26.10, 59.47, 84.40, 153.72, 195.44, 228.97 and 281.80 kg , correspondingly. The differences between highest and lowest breeding values were 11, 3, 19, 3, 5, 3, 3 and 2 kg for BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC, in that order (table 51).

#### **4.13.1.3. Minimum Variance Quadratic Unbiased Estimator**

The average breeding values of sires for BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC estimated by MIVQUE were observed to be  $28.02 \pm 0.87$ ,  $65.29 \pm 2.19$ ,  $100.63 \pm 1.77$ ,  $170.35 \pm 5.18$ ,  $222.55 \pm 6.40$ ,  $253.97 \pm 6.88$ ,  $301.55 \pm 7.46$  and  $423.22 \pm 5.98$ kg, respectively. The values 43 and 342 for BW0, 39 and 36 for BW90, 36 and 39 for BW180, 39 and 36 for BW270, 36 and 39 for BW365, 39 and 36 for BW450, 37 and 38 for BW540 and 35 and 39 for WFC were the numbers of sires whose breeding values found to be above and below the average breeding values, correspondingly. The highest average breeding values observed for BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC were 29.95, 71.36, 111.30, 182.09, 239.68, 268.93, 322.94 and 494.20 kg, respectively and lowest breeding values were 26.23, 60.66, 84.78, 153.73, 197.65, 232.67, 282.72 and 355.60 kg , correspondingly. The differences between highest and lowest breeding values were 11, 3, 3, 3, 3, 3, 1 and 4kg for BW0, BW90, BW180, BW270, BW365, BW450, BW540 and WFC, in that order (table 51).

#### **4.13.2. Sire evaluation for reproduction traits**

##### **4.13.2.1. Least Squares Method**

The average breeding values of sires for AFC, AFS, FLNSPC, FLPP, FLSP, and FCI estimated by Least Squares Method were found to be, 1008.65 days, 713.14 days, , 2.32 no., 277.17 days, 177.32 days, and 455.40 days, respectively The values 33 and 41 days for AFC, 38 and 36 days for AFS, 38 and 46 for FLNSPC, 44 and 40 days for FLPP, 44 and 40 days for FLSP, 46 and 38 days for FCI were the numbers of sires whose breeding values found to be above and below the average breeding values, correspondingly. The highest average breeding values observed for AFC, AFS, FLNSPC, FLPP, FLSP, and FCI were 1368.31 days, 1040.79 days, 5.71 no., 287.96 days, 436.76 days and 741.88 days, respectively and lowest breeding values were 776.76 days, 502.04 days, 0.06, 269.89 days, 48.80 days, and 316.69 days, correspondingly. The differences between highest and lowest breeding values were 591.55 days, 538.75 days, 5.65524 no., 18.08 days, 387.96 days and 425.20 days for AFC, AFS, FLNSPC, FLPP, FLSP, and FCI, in that order (table 51).

#### **4.13.2.2. Restricted Maximum Likelihood**

The average breeding values of sires for AFC, AFS, FLNSPC, FLPP, FLSP, and FCI estimated by Restricted Maximum Likelihood were observed to be  $877.53 \pm 39.96$ ,  $593.15 \pm 36.86$ ,  $2.05 \pm 0.30$ ,  $273.62 \pm 1.78$ ,  $186.95 \pm 16.76$  and  $470.54 \pm 17.40$ , respectively. The values 31, 43 for AFC, 31, 43 for AFS, 40, 44 for FLNSPC, 38, 46 for FLPP, 35, 49 for FLSP and 38, 46 for FCI were the numbers of sires whose breeding values found to be above and below the average breeding values, correspondingly. The highest average breeding values observed for AFC, AFS, FLNSPC, FLPP, FLSP, and FCI were 975.87 days, 674.95 days, 2.18 no., 275.39 days, 218.38 days, and 517.28 days, respectively and lowest breeding values were 761.05, 486.76 days, 1.94 no., 271.64, 162.77 and 435.55 days, correspondingly. The differences between highest and lowest breeding values were 12, 12 days, 14 no., 17, 14 and 8 days for AFC, AFS, FLNSPC, FLPP, FLSP, and FCI, in that order (table 51).

#### **4.13.2.3. Minimum Variance Quadratic Unbiased Estimator**

The average breeding values of sires for AFC, AFS, FLNSPC, FLPP, FLSP, and FCI estimated by MIVQUE were observed to be  $877.56 \pm 38.25$  days,  $593.32 \pm 35.02$  days,  $2.05 \pm 0.30$  no.,  $273.77 \pm 1.74$  days,  $187.1 \pm 16.65$  days and  $470.98 \pm 17.09$  days, respectively. The values 31 and 44 for AFC, 30 and 44 for AFS, 39, and 45 for FLNSPC, 39 and 45 for FLPP, 35 and 49 for FLSP, and 38 and 46 FCI were the numbers of sires whose breeding values found to be above and below the average breeding values, correspondingly. The highest average breeding values observed for AFC, AFS, FLNSPC, FLPP, FLSP, and FCI were 956.37, 654.55 days, 2.15 no. 275.18, 215.14 and 509.27 days, respectively and lowest breeding values were 777.99, 513.30 days, 1.96 no. 272.22, 165.47 and 442.70 days, correspondingly. The differences between highest and lowest breeding values were 13, 14 days, 6 no., 16, 14 and 8 days for AFC, AFS, FLNSPC, FLPP, FLSP, and FCI, in that order (table 51).

#### **4.13.3. Sire evaluation for milk production traits**

##### **4.13.3.1. Least Squares Method**

The average breeding values of sires for FLMY, F305\_DMY, FLL, FDP, FPY, and FDPY estimated by LSM were found to be, 4258.49 kg, 3597.69 kg, 369.09 days, 93.83 days, 20.56 kg, and 47.09 days, respectively. The values 41 and 32 for FLMY, 46 and 27 for FL305\_DMY, 36 and 37 for FLL, 21 and 52 for FLDP, 41 and

33 FLPY, 41 and 32 for FLDPY were the numbers of sires whose breeding values found to be above and below the average breeding values, correspondingly. The highest average breeding values observed for FLMY, F305\_DMY, FLL, FDP, FPY, and FDPY were 6883.13, 5317.64 kg, 514.42 days, 137.51 days, 32.54 kg and 81.00 days respectively and lowest breeding values were 2002.86, 1957.92 kg, 278.54 days, 50.34 days, 12.75 kg and 24.63 days, correspondingly. The differences between highest and lowest breeding values were 4880.27, 3359.72 kg, 235.88 days, 87.17 days, 19.80 kg and 56.37 days for FLMY, F305\_DMY, FLL, FDP, FPY, and FDPY, in that order (table 51).

#### **4.13.3.2. Restricted Maximum Likelihood**

The average breeding values of sires for FLMY, F305\_DMY, FLL, FDP, FPY, and FDPY estimated by REML were observed to be  $3303.07 \pm 654.44$ ,  $3368.10 \pm 418.57$  kg,  $353.44 \pm 18.27$  days,  $85.21 \pm 17.82$  days,  $16.18 \pm 2.94$  kg and  $53.34 \pm 3.36$  days, respectively. The values 38, 36 for FLMY, 38, 36 for FL305\_DMY, 35, 39 for FLL, 32, 42 for FLDP, 37, 37 for FLPY and 37, 37 for FLDPY were the numbers of sires whose breeding values found to be above and below the average breeding values, correspondingly. The highest average breeding values observed for FLMY, F305\_DMY, FLL, FDP, FPY, and FDPY were 4204.44, 3965.49 kg, 389.38 days, 100.68 days, 17.68 kg and 67.37 days, respectively and lowest breeding values were 2672.05, 2857.38 kg, 326.35 days, 78.26 days, 14.45 kg and 39.83 days, correspondingly. The differences between highest and lowest breeding values were 2, 2, 4, 10, 0 and 0, in that order (table 51).

#### **4.13.3.3. Minimum Variance Quadratic Unbiased Estimator**

The average breeding values of sires for FLMY, F305\_DMY, FLL, FDP, FPY, and FDPY estimated by MIVQUE were observed to be  $3293.22 \pm 648.19$  kg,  $3364.94 \pm 414.30$  kg,  $353.43 \pm 18.30$  days,  $84.64 \pm 18.08$  days,  $16.25 \pm 2.93$  kg and  $53.18 \pm 3.35$  days, respectively. The values 38 and 36 for FLLMY, 39 and 35 for FL305\_DMY, 35 and 39 for FLL, 32 and 42 for FLDP, 37 and 37 for FLPY, 38 and 36 for FLDPY were the numbers of sires whose breeding values found to be above and below the average breeding values, correspondingly. The highest average breeding values observed for FLMY, F305\_DMY, FLL, FDP, FPY, and FDPY were 4063.63, 3862.73 kg, 389.72 days, 105.26 days, 17.45 kg and 66.03 days, respectively and lowest breeding values were 2733.51, 2938.60 kg, 326.11, 73.94 days, 14.82 kg and 40.43 days, correspondingly. The differences between highest and lowest breeding values were 2, 4 kg, 4 days, 10 days, 0, and 2 days for FLMY, F305\_DMY, FLL, FDP, FPY, and FDPY, in that order (table 51).

**51. Average breeding values of sires for first lactation performance traits estimated by different methods**

<b>Performance Traits</b>	<b>Methods</b>	<b>Avg. BV</b>	<b>Min. BV</b>	<b>Max. BV</b>	<b>Number of sires above avg. BV</b>	<b>Number of sires below avg. BV</b>	<b>Range</b>
BW0	LSM	29.39±0.17	23.45	36.72	42	33	13.27
	REML	28.07±0.90	26.10	30.32	43	32	11.00
	MIVQUE	28.02±0.87	26.23	29.95	43	32	11.00
BW90	LSM	59.55±0.42	44.80	76.30	40	35	31.50
	REML	65.37±2.31	59.47	72.82	39	36	3.00
	MIVQUE	65.29±2.19	60.66	71.36	39	36	3.00
BW180	LSM	102.91±0.71	77.05	128.75	37	38	51.70
	REML	100.76±1.80	84.40	111.90	28	47	19.00
	MIVQUE	100.63±1.77	84.78	111.30	36	39	3.00
BW270	LSM	147.11±1.02	107.11	178.90	54	21	71.79
	REML	170.35±5.18	153.72	182.11	39	36	3.00
	MIVQUE	170.35±5.18	153.73	182.09	39	36	3.00
BW365	LSM	195.51±1.16	135.84	236.40	53	22	100.56
	REML	223.23±6.59	195.44	241.89	40	35	5.00
	MIVQUE	222.55±6.40	197.65	239.68	36	39	3.00
BW450	LSM	243.75±1.20	187.61	286.27	50	25	98.66
	REML	254.99±7.24	228.97	272.77	39	36	3.00
	MIVQUE	253.97±6.88	232.67	268.93	39	36	3.00
BW540	LSM	291.36±1.28	219.67	345.40	47	28	125.74
	REML	301.86±7.65	281.80	325.17	36	39	3.00
	MIVQUE	301.55±7.46	282.72	322.94	37	38	1.00
AFC	LSM	1008.65±8.08	776.76	1368.31	33	41	591.55
	REML	877.53±39.96	761.05	975.87	31	43	12.00
	MIVQUE	877.56±38.25	777.99	956.37	31	44	13.00
AFS	LSM	713.14±7.95	502.04	1040.79	38	36	538.75
	REML	593.15±36.86	486.76	674.95	31	43	12.00
	MIVQUE	593.32±35.02	513.30	654.55	30	44	14.00
WFC	LSM	404.35±1.84	335.12	502.30	44	30	167.18
	REML	423.21±5.96	355.76	493.99	36	38	2.00
	MIVQUE	423.22±5.98	355.60	494.20	35	39	4.00

Performance Traits	Methods	Avg. BV	Min. BV	Max. BV	Number of sires above avg. BV	Number of sires bellow avg. BV	Range
FLNSPC	LSM	2.32±0.06	0.06	5.71	38	46	5.66
	REML	2.05±0.30	1.94	2.18	40	44	14.00
	MIVQUE	2.05±0.30	1.96	2.15	39	45	6.00
FLPP	LSM	277.17± 0.27	269.89	287.96	44	40	18.08
	REML	273.62±1.78	271.64	275.39	38	46	17.00
	MIVQUE	273.77±1.74	272.22	275.18	39	45	16.00
FLSP	LSM	177.32±5.23	48.80	436.76	44	40	387.96
	REML	186.95±16.76	162.77	218.38	35	49	14.00
	MIVQUE	187.1±16.65	165.47	215.14	35	49	14.00
FCI	LSM	455.4±5.21	316.69	741.88	46	38	425.20
	REML	470.54±17.40	435.55	517.28	38	46	8.00
	MIVQUE	470.98±17.09	442.70	509.27	38	46	8.00
FLMY	LSM	4258.49±67.64	2002.86	6883.13	41	32	4880.27
	REML	3303.07±654.44	2672.05	4204.44	38	36	2.00
	MIVQUE	3293.22±648.19	2733.51	4063.63	38	36	2.00
F305_DMY	LSM	3597.69±42.59	1957.92	5317.64	46	27	3359.72
	REML	3368.1±418.57	2857.38	3965.49	38	36	2.00
	MIVQUE	3364.94±414.30	2938.60	3862.73	39	35	4.00
FLL	LSM	369.09±4.50	278.54	514.42	36	37	235.88
	REML	353.44±18.27	326.35	389.38	35	39	4.00
	MIVQUE	353.43±18.30	326.11	389.72	35	39	4.00
FDP	LSM	93.83±1.53	50.34	137.51	21	52	87.17
	REML	85.21±17.82	78.26	100.68	32	42	10.00
	MIVQUE	84.64±18.08	73.94	105.26	32	42	10.00
FPY	LSM	20.56±0.29	12.75	32.54	41	33	19.80
	REML	16.18±2.94	14.45	17.68	37	37	0.00
	MIVQUE	16.25±2.93	14.82	17.45	37	37	0.00
FDPY	LSM	47.09±1.14	24.63	81.00	41	32	56.37
	REML	53.34±3.36	39.83	67.37	37	37	0.00
	MIVQUE	53.18±3.35	40.43	66.03	38	36	2.00

#### **4.13.4. Sire evaluation for reproduction and milk production traits from all lactations**

##### **4.13.4.1. Least Squares Method**

The breeding values of crossbreed cattle for ALNSPC, ALPP, ALSP, ALCI, ALMY, AL305\_DMY, ALL, ALDP, ALPY, and ALDPY estimated by LSM were found to be 2.37 no., 277.00 days, 174.23 days, 451.59 days, 4459.74 kg, 3805.53 kg, 369.01 days, 91.50 days, 21.75 kg, and 47.15 days, in that order whereas the lowest and highest breeding values were 1.24 and 6.88, 269.11 and 284.13, 24.13 and 401.47, 224.31 and 659.22, 2598.88 and 6767.33, 2677.82 and 5554.55, 252.76 and 500.21, 55.61 and 141.56, 17.34 and 31.77 and 26.90 and 79.35 for ALNSPC, ALPP, ALSP, ALCI, ALMY, AL305\_DMY, ALL, ALDP, ALPY, and ALDPY, respectively. The values 45, 54 for ALNSPC, 47, 52 for ALPP, 53, 46 for ALSP, 54, 45 for ALCI, 62, 25 for ALMY, 61, 26 for AL305\_DMY, 50, 37 for ALL, 38, 49 for ALDP, 64, 23 for ALPY, and 58, 29 for ALDPY were the numbers of sires whose breeding values observed to be above and below the average breeding values, correspondingly. The differences between highest and lowest breeding values were 5.64 no., 15.01 days, 377.33 days, 434.91 days, 4168.44 kg, 2876.73 kg, 247.45 days, 85.95 days, 14.43 kg and 52.45 days for FLMY, F305\_DMY, FLL, FDP, FPY, and FDPY, in that order (table 52).

##### **4.13.4.2. Restricted Maximum Likelihood**

The breeding values of crossbreed cattle for ALNSPC, ALPP, ALSP, ALCI, ALMY, AL305\_DMY, ALL, ALDP, ALPY, and ALDPY estimated by REML were found to be  $2.45 \pm 0.35$  no.,  $276.91 \pm 0.42$  days,  $215.50 \pm 30.02$  days,  $501.39 \pm 30.24$  days,  $4826.40 \pm 440.46$  kg,  $3942.16 \pm 331.07$  kg,  $352.48 \pm 16.69$  days,  $90.50 \pm 1.47$  days,  $23.38 \pm 2.16$  kg and  $69.73 \pm 4.53$  days, in that order whereas the minimum and maximum breeding values were 2.42 and 2.49, 275.49 and 278.61, 199.25 and 226.80, 470.53 and 527.47, 4201.54 and 5451.63, 3566.63 and 4380.04, 338.43 and 366.53, 80.34 and 112.13, 22.51 and 24.76 and 68.49 and 70.51 for ALNSPC, ALPP, ALSP, ALCI, ALMY, AL305\_DMY, ALL, ALDP, ALPY, and ALDPY, respectively. The values 34 and 65 for ALNSPC, 48 and 51 for ALPP, 46 and 53 for ALSP, 46 and 53 for ALCI, 41 and 46 for ALMY, 41 and 46 for AL305\_MY, 43 and 44 for ALL, 38 and 49 for ALDP, 37 and 50 for ALPY, 43 and 44 for ALDPY were the numbers of sires whose breeding values observed to be above and below the average breeding values, correspondingly. The differences between highest and

lowest breeding values were 31 no., 3 days, 7 days, 7 days, 5 kg, 5 kg, 1 day, 11 days, 13 kg and 1 day for FLMY, F305\_dMY, FLL, FDP, FPY, and FDPY, in that order (table 52).

#### **4.13.4.3. Minimum Variance Quadratic Unbiased Estimator**

The breeding values of crossbreed cattle estimated for ALNSPC, ALPP, ALSP, ALCI, ALMY, AL305\_DMY, ALL, ALDP, ALPY, and ALDPY by MIVQUE0 were found to be  $2.44 \pm 0.35$  no.,  $276.93 \pm 0.40$  days,  $213.44 \pm 30.23$  days,  $500.64 \pm 30.35$  days,  $4791.87 \pm 428.60$  kg,  $3905.40 \pm 325.42$  kg,  $351.76 \pm 16.17$  days,  $90.03 \pm 1.58$  days,  $23.16 \pm 2.16$  kg and  $69.76 \pm 4.53$  days, in that order whereas the minimum and maximum breeding values were 2.42 and 2.49, 275.93 and 278.21, 186.81 and 232.11, 442.70 and 509.27, 4325.15 and 5205.6, 3626.07 and 4199.47, 344.38 and 358.47, 76.77 and 113.89, 22.47 and 24.24, 68.27 and 70.72 for ALNSPC, ALPP, ALSP, ALCI, ALMY, AL305\_DMY, ALL, ALDP, ALPY, and ALDPY, respectively. The values 59 and 40 for ALNSPC, 48 and 51 for ALPP, 46 and 53 for ALSP, 8 and 81 for ALCI, 41 and 46 for ALMY, 40 and 47 for AL305\_DMY, 44 and 43 for ALL, 41 and 46 for ALDP, 37 and 50 for ALPY, 43 and 44 for ALDPY were the numbers of sires whose breeding values observed to be above and below the average breeding values, correspondingly. The differences between highest and lowest breeding values were 19 no., 3 days, 7 days, 73 days, 5 kg, 7 kg, 1 day, 5 days, 13 kg and 1 day for FLMY, F305\_DMY, FLL, FDP, FPY, and FDPY, in that order (table 52).

**Table 52 Average breeding values for milk production and reproduction traits of sires from all lactation by different methods**

Traits	Methods	Avg. BV	Min. BV	Max. BV	Number of sires above average BV	Number of sires bellow average BV	Range
ALLNSPC	LSM	2.37±0.04	1.24	6.88	45	54	5.64
	REML	2.45±0.35	2.42	2.49	34	65	31.00
	MIVQUE	2.44±0.35	2.42	2.49	59	40	19.00
ALPP	LSM	277± 0.18	269.11	284.13	47	52	15.01
	REML	276.91±0.42	275.49	278.61	48	51	3.00
	MIVQUE	276.93±0.40	275.92	278.21	48	51	3.00
ALSP	LSM	174.23±3.10	24.13	401.47	53	46	377.33
	REML	215.50±30.02	199.25	226.80	46	53	7.00
	MIVQUE	213.44±30.23	186.81	232.11	46	53	7.00
ALCI	LSM	451.59±3.15	224.31	659.22	54	45	434.91
	REML	501.39±30.24	470.53	527.47	46	53	7.00
	MIVQUE	500.64±30.35	442.70	509.27	8	81	73.00
ALMY	LSM	4459.74±43.59	2598.88	6767.33	62	25	4168.44
	REML	4826.4±440.46	4201.54	5451.63	41	46	5.00
	MIVQUE	4791.87±428.60	4325.15	5205.60	41	46	5.00
AL305_DMY	LSM	3805.53±28.45	2677.82	5554.55	61	26	2876.73
	REML	3942.16±331.07	3566.63	4380.04	41	46	5.00
	MIVQUE	3905.4±325.42	3626.07	4199.47	40	47	7.00
ALL	LSM	369.01±2.92	252.76	500.21	50	37	247.45
	REML	352.48±16.69	338.43	366.53	43	44	1.00
	MIVQUE	351.76±16.17	344.38	358.47	44	43	1.00
ALDP	LSM	91.50±0.98	55.61	141.56	38	49	85.95
	REML	90.50±1.47	80.34	112.13	38	49	11.00
	MIVQUE	90.03±1.58	76.77	113.89	41	46	5.00
ALPY	LSM	21.75±0.19	17.34	31.77	64	23	14.43
	REML	23.38±2.16	22.51	24.76	37	50	13.00
	MIVQUE	23.16±2.16	22.47	24.24	37	50	13.00
ALDPY	LSM	47.15±0.71	26.90	79.35	58	29	52.45
	REML	69.73±4.53	68.49	70.51	43	44	1.00
	MIVQUE	69.76±4.53	68.27	70.72	43	44	1.00

#### **4.13.5. Sire ranking for first lactation traits**

Sires of top 10 ranks on the basis of estimated breeding values of sires for first and all lactations performance traits by all three methods are presented in table 68 and 69, respectively. Sire evaluation is generally aimed at selecting first few top ranking sires.

The top 10 Sires ranked on the basis of yearling body weight revealed that Sire No. 53 ranked 1<sup>st</sup> by REML and MIVQUE0, Sire No. 61 by LSM. Sire No. 48 ranked 2<sup>nd</sup> by REML and MIVQUE0, Sire No. 82 by LSM. Sire No. 50 ranked 3<sup>rd</sup> by REML, MIVQUE0, and LSM for yearling body weight.

The top 10 Sires ranked on the basis of body weight at 540 days of age revealed that Sire No. 48 ranked 1<sup>st</sup> by REML and MIVQUE0, while Sire No. 87 ranked first by LSM. Sire No. 80 ranked 2<sup>nd</sup> by REML and MIVQUE0 while Sire No. 34 by LSM. Sire No.74 ranked 3<sup>rd</sup> by REML, MIVQUE0, and Sire No. 97 by LSM for body weight at 540 days of age.

The top 10 Sires ranked' on the basis of body weight at first calving revealed that Sire No. 54 ranked 1<sup>st</sup> by REML and MIVQUE0, Sire No. 52 by LSM. Sire No. 55 ranked 2<sup>nd</sup> by REML, MIVQUE0 and LSM. Sire No. 57 ranked 3<sup>rd</sup> by REML and MIVQUE0 whereas Sire No. 54 ranked 3<sup>rd</sup>by LSM.

The top 10 Sires ranked on the basis of age at first calving revealed that Sire No. 21 ranked 1<sup>st</sup> by REML and MIVQUE0 and Sire No. 18 by LSM. Sire No. 98 ranked 2<sup>nd</sup> by REML and MIVQUE0, Sire No. 76 by LSM. Sire No. 99 ranked 3<sup>rd</sup> by REML and MIVQUE0 whereas Sire No. 3 ranked 3<sup>rd</sup> by LSM.

The top 10 Sires ranked on the basis of calving interval revealed that Sire No. 109 ranked 1<sup>st</sup> by REML and MIVQUE0 and Sire No. 18 by LSM. Sire No. 59 ranked 2<sup>nd</sup> by REML and MIVQUE0 and Sire No. 3 by LSM. Sire No. 18 ranked 3<sup>rd</sup> by REML and Sire No. 60 by MIVQUE0 whereas Sire No. 90 ranked 3<sup>rd</sup> by LSM.

The top 10 Sires ranked on the basis of first lactation total lactation milk yield revealed that Sire No. 15 ranked 1<sup>st</sup> by REML and MIVQUE0, Sire No. 16 by LSM. Sire No. 26 ranked 2<sup>nd</sup> by REML, MIVQUE0 and LSM. Sire No. 94 ranked 3<sup>rd</sup> by REML and MIVQUE0 whereas Sire No. 20 ranked 3<sup>rd</sup> by LSM. The top 10 Sires ranked on the basis of first lactation 305 days milk yield revealed that Sire No. 43 ranked 1<sup>st</sup> by REML, MIVQUE0 and LSM. Sire No. 94 ranked 2<sup>nd</sup> by REML and MIVQUE0 and Sire No. 67 by LSM. Sire No. 26 ranked 3<sup>rd</sup> by REML, MIVQUE0 and LSM.

#### 4.13.6. Sire ranking based on pooled lactation traits

The top 10 Sires ranked on the basis of all lactation total lactation milk yield revealed that Sire No. 26 ranked 1<sup>st</sup> by REML, MIVQUE0 and LSM. Sire No. 43 ranked 2<sup>nd</sup> by REML, Sire No. 15 by MIVQUE0 and Sire No. 65 by LSM. Sire No. 65 ranked 3<sup>rd</sup> by REML and Sire No. 43 by MIVQUE0 and LSM.

The top 10 Sires ranked on the basis of all lactation 305 days lactation milk yield revealed that Sire No. 43 ranked 1<sup>st</sup> by REML, MIVQUE0 and LSM. Sire No. 26 ranked 2<sup>nd</sup> by REML, Sire No. 67 by MIVQUE0 and Sire No. 65 by LSM. Sire No. 67 ranked 3<sup>rd</sup> by REML and Sire No. 26 by MIVQUE0 and LSM.

The top 10 Sires ranked on the basis of all lactation length of lactation period revealed that Sire No. 26 ranked 1<sup>st</sup> by REML, MIVQUE0 and LSM. Sire No. 104 ranked 2<sup>nd</sup> by REML and MIVQUE0 and Sire No. 16 by LSM. Sire No. 15 ranked 3<sup>rd</sup> by REMLMIVQUE0 and Sire No. 104 by LSM.

The sires used across the thirty two years period were ranked based on major economical important traits. For ranking of sires both the amplitude and precision of heritability estimates were considered. So that traits with intermediate high to high heritability estimates with low to intermediate low standard errors of the  $h^2$  values were chosen as basis of ranking. Single trait sire ranking was done. For ranking sire, pooled data (for genetic group) of each selected trait were properly adjusted for significant effects of fixed factors. Furthermore, the genetic group differences were taken care by the model. Besides, many sires produced progenies with all genetic groups. Since there would be genetic link across genetic groups, comparison sires with progenies performances with different genetic groups could also likely be possible. There were changes in the rank of first few top sires by different methods of sire evaluation. The results indicated that all sires would not rank same for first lactation and pooled lactation traits. However, the rank of sires for different traits revealed that 4.5% of top sires almost had similar rank for first and all lactation traits. These results suggested that to improve life time productivity major culling of bulls of cow should be done on the basis of their daughter's first lactation milk yield. The EBV's of sire revealed that REML method showed small genetic variation in comparison to MIVQUE0 method of sire evaluation used in the study. Same results are also observed by Dalal *et al.* (1999), Dubey and Singh (2005) and Garima (2006) on the basis of first lactation and lifetime traits. The result revealed that sire number 26 for ALL and ALMY and 43 for AL305\_DMY had the highest merit computed by LSM, REML and MIVQUE0.

**Table 53. Ranks (R) of sires based on estimated breeding values of various first lactation performance traits by different methods**

Traits	Methods		1	2	3	4	5	6	7	8	9	10
BW365	REML	Sire	53	48	50	61	80	99	82	49	35	109
		N	9	11	6	9	10	5	6	7	6	11
		BV	241.88	238.76	237.98	237.54	236.87	236.08	235.15	234.63	234.1	233.72
	MIVQUE	Sire	53	48	50	61	80	99	82	49	35	109
		N	9	11	6	9	10	5	6	7	6	11
		BV	239.68	236.61	235.5	235.34	234.83	233.86	232.97	232.67	232.3	231.98
	LSM	Sire	61	82	50	80	16	48	67	109	99	74
		N	9	6	6	10	5	11	6	11	5	5
		BV	236.40	235.47	235.31	233.12	232.08	230.31	230.19	227.83	226.07	224.01
BW540	REML	Sire	48	80	74	61	17	35	25	55	8	53
		N	11	10	5	9	10	6	10	5	10	9
		BV	325.17	316.27	315.23	314.77	314.66	314.21	312.94	312.87	312.87	312.83
	MIVQUE	Sire	48	80	74	17	61	35	8	25	55	53
		N	11	10	5	10	9	6	10	10	5	9
		BV	322.94	314.65	313.36	313.28	313.26	312.82	311.73	311.59	311.37	311.34
	LSM	Sire	48	74	80	81	61	25	17	72	16	51
		N	11	5	10	5	9	10	10	5	5	5
		BV	345.40	339.50	334.25	332.43	331.45	328.59	327.20	326.90	326.43	324.92
AFC	REML	Sire	21	98	99	18	113	68	25	74	3	8
		N	11	8	5	8	16	14	10	5	7	10
		BV	761.05	765.68	810.37	821.93	827.25	829.81	832.02	832.22	836.51	838.42
	MIVQUE	Sire	21	98	99	18	113	68	25	74	8	3
		N	11	8	5	8	16	14	10	5	10	7
		BV	777.99	785.63	825.66	833.97	835.67	836.07	841.48	842.44	844.51	845.96
	LSM	Sire	18	76	3	25	98	99	74	91	21	113
		N	8	6	7	10	8	5	5	6	11	16
		BV	776.76	787.63	808.27	823.55	827.47	830.36	832.93	834.11	858.99	861.60
WFC	REML	Sire	54	55	57	52	56	61	47	87	35	50
		N	10	5	5	8	7	9	5	6	6	6
		BV	493.99	479.2	476.92	475.13	467.89	467.89	459.96	458.66	455.17	454.41
MIVQUE	Sire	54	55	57	52	56	61	47	87	35	50	

	LSM	N	10	5	5	8	7	9	5	6	6	6	
		BV	494.19	479.53	477.19	475.48	468.06	468.02	460.14	458.82	455.33	454.54	
		Sire	52	55	54	57	56	61	47	87	35	51	
		N	8	5	10	5	7	9	5	6	6	5	
		BV	502.30	500.43	498.95	490.41	471.68	468.02	466.35	461.60	459.54	456.77	
FCI	REML	Sire	20	103	21	18	107	109	40	51	57	47	
		N	7	15	11	8	18	11	7	5	5	5	
		BV	455.56	458.7	460.11	460.38	461.18	461.49	461.8	461.83	462.58	462.83	
	MIVQUE	Sire	20	103	21	18	107	109	40	51	57	47	
		N	7	15	11	8	18	11	7	5	5	5	
		BV	456.52	459.47	460.94	461.21	461.94	462.26	462.54	462.62	463.31	463.53	
	LSM	Sire	18	3	67	91	56	109	72	54	64	59	
		N	8	7	6	6	7	11	5	10	5	14	
		BV	316.69	318.69	327.57	330.53	334.81	338.18	353.22	356.81	359.69	368.61	
	FLMY	REML	Sire	15	26	94	16	20	76	43	67	61	89
			N	10	5	14	5	7	6	7	6	9	6
			BV	4204.4	4028.2	3957.9	3871.8	3826.6	3771.2	3731.1	3723.8	3718.4	3697.4
MIVQUE		Sire	15	26	94	16	20	76	61	43	67	89	
		N	10	5	14	5	7	6	9	7	6	6	
		BV	4063.6	3895.0	3869.8	3752.57	3731.5	3676.4	3650.0	3642.5	3639.6	3623	
LSM		Sire	16	26	20	76	15	67	94	43	89	5	
		N	5	5	7	6	10	6	14	7	6	11	
		BV	6883.1	6824.8	6218.7	6208.2	6104.5	6002.2	5932.6	5874.8	5777.8	5653.6	
FL305_DMY		REML	Sire	43	94	26	67	20	5	108	7	61	89
			N	7	14	5	6	7	11	5	12	9	6
			BV	4195.1	4099.1	3991.0	3983.95	3976.7	3924.8	3904.5	3889.6	3883.35	3871.44
	MIVQUE	Sire	43	94	26	20	67	5	7	108	61	89	
		N	7	14	5	7	6	11	12	5	9	6	
		BV	3865.9	3817.0	3700.3	3691.58	3691.5	3649.8	3625.6	3625.2	3617.9	3601.34	
	LSM	Sire	43	94	26	20	67	5	7	108	61	89	
		N	7	14	5	7	6	11	12	5	9	6	
		BV	5317.6	4903.6	5048.9	4956.21	5087.1	4802.7	4634.9	4948.0	4575.62	4729.79	

**Table 54. Ranks (R) of sires based on estimated breeding values of various all lactation production and reproduction traits by different methods**

Traits	Methods		1	2	3	4	5	6	7	8	9	10	
ALMY	REML	Sire	26	43	65	15	44	61	16	21	40	74	
		N	18	15	6	17	20	20	6	39	13	15	
		BV	5451.6	5244	5236.2	5230.4	5196.8	5191.31	5181.82	5154.17	5119.17	5107.68	
	MIVQUE	Sire	26	15	43	61	65	44	21	16	94	67	
		N	18	17	15	20	6	20	39	6	50	19	
		BV	5205.6	5065	5065.4	5051.2	5044.1	5041.46	5029.97	5012.7	5005.57	4981.4	
	LSM	Sire	26	65	43	40	30	16	44	85	15	11	
		N	18	6	15	13	7	6	20	9	17	22	
		BV	6767.3	6703	6487.0	6432.4	6322.1	6226.22	6199.3	6061.06	5900.49	5812.6	
	AL305_DMY	REML	Sire	43-	26	67	65	61	94	74	20	21	11
			N	15	18	19	6	20	50	15	47	39	22
			BV	4380.0	4297	4296.0	4270.8	4215	4164.4	4158.5	4151.96	4151.3	4150.95
MIVQUE		Sire	43	67	26	65	61	94	21	20	7	74	
		N	15	19	18	6	20	50	39	47	43	15	
		BV	4199.5	4145	4140.6	4106.9	4102.8	4079.99	4059.33	4051.67	4051.45	4048.32	
LSM		Sire	65	43	26	44	54	57	11	42	67	74	
		N	6	15	18	20	13	5	22	17	19	15	
		BV	5496.5	5452	4984.4	4820.5	4809.1	4744.79	4695.32	4686.87	4667.65	4662.98	
ALL		REML	Sire	26	104	15	16	94	21	89	40	59	44
			N	18	19	17	6	50	39	12	13	21	20
			BV	366.53	363.4	361.9	361.72	360.79	360.07	359.88	359.71	359.64	359.55
	MIVQUE	Sire	26	104	15	94	16	21	89	7	59	40	
		N	18	19	17	50	6	39	12	43	21	13	
		BV	358.47	357.2	356.16	356.13	355.96	355.74	355.33	355.28	355.27	355.16	
	LSM	Sire	26	16	104	40	70	85	30	21	9	94	
		N	18	6	19	13	5	9	7	39	16	50	
		BV	497.67	470.2	457.42	445.79	444.77	439.12	438.86	433.51	429.13	422.48	

N: number of daughters per sire

**Keys:**

<b>Sire ID</b>	<b>Sire Code</b>	<b>Sire ID</b>	<b>Sire Code</b>
HRS256	S103	HFA10	S72
HRS265	S104	HFA113	S74
HRS548	S107	HFC1017	S76
HRS683	S108	11H2563	S8
HRS712	S109	HFI344	S80
15H416	S11	HFI95	S82
HRS812	S113	HFN3171	S85
1F1130	S15	HFN3192	S87
1F804	S16	HHS831	S89
1F816	S17	11H528	S9
1F994	S18	HHS973	S91
21H380	S20	HRS110	S94
21H465	S21	HRS203	S98
3F940	S25	HRS204	S99
3H670	S26		
22518	S3		
FC1152	S30		
FC1201	S35		
FC1238	S40		
FC1273	S42		
FC1278	S43		
FC1297	S44		
FC1358	S47		
FC1362	S48		
FC1387	S49		
11H1528	S5		
FC1393	S50		
FC1400	S52		
FC1426	S53		
FC1451	S54		
FC1461	S55		
FC1475	S56		
FC1500	S57		
FCB517	S59		
FCB847	S61		
HF1016	S64		
HF1022	S65		
HF1325	S67		
HF162	S68		
11H2262	S7		

#### **4.13.7. Efficiency of sire evaluation methods**

Efficiency of the methods of sire evaluation was determined by comparing the product moment correlations and rank correlation of breeding values of sires estimated by various sire evaluation methods for the first and all lactation performance traits. The product moment correlations between the breeding values of sires and the rank correlations between the rankings of sires by various methods are presented in table 55-56. The results indicated that association between the Restricted Maximum Likelihood (REML) and other methods of sire evaluation ranging from 0.85 to 1.0 (Rank correlation) and 0.86 to 1.0 (Product moment correlation) for growth traits, from 0.72 to 1.0 (Rank correlation) and 0.69 to 1.0 (Product moment correlation) for first lactation reproduction traits and from -0.04 to 1.0 (Rank correlation) and -0.09 to 1.0 (Product moment correlation) for first lactation milk production traits. All the estimates of simple and rank correlation were highly significant ( $P < 0.01$ ), whilst the correlation between REML with other sire evaluation methods ranged 0.79 to 1.0 (Rank correlation) and 0.73 to 1.0 (Product moment correlation) for milk production traits from all lactations.

It was inferred that ranking of sires by these methods did not alter significantly except between REML and LSM for ALMY, 305\_DMY and ALL whereby the probability of ranking sires similarly for these traits are very low as well as insignificant. The higher and statistically significant ( $P < 0.01$ ) rank and product movement correlations among different sire evaluation methods for BW365, BW540, WFC, and AFC indicated that there was higher degree of similarity of ranking sires by all three methods; however higher and significant correlation between REML and MIVQUE0 in similarly ranking of sires for FLMY, FL305\_DMY, AL305\_DMY, ALMY and ALL. LSM had least correlation estimates in ranking sires similarly with REML and MIVQUE0 for first and pooled lactation milk production traits. The results of the present investigation revealed that both REML and MIVQUE0 methods could be considered as good methods for ranking of sires for milk production traits with high efficiency. In ranking of sires for growth and reproduction traits, LSM would be considered as an option next to REML and MIVQUE0.

**Table 55. Spearman (above diagonal) and Pearson (below diagonal) correlation among sire breeding values for various first lactation performance traits by different methods**

LSM	0.83**	0.83**	
<b>BW365</b>			
	REML	MIVQUE0	LSM
REML		1.00**	0.86**
MIVQUE0	1.00**		0.85**
LSM	0.89**	0.88**	
<b>BW540</b>			
	REML	MIVQUE0	LSM
REML		1.00**	0.87**
MIVQUE0	1.00**		0.86**
LSM	0.87**	0.86**	
<b>AFC</b>			
	REML	MIVQUE0	LSM
REML		1.00**	0.90**
MIVQUE0	1.00**		0.89**
LSM	0.88**	0.87**	
<b>WFC</b>			
	REML	MIVQUE0	LSM
REML		1.00**	0.99**
MIVQUE0	1.00**		0.99**
LSM	0.99**	0.99**	
<b>FCI</b>			
	REML	MIVQUE0	LSM
REML		1.00**	0.73**
MIVQUE0	1.00**		0.72**
LSM	0.70**	0.69**	
<b>FLMY</b>			
	REML	MIVQUE0	LSM
REML		1.00**	-0.04 <sup>ns</sup>
MIVQUE0	1.00**		-0.05 <sup>ns</sup>
LSM	-0.09 <sup>ns</sup>	-0.09 <sup>ns</sup>	
<b>FL305_DMY</b>			
	REML	MIVQUE0	LSM
REML		1.00**	0.03 <sup>ns</sup>
MIVQUE0	1.00**		0.02 <sup>ns</sup>
LSM	0.03**	0.03**	

**Table 56. Spearman (above diagonal) and Pearson (below diagonal) correlation among sire breeding values for performance traits from all lactations by different methods**

ALMY			
	REML	MIVQUE0	LSM
REML		1.00**	0.86**
MIVQUE0	1.00**		0.84**
LSM	0.85**	0.82**	
AL305_DMV			
	REML	MIVQUE0	LSM
REML		1.00**	0.86**
MIVQUE0	1.00**		0.85**
LSM	0.86**	0.83**	
ALL			
	REML	MIVQUE0	LSM
REML		1.00**	0.79**
MIVQUE0	1.00**		0.78**
LSM	0.75**	0.73**	

#### **4.14. Growth Curve Modeling**

##### **4.14.1. Growth curve parameters**

The estimates of average growth curve parameters and their standard errors in crossbred cattle under various non-linear models are depicted in the table 57. This study revealed that the asymptotic mature body weight (A) varied from 413.90±7.479 Kg for Logistic to 1087.80±125 Kg for Von Bertalanffy models. Followed to Von Bertalanffy model, Broody (701.90±111.1 kg) and Richard (694.1142±5.21 kg) models gave higher asymptotic mature body weight (A) whereas moderate asymptotic mature body weight were observed in Quadratic (433.32±5.81), Gompertz (446.30±4.768 kg) and Cubic (458.30±1.04) models. Variations in constant of integration (B) values were observed across the different non-linear models where Logistics gave the highest B value (9.766±0.55) and Cubic model estimated the lowest B Value (0.3096±0.01) (Table 72). Broody, Von Bertalanffy and Richard models estimated nearly similar B values. The values of maturation rate (K) varied across the various models. Relatively high maturation rate (0.0059±0.0002) was found in Logistic model while the smallest maturation rate was observed in the Quadratic (-0.0002±4×10<sup>-4</sup>) models. Maturation rate (K) was also remained small in other models.

The asymptotic mature body weights (A) estimated in this study using Quadratic, Logistics and Gompertz models were lower than previous findings reported by Salem *et al.*, 2013 for Frisian crossbred calves using Broody model,

Berry *et al.* (2005) for female Holstein Frisian dairy cattle using Von Bertalanffy model, and Bahri *et al.* (2004) for Brown Swiss cattle using Richard model. The mature weights for the above models were also lower than findings of Jenkins *et al.* (1991), who reported that estimated mature weight of Brown Swiss was 520 kg. This might be the present study we used weight data of animals from birth up to age 1008 days at the last weighing. Thus, the (A) estimate reflects the mean of the weight at the last weightings. However the estimates of asymptotic mature body weights (A) of this study were higher than other previous studies performed by Salim *et al.* (2015) for Dhofari using Von Bertalanffy, Ozgur and Serkan (2014) for Holstein calves using Logistic model and Kedma *et al.* (2013) for Nellore cows using Von Bertalanffy. The asymptotic mature body estimated under Von Bertalanffy model was comparable with report of Ozgur and Serkan (2014) for female Holstein calves.

For this study, the maturity rate (K) estimate was found to be lower than maturity rate (K) estimates reported by Berry *et al.* (2005) for female Holstein Frisian dairy cattle using Von Bertalanffy model, Bahri *et al.* (2004) for Brown Swiss; Kedma *et al.*, 2013; Salem *et al.*, 2013) for Frisian crossbred calves and Ozgur and Serkan (2014) for female Holstein calves. The integration constant (B) values found in the current study were lower as compared with other previous findings. Salem *et al.*, 2013 reported B values of  $146.00 \pm 2.1$  for Frisian crossbred calves using Broody model and Berry *et al.* (2005) for female Holstein Frisian dairy cattle estimated B values of  $62.5 \pm 0.74$  using Von Bertalanffy model. However the B values estimated by Logistics, and Gompertz were higher than previous results reported by Bahri *et al.* (2004) ( $0.63 \pm 0.024$ ) for Brown Swiss cattle, Salim *et al.* (2015) ( $0.522 \pm 0.004$ ) for Dhofari using Von Bertalanffy, Ozgur and Serkan (2014) ( $1.77 \pm 0.05$ ) for Holstein calves using Logistic model and Kedma *et al.* (2013) for Nellore cows using Von Bertalanffy.

### 57. Average growth curve parameters ( $\pm$ SE) in crossbred cattle

Models	Estimates of growth parameters			
	A (kg)	B	K	M
Broody	$701.90 \pm 111.1$	$0.98 \pm 0.01$	$0.001 \pm 0.0002$	
Von Bertalanffy	$1087.80 \pm 125.00$	$0.98 \pm 0.05$	$0.0003 \pm 0.06$	
Logistics	$413.90 \pm 7.479.00$	$9.77 \pm 0.55$	$0.01 \pm 0.0002$	
Gompertz	$446.30 \pm 4.77$	$2.73 \pm 0.03$	$0.003 \pm 0.000063$	
Richard	$694.11 \pm 5.21$	$0.98 \pm 0.01$	$0.001 \pm 0.0002$	$1.64 \pm 0.0002$
Quadratic	$433.32 \pm 5.81$	$0.58 \pm 0.04$	$-0.0002 \pm 4 \times 10^{-4}$	
Cubic	$458.30 \pm 1.04$	$0.31 \pm 0.01$	$0.0006 \pm 4 \times 10^{-4}$	$56 \times 10^{-6} \pm 3 \times 10^{-7}$

#### 4.14.2. Phenotypic correlation among growth curve parameters

The estimates of phenotypic correlation among growth curve parameters in crossbred dairy cattle are presented in Table 59. The results revealed that parameters A and B were associated significantly ( $P < 0.01$ ) as well as negatively for Broody (-0.297), Von Bertalanffy (-0.999), Gompertz (-0.151), Quadratic (-0.792) and Cubic (-0.782) models whereas the phenotypic correlation between A and B parameters of Logistics and Richards models were positive and highly significant ( $P < 0.01$ ) for Richards but positive and insignificant ( $P > 0.05$ ) for Logistics with respective figures of 0.517 and 0.047, respectively.

Moreover, highly significant ( $P < 0.01$ ), negative and high phenotypic correlation between A and K growth parameters were found for the Broody (-0.988), Logistics (-0.551), Gompertz (-0.811) and Richards (-0.501) models and on the other hand, growth parameters A and K were significantly ( $P < 0.01$ ) and positively correlated in the Von Bertalanffy, Quadratic and Cubic models with corresponding values of 0.998, 0.656, and 0.583, respectively. The phenotypic correlation coefficient between B and K varied from -0.999 for the Von Bertalanffy model to 0.707 for the Logistics model. In the Broody (0.394) model, the correlation coefficients between B and K were observed to be positive and intermediate while in the Gompertz (0.600), it was found to be positive and high. However significant ( $P < 0.01$ ), negative and high phenotypic correlation between B and K parameters were seen in the Cubic models (-0.885). The phenotypic correlations of M with A B and K for Richards's model in our study were -0.306, -0.998 and 0.001, respectively whereas values of phenotypic correlation of M with A B and K in the Cubic models were found to be -0.202, -0.315, and 0.001, respectively.

**Table 58. Predicted body weight and error (kg) for different growth curve models in crossbred dairy cattle**

Age (day)	OABW	Non-linear models													
		Broody		Von Bertalanffy		Logistics		Gompertz		Richards		Quadratic		Cubic	
		PABW	RE	PABW	RE	PABW	RE	PABW	RE	PABW	RE	PABW	RE	PABW	RE
0	29.40	3.52	25.88	13.40	16.00	38.47	-9.06	29.03	0.38	13.32	16.09	29.40	0.00	27.30	2.10
30	37.04	23.63	13.40	30.43	6.60	45.14	-8.10	37.74	-0.70	30.45	6.59	37.04	0.00	36.53	0.51
60	46.56	43.02	3.54	47.61	-1.05	52.81	-6.25	47.84	-1.28	47.71	-1.15	46.56	0.00	47.05	-0.49
90	59.42	61.71	-2.30	64.35	-4.93	61.56	-2.14	59.29	0.13	64.53	-5.11	59.42	0.00	58.48	0.93
120	73.31	79.73	-6.43	80.66	-7.35	71.47	1.84	71.98	1.33	80.91	-7.60	73.31	0.00	70.75	2.56
150	87.33	97.11	-9.77	96.55	-9.22	82.61	4.73	85.76	1.57	96.86	-9.53	87.34	0.00	83.75	3.58
180	102.77	113.85	-11.09	112.04	-9.28	95.00	7.77	100.49	2.28	112.40	-9.64	102.77	0.00	97.42	5.35
270	146.80	160.57	-13.78	156.18	-9.38	139.42	7.37	148.37	-1.58	156.63	-9.84	146.80	0.00	141.55	5.25
365	195.49	204.62	-9.13	199.20	-3.71	195.16	0.33	200.57	-5.08	199.68	-4.19	195.50	0.00	191.25	4.24
450	243.88	239.94	3.94	234.82	9.06	246.80	-2.91	244.75	-0.87	235.26	8.62	243.89	0.00	236.31	7.57
540	291.57	273.55	18.03	269.80	21.77	296.26	-4.69	286.38	5.20	270.15	21.42	291.57	0.00	282.41	9.16
1008	404.55	399.52	6.69	413.78	-7.57	403.90	2.31	407.23	-1.01	413.10	-6.88	406.21	0.01	408.64	-2.43

OABW: Observed average body weight; PABW: Predicted average body weight; RE: Residual error;

**Table 59. Estimates of phenotypic correlation among growth curve parameters in crossbred cattle**

Broody model (above diagonal) and Von Bertalanffy (below diagonal)				
	A	B	K	M
A		-0.30**	-0.99**	
B	-1**		0.39**	
K	0.998**	-1.00**		
Logistics model (above diagonal) and Gompertz (below diagonal)				
A		0.05ns	-0.55**	
B	-0.15**		0.71**	
K	-0.81**	0.60**		
Richard model (above diagonal) and Cubic (below diagonal)				
A		0.80**	-0.90**	-0.80**
B	-0.78**		-0.97**	-1**
K	0.58**	-0.89**		0.971**
M	-0.202	-0.32**	0.001ns	
Quadratic model				
A		-0.79**	0.66**	
B			-0.95**	
K				

\*\*P<0.01; ns: non-significant

Biologically, the most important relationship is that between mature weight (A) and maturation rate (k), which in the present study was negative and highly significant (P<0.01) for the Broody (-0.99), Logistics (-0.55), Gompertz (-0.81) and Richards (-0.50) models, indicating that animals that mature early are less likely to attain as large mature weights as those that mature more slowly in early life. Lopez de Torre *et al.* (1992) for the different cattle breeds and Bahri *et al.* (2004) for Brown Swiss cattle using Richards model found similar findings about associations between A and k. Also DeNise (1985) stated that smaller cows at maturity reached the mature weight at younger ages than large cows at maturity. Growth parameter M was negatively (P<0.01) associated with A and B parameters in both Richard and Cubic models. In line with the present findings, DeNise and Brinks (1985) and Bahri *et al.* (2004) for Brown Swiss cattle reached similar conclusions about relationship between M and A and B parameters. The positive correlations between A and B parameters found in the Logistics model indicates that animal with light birth weight would have heavier mature weight. Similar results were reported by DeNise and Brinks (1985), and Bahri *et al.* (2004) for Brown Swiss cattle who found the correlation between those parameters as positive.

#### 4.14.3. Model fit statistics

The fitting of observed and predicted weight-age data of crossbred dairy cattle by various non-linear models are presented in Fig. 14-19 and the goodness of fit statistics for various non-linear models is presented in Table 60. The Quadratic model gave highest fit to the weight-age data (Fig.14) with  $R^2$ , MSE, AIC and CV values of 100%, 0.00001, -144.52 and 0.002%, respectively. The Gompertz model have also best fitted the observed weight-age data with predicted weight-age data (Fig. 15) with highest  $R^2$  (100%), lower MSE (6.88), low AIC (24.96) and lower CV (1.83) values. The fitting of observed weight-age data with predicted ones were also found to be higher in the Cubic (Fig. 16), Logistic (Fig. 17) Richard (Fig. 19) and Von Bertalanffy models (Fig. 19). The  $R^2$ , MSE, AIC and CV estimates observed for Cubic, Logistic, Richard and Von Bertalanffy models were 99.90%, 11.98, 31.61 and 2.47%;, 99.80%, 34.39, 44.27, and 4.07%; 99.20%, 125.23, 59.77, and 7.80%; and 99.20%, 125.37, 59.79 and 7.82%, respectively. However the Broody model depicted good fit to the weight-age data with high  $R^2$  (98.90%), high MME (174.56), intermediate AIC (63.76) and low CV (9.32%); but it gave low fit to the data when compared with the other non-linear models used in the study.

Coefficients of determination ( $R^2$ ) values have been used to evaluate the fit of the models in some studies (Goonewardene *et al.*, 1981; Akbaş *et al.*, 2006). The models that gave the highest  $R^2$  values have been accepted as the best fitting models. Based on the values of model parameters found in the present study, it was concluded that all the non-linear models adequately fit the weight-age data from birth to 1008 days of age in crossbred cattle; however the Quadratic and Gompertz models followed by Cubic and Logistic models gave best fit and reliable description to the growth curve characteristics of Sahiwal crossbred cattle compared with other models used. The present finding was in agreement with previous studies carried out by Souza *et al.* (2010) who reported that the Logistic equation presented the best goodness of fit for the growth curve in the indubrasil and Ozgur and Serkan (2014) who did their study on determination of growth curves of female Holstein calves using five non-linear models and concluded that the Logistic model can be exclusively used for estimating the growth curves and live weights of the calves in their early periods of lives. Similarly Quadratic model gave best fit growth curve of Merino sheep in Kenya (Keskin *et al.*, 2009) and Gompertz model well described growth characteristics of Dhofari cattle in Brazil (Salim *et al.* (2015).

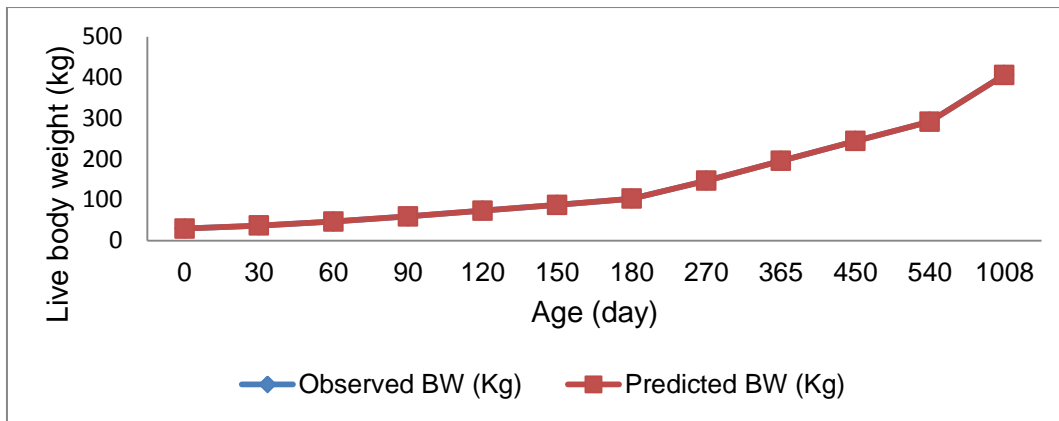
We therefore recommended these three models with corresponding developed equations, namely Quadratic ( $R^2= 100\%$ ), Gompertz (100%), Cubic ( $R^2= 99.90\%$ ) and Logistics ( $R^2= 99.80\%$ ) for estimating later live weight from early age live weight between births to 1008 days. The corresponding developed equations for description of growth curve characteristics of crossbred cattle managed under DLF of GADVASU were as follow:

1.  $LW_T = 433.32 + 0.582 \times T - 0.0002 \times T^2$  for Quadratic model
2.  $LW_T = 446.30 \times \exp(-2.734 \times \exp(-0.0034 \times T))$  for Gompertz model
3.  $LW_T = 458.30 + 0.310 \times T + 0.0006 \times T^2 + 56 \times 10^{-6} \times T^3$  for Cubic model
4.  $LW_T = 406.22 / (1 + 0.005 \times \exp(-3.951 \times T))$  for Logistics model

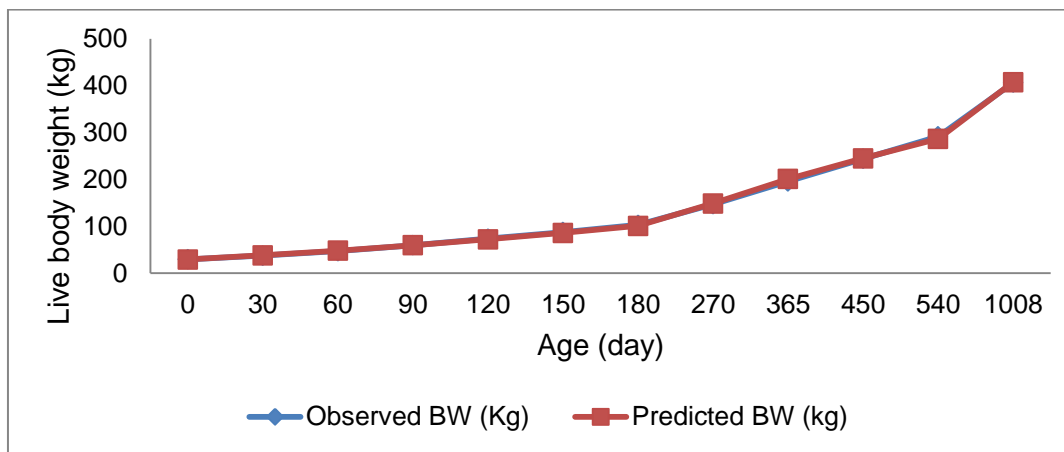
Where T = the age (day) of the animal during measurement is taken and  $LW_T$  = Live body weights at age T (day) of crossbred cattle

**Table 60. Estimates of model parameters of various non-linear models in crossbred cattle**

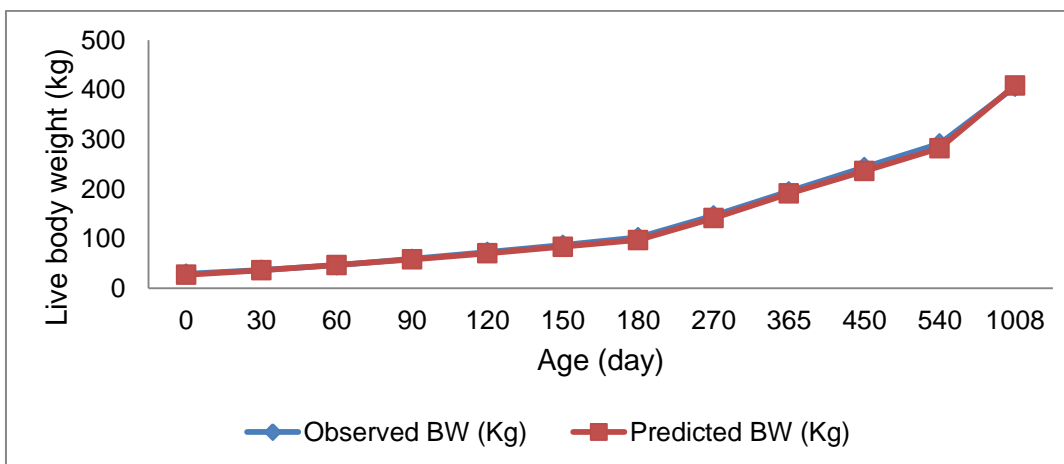
Models	Estimates of model parameters							Rank
	C(P)	R <sup>2</sup> (%)	R <sup>2</sup> Adj (%)	AIC	MSE	SSE	CV (%)	
Broody	2.00	98.90	98.75	63.76	174.56	1745.59	9.32	5
Von Bertalanffy	2.00	99.20	99.10	59.79	125.37	1253.73	7.82	4
Logistics	2.00	99.80	99.75	44.27	34.39	343.88	4.07	3
Gomertez	2.00	100.0	99.95	24.96	6.88	68.80	1.83	1
Richard	2.00	99.20	99.10	59.77	125.23	1252.32	7.80	4
Quadratic	2.00	100.00	100.00	-144.52	0.00001	0.0001	0.002	1
Cubic	2.00	99.90	99.80	31.61	11.98	119.80	2.47	2



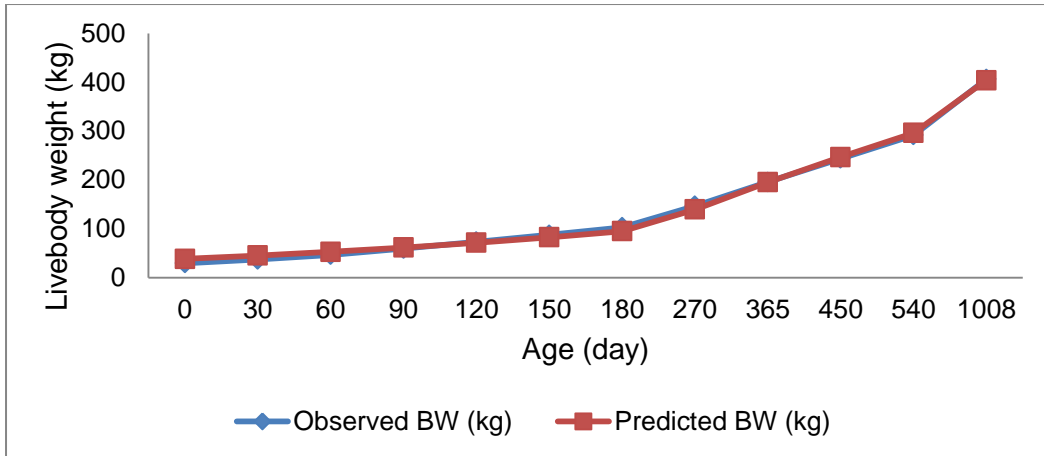
**Fig. 14. Growth curves of observed versus predicted body weights (BW) over age (days) fitted under Quadratic model in crossbred cattle**



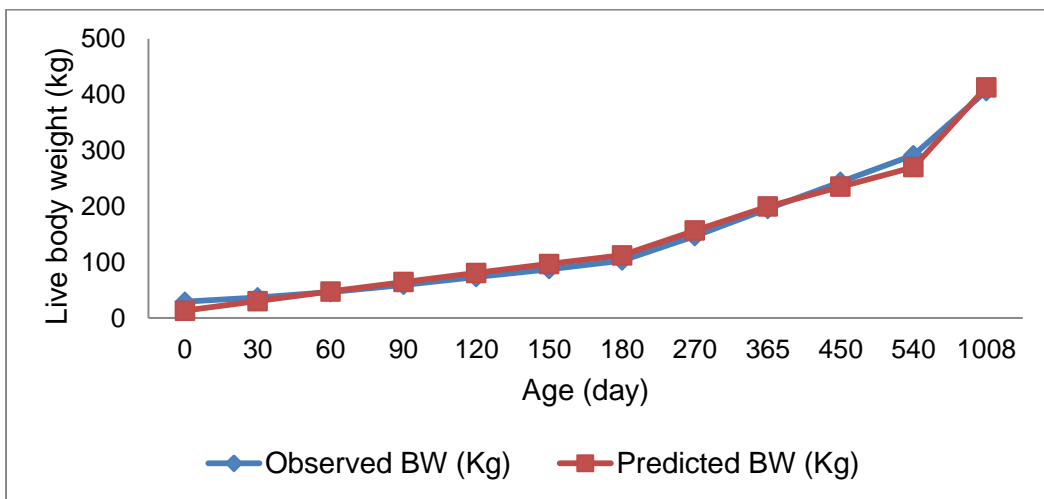
**Fig. 15. Growth curves of observed versus predicted body weights (BW) over age (days) fitted under Gompertz model in crossbred cattle**



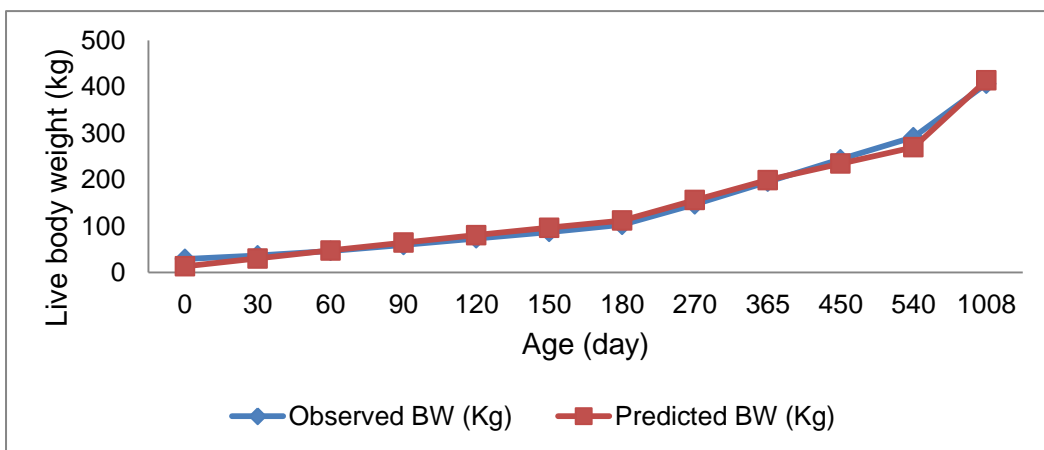
**Fig. 16. Growth curves of observed versus predicted body weights (BW) over age (days) fitted under Cubic model in crossbred cattle**



**Fig. 17. Growth curves of observed versus predicted body weights (BW) over age (days) fitted under Logistics model in crossbred cattle**



**Fig. 18. Growth curves of observed versus predicted body weights (BW) over age (days) fitted under Richard model in crossbred cattle**



**Fig. 19. Growth curves of observed versus predicted body weights (BW) over age (days) fitted under Von Bertalanffy model in crossbred cattle**

## 4.15. Lactation Curve Modeling

### 4.15.1. Lactation curve parameters

The average lactation curve parameters of crossbred cattle are estimated under various non-linear models (Table 61). The parameter 'a' was found to be positive and varied between 0.29 kg for the Inverse Polynomial Model to 16.336 kg for the EDF. Followed to EDF, PEM estimated high and positive 'a' parameter whereas the 'a' parameter values for GTF, MLF, and PRM were found to be  $10.18 \pm 0.28$ ,  $7.21 \pm 0.29$  and  $5.11 \pm 0.28$ , correspondingly. Also the parameter 'b' showed variation across the different non-linear models. The estimates of the parameter 'b' ranged from  $-1.44 \pm 0.03$  (MLF) to  $0.141 \pm 0.01$  (GTF). Positive parameter 'b' was found in IPM, and GTF with corresponding values of  $0.05 \pm 0.0003$  and  $0.14 \pm 0.01$  while negative parameter 'b' was observed in the PEM, MLF and PRM which had values as  $0.0004 \pm 0.0002$ ,  $-1.44 \pm 0.03$  and  $-0.10 \pm 0.0023$ , respectively. Similarly, differences were seen among the various non-linear models fitted to the 305 days milk yield for the 'c' parameter values. In models having three parameters, 'c' parameter ranged from  $4.84 \times 10^{-6} \pm 4.81 \times 10^{-7}$  in PEM model to 4.670.12 in the MLF. In the EDF, IPM, GTF and PRM, the 'c' parameter was positive and their corresponding values were  $0.002 \pm 4.3 \times 10^{-5}$ ,  $0.0002 \pm 1.82 \times 10^{-6}$ ,  $0.003 \pm 7.4 \times 10^{-5}$  and  $0.00013 \pm 4.742 \times 10^{-6}$ . Parameters, 'd' and 'f' in PRM, which represent the increasing slope of lactation curve, were  $4.24 \pm 0.10$  and  $-6.52 \pm 0.15$ , respectively. For Gamma type function, the daily milk yield raised from calving to peak production of 15.15 kg reached on day 45.48 and then decreased gradually to dryness with a persistency of lactation of 6.59.

The modeling of lactation curve provides guidelines in formulating farm managerial practices in dairy cows. The average initial daily milk yields (kg) estimated under all non-linear models except EDF ('a'=16.31 kg) were low as compared to previous findings reported by Rekik *et al.* (2006) ( $a = 16.6$ kg), Tekerli *et al.* (2000) ( $\ln(a) = 2.71$ ) in Turkey, Boujenane and Hilal (2012) in Morocco (17 kg) and Chegini *et al.* (2015) in Iran (15.08 kg). However average initial daily milk yields of all non-linear models excluding IPM were higher than that found by Gradiz *et al.* (2009) for Holstein  $\times$  Brahman, Holstein  $\times$  Brown Swiss and Brown Swiss  $\times$  Brahman crossbred cows ( $a = 4.67 \pm 3.35$  kg) in Honduras; Abdel-Salam *et al.* (2011) ( $a = 1.90$  kg) in Egypt, and Subham *et al.* (2017) for Jersey crossbred cattle using Log Transformed Gamma-type Function ('a'= 0.44 kg).

The average 'a' value estimated using EDF was also higher than that of Cole and Null (2009) who reported for dairy cattle under Wood model ('a'=13.01 kg). Occurrence of variations in the parameter 'a' value may be due to differences in genetic groups or in herd management (Osorio-Arce and Segura-Correa, 2005). The average b and c values in the IPM ( $0.05 \pm 0.0003$ ;  $0.0002 \pm 1.82 \times 10^{-6}$ ) and GTF ( $0.14 \pm 0.01$ ;  $0.0031 \pm 7.4 \times 10^{-5}$ ) were in the scale of the previous studies as reported by Tekerli *et al.* (2000) for Holstein cows; Cole and Null (2009) for dairy cows; Gradiz *et al.* (2009); Chegini *et al.* (2015). For this study, the b parameter values in the all non-linear models were also lower than previous studies reported by various investigators [e.g. Dohare *et al.* (2014) for Frieswal cattle (b=1.09); Subham *et al.* (2017) for Jersey crossbred cattle (5.788) and Yogesh *et al.* (2017) for Gir crossbred cattle (b=0.43)]. The c parameter values ( $4.668 \pm 0.120$ ) estimated under MLF was higher than other previous findings reported by (Dohare *et al.* (2014) for Frieswal cattle (c=1.01); Suham *et al.* (2017) for Jersey crossbred cattle (c=-3.49) and Yogesh *et al.* (2017) for Gir crossbred cattle (c=0.21) and Tekerli *et al.* (2000) for Holstein cows (c=0.0044). The production at the peak (15.145kg) estimated under GTF was low compared to the study by Tekerli *et al.* (2000), Chegini *et al.* (2015) and Khalifa *et al.*, 2018); but high compared to the previous work on Holstein cows (Gradiz *et al.*, 2009; Cankaya *et al.*, 2011). The date at the peak after calving (45.484 days) was less than that reported by Chegini *et al.* (2015); Khalifa *et al.*, 2018 but higher than to those found by Cankaya *et al.* (2011) and Boujenane and Hilal (2012). Similarly, the persistency of lactation found in GTF (7.0) was higher than that found for Holstein cattle (Tekerli *et al.*, 2000; Rekik *et al.*, 2006; Atashi *et al.*, 2007). Existing differences in these parameters might be the result of a combination of genetic, diet, management and specific climatic effects. The positive parameter 'a' in all models clearly indicated that this parameter explained the increasing part of the lactation curve. Based on the sign/direction of the parameters 'b' and 'c' obtained in the present study, it was determined that IPM curve followed by GTF which applied to fit the 305 days milk data were typical standard curve for crossbred cattle. Similar findings were reported by Yogesh *et al.* (2017) for Gir crossbreds and Subham *et al.*, 2017 for Jersey crossbreds. Standard typical lactation curves are with positive b and c parameters (Shimizu and Umrod, 1976; Tekerli *et al.*, 2000). However PEM, MLF and PRM curves are atypical curves with negative parameter b and positive parameter c. Atypical curve might happen due to the absence of a lactation peak (Boujenane and

Hilal, 2012; Jeretina *et al.*, 2013; Chegini *et al.*, 2015). Cows with incorrect data, lack of information, frequent changes in the quantity and quality of the ration, physiological and health problems might manifest atypical lactation curve (Rekik and Ben Gara, 2004).

#### **4.15.2. Phenotypic correlation among lactation curve parameters**

The estimates of phenotypic correlation among lactation curve parameters in crossbred cattle are presented in Table 62. The results of the study indicated that the relationships between parameters b and c for IPM, MLF and PRM were highly significant ( $P < 0.01$ ), negative and high with corresponding values of -0.89, -0.97 and -0.98, in that order while the correlation between b and c parameters in the PEM (0.97) and GTF (0.92) models were positive, highly significant ( $P < 0.01$ ) and higher. For the PRM, the values of correlation between b and f and c and d parameters were negative, highly significant ( $P < 0.01$ ), and higher with the corresponding values -0.97, and -0.85, in that order. Parameters a and b were associated negatively and significantly ( $P < 0.01$ ) for PEM (-0.87), IPM (-0.81) and GTF (-0.98) whereas correlation between a & b parameters of PRM and MLF were highly significant ( $P < 0.01$ ), positive and high with respective figures of 0.87 and 0.89, respectively. Whilst the parameters a and c were associated negatively and highly significantly ( $P < 0.01$ ) for PEM (-0.76), MLF (-0.97), GTF (-0.83), and PRM (-0.76) whereas correlation between a and c parameters of EDF, and IPM were positive, highly significant ( $P < 0.01$ ) and high with respective values of 0.84 and 0.64, respectively.

The relationships among all the lactation curve parameters are important, but the relationships between b and c parameters of the non-linear models are very important because (a) is always positive and influence the average level of production. The negative relationship between b and c observed in the IPM, MLF and PRM models clearly demonstrated that high daily milk production may be maintained throughout the lactation which in turn has high implication for economic return of the dairy producers; but the positive relationships between b and c found for PEM and GTF told that the milk production may continuously increase or continuously decrease, which meant that the persistency became low and thereby throughout the lactation, high milk production may not be maintained. The negative correlation between a and b parameters found in the present study found for the PEM,

IPM and GTF clearly showed that the crossbred cows with smaller initial daily milk production might have high peak milk yield. However the positive association between parameters a and b observed in our study for the PRM and MLF noticeably indicated that the crossbred cows with high initial daily milk production would have low peak milk production; but average milk yield over the complete lactation could be high in both cases. The negative correlation between a and c parameters found in the present study found for the PEM, MLF GTF and PRM showed that the crossbred cows with smaller initial daily milk production might have high persistency in maintaining high milk production in the decline phase post peaking. However the positive association between parameters a and c observed in our study for the peak EDF, and IPM indicated that the crossbred cows with high initial daily milk production would have low persistency.

**Table 61. Estimates of average lactation curve parameters of crossbred cattle**

Models	Lactation curve parameters							
	A	B	c	d	f	PY	DIMP	Pe
EDF	16.34±0.11		0.002±4.3×10 <sup>-5</sup>					
PEM	15.29±0.14	-0.0004±0.0002	4.84×10 <sup>-6</sup> ±4.81×10 <sup>-7</sup>					
IPM	0.29±0.01	0.05±0.0003	0.0002±1.82×10 <sup>-6</sup>					
GTF	10.18±0.28	0.14±0.01	0.003±7.4×10 <sup>-5</sup>			15.15	45.48	6.59
MLF	7.21±0.29	-1.44±0.03	4.67±0.12					
PRM	5.11±0.28	-0.10±0.002	0.0001±4.74×10 <sup>-6</sup>	4.24±0.10	-6.52±0.15			

**Table 62. Estimates of phenotypic correlation among lactation curve parameters in crossbred cattle**

EDF					
	A	b	c	d	f
a			0.84**		
c					
PEM (above diagonal) and IPM (below diagonal)					
a		-0.87**	-0.76**		
b	-0.81**		0.97**		
c	0.64**	-0.89**			
GTF (above diagonal) and MLF (below diagonal)					
a		-0.98**	-0.83**		
b	0.89**		0.92**		
c	-0.97**	-0.97**			
PRM					
a		0.89**	-0.76**	0.98**	0.97**
b			-0.98**	0.94**	-0.97**
c				-0.85**	0.91**
d					0.99**
f					

#### 4.15.3. Model fit statistics

The fitting of observed and predicted daily milk yield data of crossbred dairy cattle by various non-linear lactation curve models are presented in Fig. 20-25 and the goodness of fit statistics for various non-linear models are presented in Table 63. The Polynomial regression model gave highest fit to the daily milk yield data (Fig.25) with  $R^2$ , MSE, AIC and CV values of 98.10%, 0.09, -743.31 and 2.37 %, respectively. The Inverse Polynomial Model have also best fitted the observed daily milk yield data with predicted daily milk yield data (Fig.20) with highest  $R^2$  (98.05%), lower MSE (0.089), low AIC (-735.90) and lower CV (2.40%) values. The fitting of observed daily milk yield data with predicted ones were also found to be higher in the Mixed Log Function (Fig. 22), and Gamma-Type Function (Fig. 21). The  $R^2$ , MSE, AIC and CV estimates observed for Mixed Log Function and Gamma-Type Function were 96.46%, 0.16, -558.16 and 3.21%; 95.85%, 0.190, -505.24 and 3.50%, respectively. However the Exponential Decline Function (Fig. 24)) and Parabolic Exponential Model (Fig. 23) depicted relatively low fit to the daily milk yield data when compared with the other non-linear models used in the study. The  $R^2$ , MSE, AIC and CV values for Exponential Decline Function were 86.02%, 0.54, -183.69, 5.94%, respectively whereas the Parabolic Exponential Model described the milk yield data of crossbred dairy cattle with  $R^2$ , MSE, AIC and CV estimates of 89.61%, 5.29, -253.67 and 0.43%, in that order.

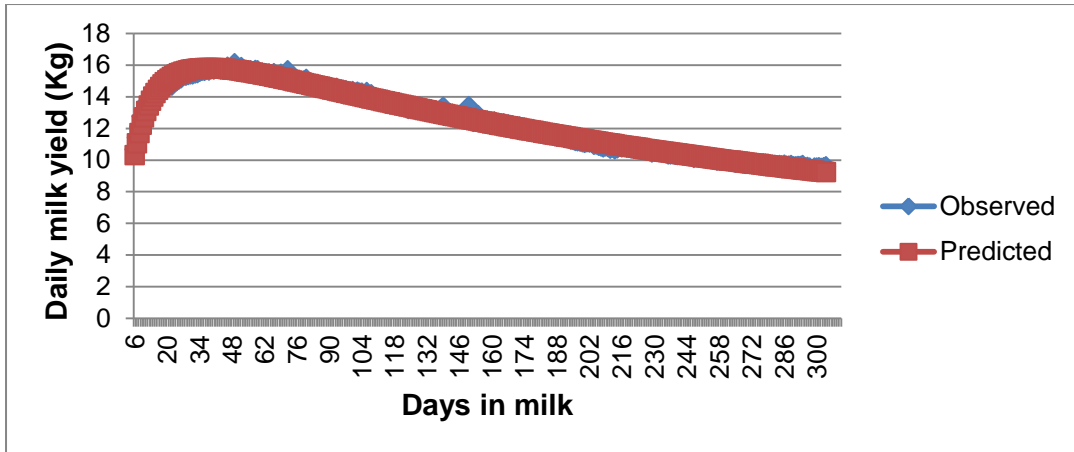
Coefficient of determination ( $R^2$ ) values have been used to evaluate the fit of the models in some studies (Akbaş *et al.*, 2006).The models that gave the highest  $R^2$  values have been accepted as the best fitting models. Based on the values of model parameters investigated in the present study, non-linear models namely EDF and PEM could adequately fit the daily milk yield data for 305 days lactation; but the PRM, and IPM models followed by MLF and GTF models gave best fit and reliable description to the lactation curve pattern and characteristics of crossbred cattle. However only two models namely IPM and GTF could be chosen with corresponding developed equations for predicting daily milk production from calving to 305 days in milk of crossbred cattle managed under DLF of GADVASU because IPM and GTF curves were standard typical curves for the cattle. This finding was in agreement with previous studies carried out by various workers.

Singh *et al.* (1998) reported that Inverse Quadratic Polynomial (IQP) model was the best function in explaining the first lactation curve based on monthly as well as weekly milk records of Jersey x Sahiwal F1 cows whereas Yogesh *et al.* (2017) for Gir crossbreds with R<sup>2</sup>=90.50% and Cole and Null (2009) for dairy cattle with R<sup>2</sup>=91.25% under Gamma Type and Tekerli *et al.* (2000) reported that Log Transformed Gamma Function gave best fit to daily milk yield of Holstein cows with R<sup>2</sup>=70.80%.

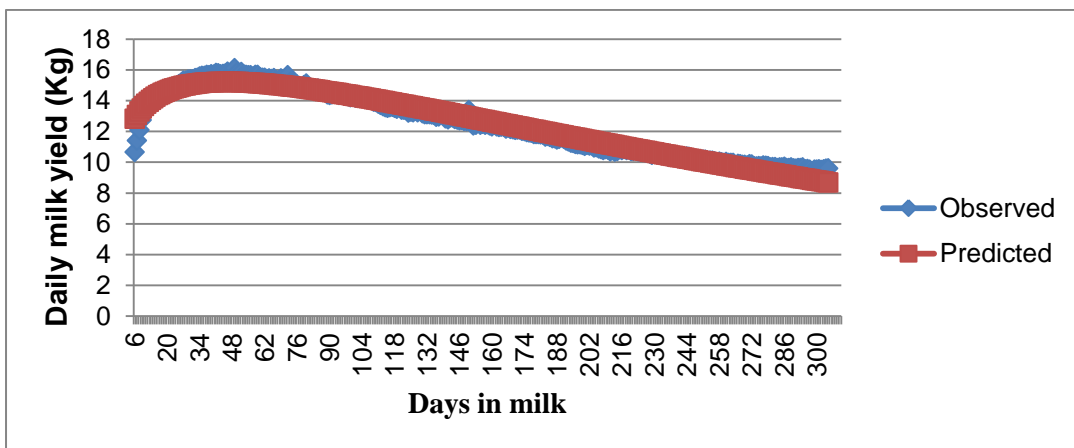
$DMY_T = T / (0.285 + 0.0484 \times T + 0.000194 \times T^2)$  for Inverse Polynomial Model  
 $DMY_T = 10.180T^{0.141} \times \exp(-0.0031 \times T)$ ; for Gamma – Type Function Where, T is the days in milk of the animal and DMY<sub>T</sub>: Daily milk at T days post calving

**Table 63. Estimates of model parameters of various non-linear models in crossbred cattle**

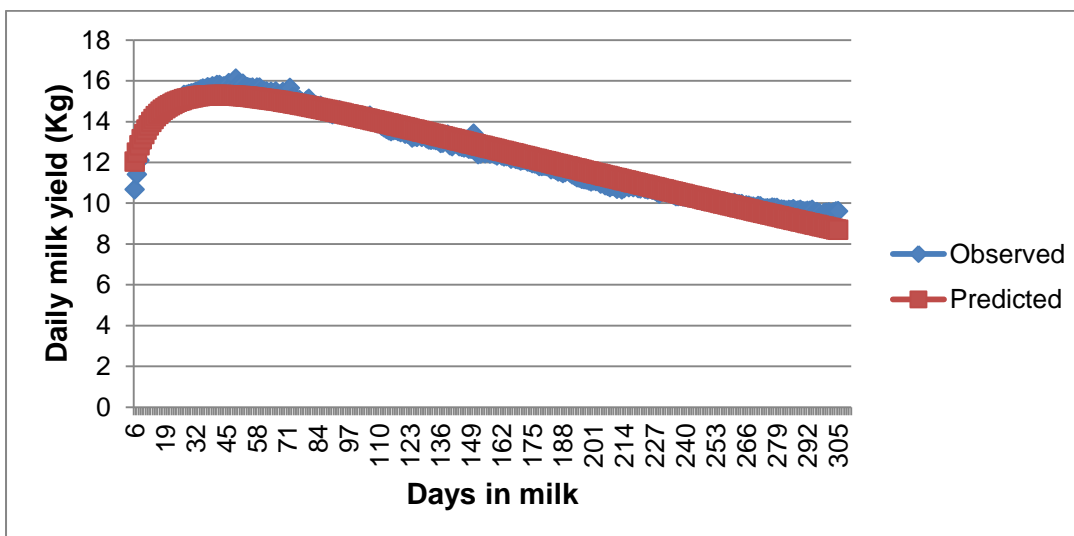
Models	Estimates of model parameters							Rank
	C(P)	R <sup>2</sup> (%)	R <sup>2</sup> adj%	AIC	MSE	SSE	CV (%)	
EDF	2	86.02	85.98	-183.69	0.54	164.83	5.94	6
PEM	2	89.61	89.57	-253.67	0.43	131.04	5.29	5
IPM	2	98.05	98.04	-735.90	0.09	26.96	2.40	2
GTF	2	95.85	95.84	-505.24	0.19	57.44	3.50	4
MLF	2	96.46	96.45	-558.16	0.16	48.29	3.21	3
PRM	2	98.10	98.10	-743.31	0.09	26.31	2.37	1



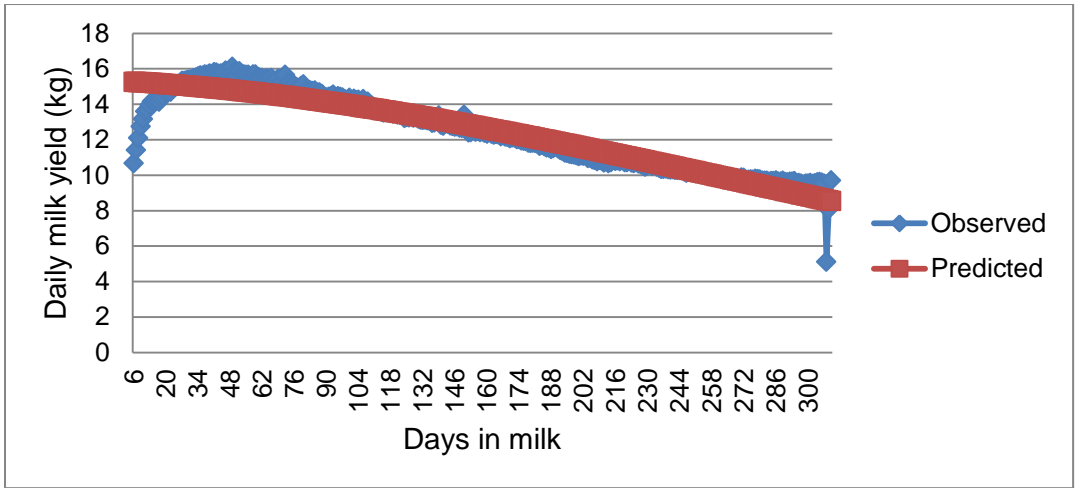
**Fig. 20. Lactation curves of observed versus predicted DMY (Kg) over 305 milk days fitted under Inverse Polynomial Model in crossbred cattle**



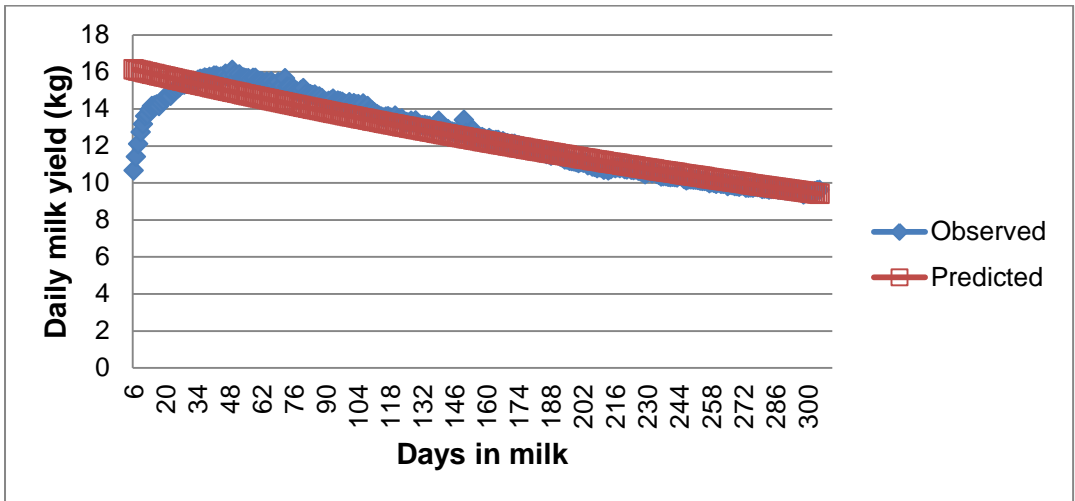
**Fig. 21. Lactation curves of observed versus predicted DMY (Kg) over 305 milk days fitted under Gamma-type Function in crossbred cattle**



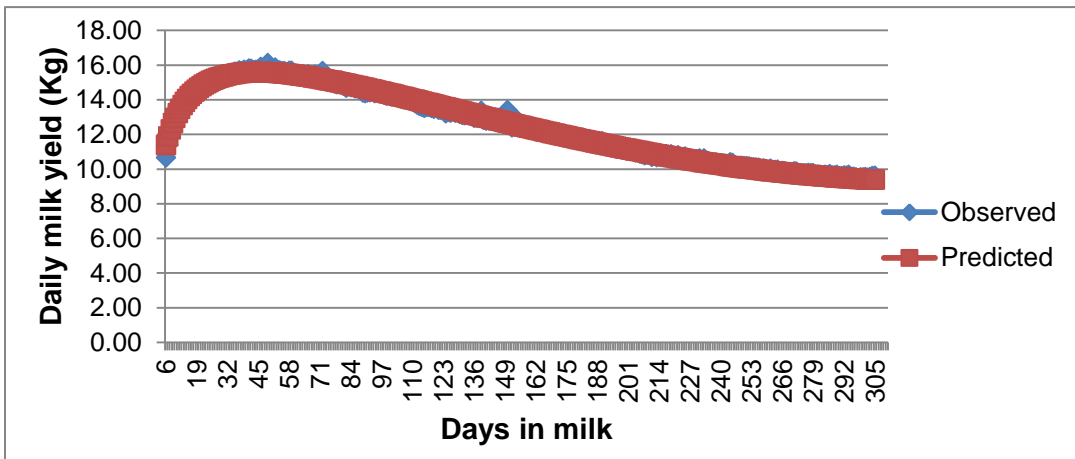
**Fig. 22. Lactation curves of observed versus predicted DMY (Kg) over 305 milk Days fitted under Mixed Log Function in crossbred cattle**



**Fig. 23. Lactation curves of observed versus predicted DMY (Kg) over 305 milk days fitted under Parabolic Exponential Model in crossbred cattle**



**Fig. 24. Lactation curves of observed versus predicted DMY (Kg) over 305 milk days fitted under Exponential decline function in crossbred cattle**



**Fig. 25. Lactation curves of observed versus predicted daily milk yield (Kg) over 305 milk days fitted under Polynomial Regression Model in crossbred cattle**

#### 4.16. Description of Data Sets of Meteorological Factors

The descriptive statistics for meteorological factors and their combinations during the period of thirty four years are presented in Tables 64. The overall means for Temp, RH, WS, Sunshine, SR, THI and THIadj were  $23.53 \pm 0.07$  °C,  $65.77 \pm 0.14\%$ ,  $1.18 \pm 0.01$  m/s,  $7.86 \pm 0.03$  hr,  $227.47 \pm 0.64$  w/m<sup>2</sup>,  $70.75 \pm 0.09$  units and  $74.53 \pm 0.09$  units, respectively. The corresponding values of CV were estimated as 31.44, 23.18, 60.39, 44.99, 31.58, 14.89 and 14.08%, in that order, whilst the average maximum and minimum temperatures and humidity were 38.60 °C, 4.80 °C and 100%, 15.50%, respectively. The mean adjusted temperature and humidity index (THIadj) exceeded the basic temperature and humidity index (THI) by 3.78 units. This might due to the effect of heat load resulted from solar radiation. This indicated that the incorporation of wind speed and solar radiation in the basic THI estimation can properly measure the level of heat stress.

**Table 64. Summary statistics of datasets of meteorological factors during the study period**

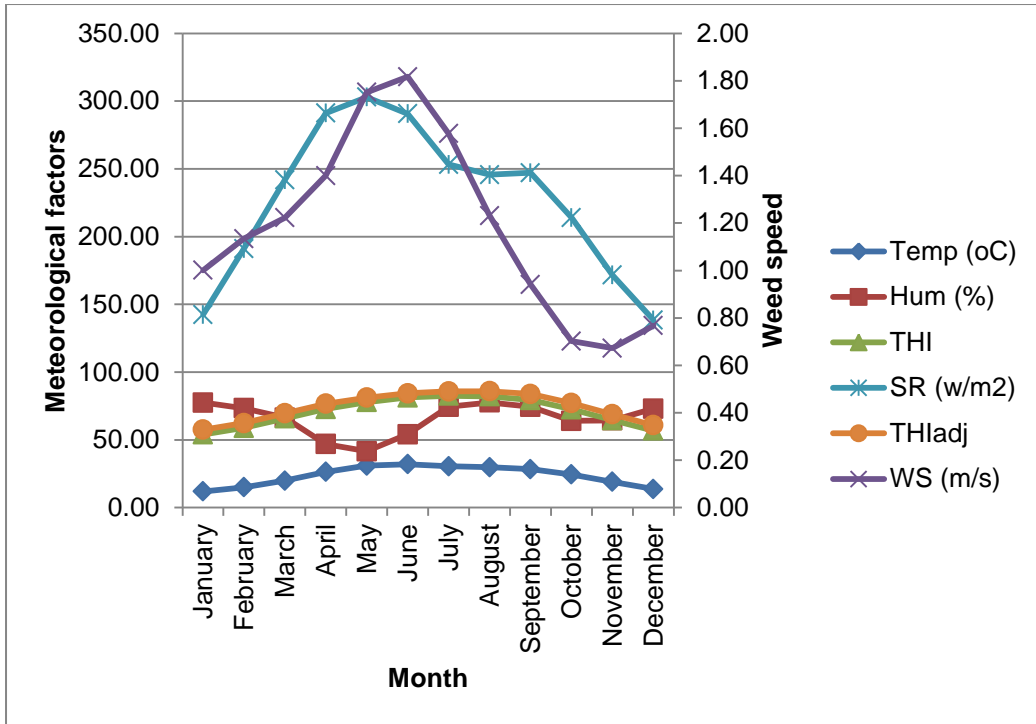
Variables	N	Mean	SD	CV	SE	Avg. Min	Avg. Max
Temp (°C)	12444	23.53	7.40	31.44	0.07	4.80	38.60
RH (%)	12444	65.77	15.25	23.18	0.14	15.50	100.00
WS (m/s)	12444	1.18	0.72	60.39	0.01	0.00	6.61
Sunshine (hr)	12444	7.86	3.54	44.99	0.03	0.00	20.00
SR (w/m <sup>2</sup> )	12444	227.47	71.83	31.58	0.64	72.96	459.18
THI (Unit)	12444	70.75	10.54	14.89	0.09	41.84	89.80
THIadj (Unit)	12444	74.53	10.50	14.08	0.09	43.41	92.31

#### 4.17. Trends of Meteorological Factors and Their Combinations

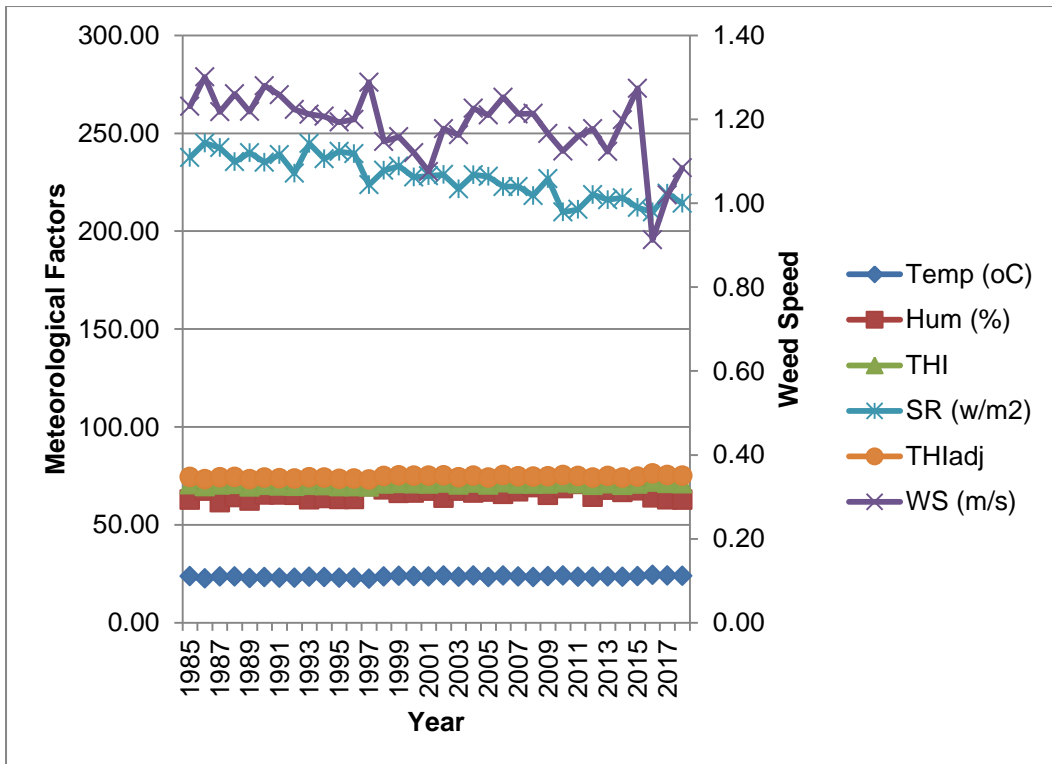
The analyses of least square and variance showed that values of all the meteorological factors (Temp, RH, WS and SR) and their combinations (THI and THIadj) significantly ( $P < 0.01$ ) varied across the different months and years during the thirty four years (1985-2018) (table 65 and Annex-table 7). This might therefore demonstrated that performance traits had direct or indirect relationships with either of date of production or month of birth or month of calving. The results unconcealed that minimum least square values ( $11.94 \pm 0.07$  °C for Temp,  $54.00 \pm 0.10$  units for THI and  $57.56 \pm 0.1$  units for THIadj) were observed in January.

However their maximum least square values were seen in different months [eg. Temp ( $32.04 \pm 0.08$  °C) in June; THI ( $82.57 \pm 0.10$  units) in July and THIadj ( $85.91 \pm 0.11^a$  units) in August]. The least square values of RH ranged from  $41.58 \pm 0.31\%$  in month of May to  $77.63 \pm 0.31\%$  in the month of August. Whilst the minimum ( $0.67 \pm 0.02$  m/s) and maximum ( $1.82 \pm 0.02$  m/s) average wind speed were found in November and June, respectively. For SR, maximum ( $302.94 \pm 1.42$  W/m<sup>2</sup>) and minimums ( $138.48 \pm 1.42$  W/m<sup>2</sup>) least square mean values were found in the month of May and December, correspondingly.

Also the variations of meteorological factors and their combinations over different years were explained by linear regression analysis (table 66, Fig. 26-27). The linear regression analysis showed that the value of temperature increased by  $0.03$  °C for every 1 year increment whereas the RH, THI and THIadj rose by  $0.07$  %,  $0.04$  unit and  $0.04$  unit, respectively for every 1 year increment but WS and SR showed decreasing trends by  $0.01$  m/s and  $0.95$  W/m<sup>2</sup>, in that order for every one year increase in the thirty four years study period (1985-2018). By 2050, the ambient temperature and relative humidity will increase to  $0.78$  °C and  $2.19$  %, respectively but the wind speed and solar radiation will decrease by  $0.03$  m/s and  $28.62$  w/m<sup>2</sup>, respectively. The fluctuations in them obtained in the present study were as a result of seasonal changes in weather patterns showing a direct relationship between environmental variables and heat production in dairy crossbred cattle and the highest humidity occurred when the temperature was lowest. In line with the present findings, previous findings were reported by Ghavi *et al.* (2012, Könyves *et al.* (2017) and Parveen (2017).



**Fig. 26. Trends of various meteorological factors over the months during the period of thirty four years (1985-2018)**



**Fig. 27. Patterns of various meteorological factors over the year**

**Table 65. Least squares means ( $\pm$ SE) of different meteorological factors**

Source	N	Temp ( $^{\circ}$ C)	RH (%)	THI	WS (m/s)	SR (W/m <sup>2</sup> )	THIadj
Overall mean	12444	23.52 $\pm$ 0.02	65.69 $\pm$ 0.09	70.75 $\pm$ 0.03	1.18 $\pm$ 0.01	227.47 $\pm$ 0.41	74.53 $\pm$ 0.03
Mont of Recording		**	**	**	**	**	**
January	1054	11.94 $\pm$ 0.07 <sup>l</sup>	77.53 $\pm$ 0.31 <sup>b</sup>	54.00 $\pm$ 0.10 <sup>l</sup>	1.00 $\pm$ 0.02	142.5 $\pm$ 1.42 <sup>j</sup>	57.56 $\pm$ 0.11 <sup>k</sup>
February	986	14.98 $\pm$ 0.08 <sup>j</sup>	73.42 $\pm$ 0.32 <sup>f</sup>	58.79 $\pm$ 0.11 <sup>j</sup>	1.13 $\pm$ 0.02 <sup>g</sup>	190.96 $\pm$ 1.47	62.42 $\pm$ 0.11 <sup>i</sup>
March	1054	19.86 $\pm$ 0.07	66.39 $\pm$ 0.31 <sup>g</sup>	65.84 $\pm$ 0.10	1.22 $\pm$ 0.02 <sup>f</sup>	241.81 $\pm$ 1.42 <sup>f</sup>	69.64 $\pm$ 0.11 <sup>g</sup>
April	1020	26.33 $\pm$ 0.08 <sup>f</sup>	46.89 $\pm$ 0.32 <sup>j</sup>	72.82 $\pm$ 0.10 <sup>f</sup>	1.40 $\pm$ 0.02 <sup>d</sup>	291.14 $\pm$ 1.44 <sup>b</sup>	76.62 $\pm$ 0.11 <sup>f</sup>
May	1054	30.97 $\pm$ 0.07 <sup>b</sup>	41.58 $\pm$ 0.31 <sup>k</sup>	77.91 $\pm$ 0.10 <sup>e</sup>	1.75 $\pm$ 0.02 <sup>b</sup>	302.94 $\pm$ 1.42 <sup>a</sup>	81.12 $\pm$ 0.11 <sup>d</sup>
June	1020	32.04 $\pm$ 0.08 <sup>a</sup>	54.17 $\pm$ 0.32 <sup>i</sup>	81.33 $\pm$ 0.10 <sup>c</sup>	1.82 $\pm$ 0.02 <sup>a</sup>	290.67 $\pm$ 1.44 <sup>c</sup>	84.32 $\pm$ 0.11 <sup>b</sup>
July	1054	30.46 $\pm$ 0.07 <sup>c</sup>	74.46 $\pm$ 0.31 <sup>d</sup>	82.57 $\pm$ 0.10 <sup>a</sup>	1.58 $\pm$ 0.02 <sup>c</sup>	253.30 $\pm$ 1.42 <sup>d</sup>	85.77 $\pm$ 0.11 <sup>a</sup>
August	1054	29.78 $\pm$ 0.07 <sup>d</sup>	77.63 $\pm$ 0.31 <sup>a</sup>	82.09 $\pm$ 0.10 <sup>b</sup>	1.23 $\pm$ 0.02 <sup>e</sup>	247.13 $\pm$ 1.42 <sup>f</sup>	85.91 $\pm$ 0.11 <sup>a</sup>
September	1020	28.37 $\pm$ 0.08 <sup>e</sup>	74.49 $\pm$ 0.32 <sup>c</sup>	79.45 $\pm$ 0.10 <sup>d</sup>	0.94 $\pm$ 0.02 <sup>i</sup>	247.13 $\pm$ 1.44 <sup>e</sup>	83.83 $\pm$ 0.11 <sup>c</sup>
October	1054	24.53 $\pm$ 0.07 <sup>g</sup>	64.05 $\pm$ 0.31 <sup>l</sup>	72.54 $\pm$ 0.10 <sup>g</sup>	0.70 $\pm$ 0.02 <sup>k</sup>	214.00 $\pm$ 1.42 <sup>g</sup>	77.16 $\pm$ 0.11 <sup>e</sup>
November	1020	19.00 $\pm$ 0.08 <sup>i</sup>	64.38 $\pm$ 0.32 <sup>l</sup>	64.54 $\pm$ 0.10 <sup>i</sup>	0.67 $\pm$ 0.02 <sup>l</sup>	171.62 $\pm$ 1.44 <sup>i</sup>	68.83 $\pm$ 0.11 <sup>g</sup>
December	1054	13.75 $\pm$ 0.07 <sup>k</sup>	73.01 $\pm$ 0.31 <sup>e</sup>	56.86 $\pm$ 0.10 <sup>k</sup>	0.77 $\pm$ 0.02 <sup>j</sup>	138.48 $\pm$ 1.42 <sup>k</sup>	60.83 $\pm$ 0.11 <sup>j</sup>

\*\*P<0.01

**Table 66. Linear regressions of various meteorological factors and their combinations on year**

Model variable	Estimates of regression parameters for various climate variables		
	a	b	R <sup>2</sup>
Temp			
Year	-28.50±14.31	0.03±0.01**	0.29
RH			
Year	-80.11±78.98	0.08±0.04**	0.10
WS			
Year	10.39±2.30	-0.01±0.001	0.33
SR			
Year	2137.14±165.64	-0.95±0.08**	0.81
THI			
Year	-10.52±19.07	0.04±0.01**	0.36
THIadj			
Year	-11.44±20.82	0.04±0.01**	0.35

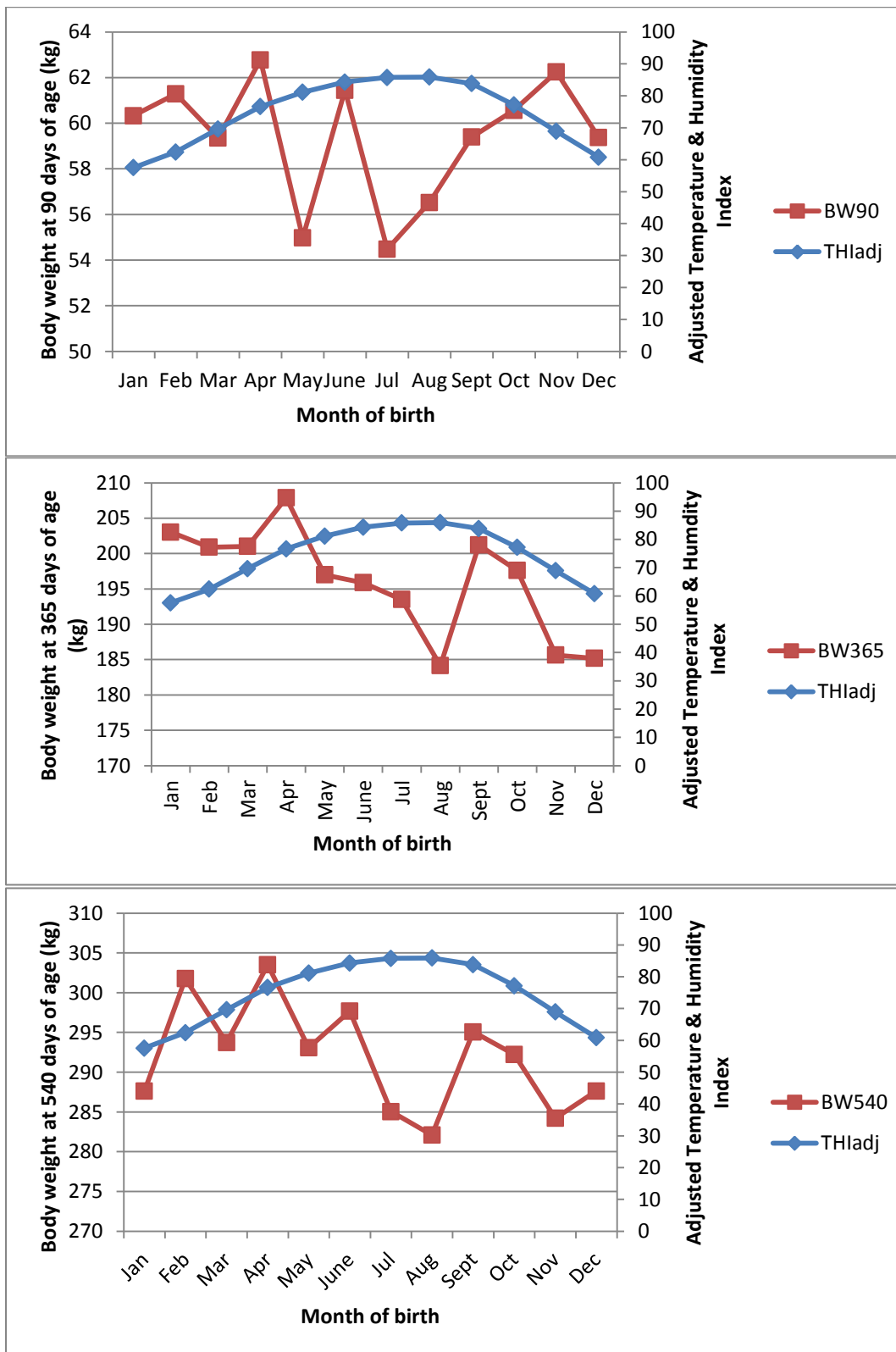
\*\*P<0.01; ns: non-significant

#### **4.18. Association between Meteorological Factors and Performance Traits**

##### **4.18.1. Relationship of meteorological factors and growth traits**

The monthly least square means for BW90, BW180, BW270, BW365, BW450 and BW540 and corresponding monthly least square means of meteorological factors and their combinations during thirty two years (1985-2016) are presented in Table 67. The highest and lowest monthly least square means for BW90, BW180, BW270, BW365, BW450 and BW540 were 62.78, 54.48; 109.04, 95.84; 158.82, 138.56; 207.89, 184.14; 256.49, 232.31; 303.52, 282.10 kg, respectively. These highest average values were observed in the month of April but the lowest average values of these traits were found in different months (in May for BW180, in July for BW90 and BW270, in August for BW365, BW450, and BW540). In the month of April, the Temp, RH, SR, THI and THIadj averaged 26.33 °C, 46.89%, 291.14 W/m<sup>2</sup>, 72.82 unit and 76.62 unit, respectively whereas in the months of May, July, and August, the average Temp, RH, SR, THI and THIadj were 30.97 °C, 41.58%, 302.94 W/m<sup>2</sup>, 77.91 unit, 81.12 unit; 30.46 °C, 74.46%, 253.30 w/m<sup>2</sup>, 82.57 unit, 85.77 unit; and 29.78 °C, 77.63%, 245.64 w/m<sup>2</sup>, 82.09 unit, 85.91 unit, respectively.

The results indicated that crossbred cows born in the months with low to moderate average Temp, SR, THI, and THIadj and relatively low RH values had high body weights for all growth traits considered in this study (table 67; Fig. 28).



**Fig. 28. Association of monthly THIadj and different growth traits over month of birth during the study period (1985-2016) in crossbred cattle**

They consistently grew well until a certain threshold. However body weights of crossbred cows born in the month with high Temp, THI, SR, THIadj and RH were observed to be low. They grew slowly but not significantly slowly.

**Table 67. Month wise least square means (LSMs) of meteorological factors and corresponding LSMs of growth traits in crossbred cattle during the study period (1985-2016)**

MOB	Temp	RH	SR	THI	THIadj	BW90	BW180	BW270	BW365	BW450	BW540
Jan	11.94	77.53	142.50	54.00	57.56	60.33	102.26	144.51	203.04	242.74	287.63
Feb	14.98	73.42	190.96	58.79	62.42	61.29	104.86	148.32	200.91	250.58	301.77
Mar	19.86	66.39	241.81	65.84	69.64	59.35	98.29	142.69	201.02	249.80	293.73
Apr	26.33	46.89	291.14	72.82	76.62	62.78	109.04	158.82	207.89	256.49	303.52
May	30.97	41.58	302.94	77.91	81.12	54.98	95.84	154.68	197.00	244.67	293.07
Jun	32.04	54.17	290.67	81.33	84.32	61.45	103.98	147.32	195.88	250.79	297.68
Jul	30.46	74.46	253.30	82.57	85.77	54.48	98.67	138.56	193.50	237.76	285.04
Aug	29.78	77.63	245.64	82.09	85.91	56.53	102.60	140.66	184.14	232.31	282.10
Sep	28.36	74.57	247.74	79.46	83.84	59.40	105.00	153.72	201.21	248.33	295.07
Oct	24.53	64.05	214.00	72.54	77.16	60.57	105.88	149.36	197.61	242.18	292.23
Nov	19.00	64.38	171.62	64.54	68.93	62.25	105.66	146.30	185.64	239.91	284.21
Dec	13.75	73.01	138.48	56.86	60.83	59.38	101.53	141.72	185.18	237.41	287.64

#### 4.18.1.1. Effects of meteorological factors on growth traits

The parameter estimates for the effects of meteorological variables and their combination on growth traits under various linear and polynomial regression models are presented Table 68-73. Temp, THI and THIadj had negative and insignificant influences on all growth traits. The combined effect of Temp and SR on BW365, BW450 and BW540 were significant ( $P < 0.05$ ); however BW90, BW180 and BW270 were not significantly influenced by the combined effects of Temp and SR. The underlined reasons for insignificant influence seen in our study might be the animals were maintained under the loose sheds and proper feeding and watering management. The average BW90 decreased by  $-0.16 \pm 0.11$ ,  $-0.12 \pm 0.07$ , and  $-0.12 \pm 0.07$  kg due to per a unit increase in Temp, THI and THIadj values, respectively, while average BW180 decreased by  $-0.06 \pm 0.16$ ,  $-0.04 \pm 0.11$  and  $-0.03 \pm 0.11$  kg per a unit increase in Temp, THI and THIadj values, in that order. The average BW270 also showed a decline by  $-0.30 \pm 0.25$ ,  $-0.15 \pm 0.18$  and  $-0.18 \pm 0.18$  kg for every 1 unit rise Temp, THI and ATI, correspondingly. A unit rise in Temp, THI and THIadj resulted in a decline by  $-0.03$ ,  $-0.06 \pm 0.23$  and  $-0.07 \pm 0.23$  kg for BW365 and by  $-0.03 \pm 0.30$ ,  $-0.03 \pm 0.21$  and  $-0.04 \pm 0.21$  kg for BW450, in that order.

The average BW540 decreased by  $-0.05\pm 0.30$ ,  $-0.02\pm 0.21$  and  $-0.02\pm 0.21$  Kg due to rise in Temp, THI and THIadj, correspondingly. Similar with the present studies, Lacetera *et al.* (1994) reported that exposure to a hot environment may negatively affect growth of young calves whereas Mitlohner *et al.* (2001) found that temperatures between 15–29 °C do not seem to exert any influence on growth performance but temperature above 30 °C adverse effects was recorded in daily weight gain. According to the same author, under high ambient air temperature and solar radiation, steers reduce daily dry matter intake, hence average daily gain and carcass weight fall down, fat thickness drops. Hisashi and Atusi (2017) indicated that Japanese black calves are susceptible to a cold environment immediately after birth, whereas they are susceptible to a heat environment 3 months after birth. Ugurlu *et al.* (2014) also found that calf birth weight was decrease with increasing of temperature and humidity index and short dry period length.

According to polynomial regression analysis (table 68-73), the average BW90 increased, decreased and increased by  $2.38\pm 6.01$ ,  $-0.09\pm 0.28$  and  $0.001\pm 0.004$  kg for 1 °C rise in average ambient temperature;  $-3.74\pm 19.45$ ,  $0.07\pm 0.29$  and  $-0.0004\pm 0.001$  kg for a unit increase in THI and  $-6.73\pm 21.91$ kg,  $0.11\pm 0.31$  kg and  $-0.001\pm 0.002$  kg for a unite increase in THIadj, correspondingly whereas the average BW180 decreased, increased and decreased by  $-5.43\pm 8.79$ ,  $0.30\pm 0.41$ ,  $-0.01\pm 0.006$  kg for 1 °C rise in average ambient temperature;  $-9.95\pm 32.35$ ,  $0.16\pm 0.48$  and  $-0.0008\pm 0.002$  kg for a unit increase in THI and  $-10.49\pm 36.74$ ,  $0.16\pm 0.51$ , and  $-0.001\pm 0.002$  kg for a unite increase in THIadj, respectively. The average BW270 also decreased, increased and decreased by  $-10.15\pm 14$ ,  $0.55\pm 0.66$  and  $-0.01\pm 0.01$  kg for 1 °C rise in average ambient temperature;  $-87.78\pm 33.32$ ,  $1.34\pm 0.49$ , and  $-0.01\pm 0.002$  kg days for a unit increase in THI and  $-98.59\pm 38.89$ ,  $1.42\pm 0.54$  and  $-0.01\pm 0.003$  kg for a unite increase in THIadj, respectively. By  $-9.65\pm 18.75$ ,  $0.96\pm 0.89$  and  $-0.01\pm 0.01$  kg for 1 °C rise in average ambient temperature the average BW365 decreased, increased and decreased; but the values of the same trait decreased, increased and decreased by  $-105.01\pm 55.83$ ,  $1.57\pm 0.82$ , and  $-0.01\pm 0.004$  kg for a unit increase in THI and  $-122.57\pm 61.91$ ,  $1.73\pm 0.86$  and  $-0.01\pm 0.004$  kg for a unite increase in THIadj, in that order. The average BW450 decreased, increased and decreased by  $5.65\pm 18.06$ ,  $-0.22\pm 0.85$  and  $0.003\pm 0.01$  kg for 1 °C rise in average ambient temperature;  $-43.11\pm 54.71$ ,  $0.68\pm 0.80$  and  $-0.004\pm 0.004$  kg for a unit increase in THI and  $-54.91\pm 60.45$ ,  $0.81\pm 0.84$ , and  $-0.004\pm 0.004$  kg for a unite

increase in THIadj, respectively. Whilst the average number of BW540 decreased, increased and decreased by  $4.55 \pm 17.91$ ,  $-0.18 \pm 0.85$  and  $0.002 \pm 0.01$  kg for 1 °C rise in average ambient temperature but the value of the trait decreased increased, and decreased by  $-40.00 \pm 55.50$ ,  $0.63 \pm 0.82$  and  $-0.003 \pm 0.004$  kg for a unit increase in THI and  $-47.94 \pm 61.96$ ,  $0.71 \pm 0.87$  and  $-0.003 \pm 0.004$  kg for a unit increase in THIadj, correspondingly.

In general, the analysis of regression indicated that the body weights of crossbred cattle at different showed a considerable tendency of decreasing when the meteorological factors increase by 1 unit beyond the thermal comfort zone although the influences of Temp, THI and THIadj on different growth traits were not found to be significant. Crossbred calves born in the month with low to moderate Temp, THI, THIadj and Humidity could reveal a trend of high body weight than those of born in the month with high meteorological factors (Fig. 28).

**Table 68. Regression of BW90 ( $\pm$ SE) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRM			Parameter estimates of various PRM				
	a	b	r <sup>2</sup>	a	B	c	d	r <sup>2</sup>
Temp	63.27 $\pm$ 2.60	- 0.16 $\pm$ 0.10 <sup>ns</sup>	19	42.77 $\pm$	2.38 $\pm$ 6.01	- 0.09 $\pm$ 0.28	0.001 $\pm$ 0.004	31
RH	60.94 $\pm$ 4.70	-0.02 $\pm$ 0.07	1.1	-184.59	11.94 $\pm$ 7.05	-0.19 $\pm$ 0.12	0.001 $\pm$ 0.001	48.68
Temp & SR	61.69 $\pm$ 3.32	b1=- 0.33 $\pm$ 0.24 <sup>ns</sup> ; b2=0.02 $\pm$ 0.03 <sup>ns</sup>	25					
THI	68.09 $\pm$ 5.21	- 0.12 $\pm$ 0.07 <sup>ns</sup>	22	126.47 $\pm$	- 3.74 $\pm$ 19.45	0.07 $\pm$ 0.29	- 0.0004 $\pm$ 0.001	39
THIadj	68.34 $\pm$ 5.58	- 0.12 $\pm$ 0.07 <sup>ns</sup>	21	199.2 $\pm$	- 6.73 $\pm$ 21.91	0.11 $\pm$ 0.31	- 0.001 $\pm$ 0.002	38

**Table 69. Regression of BW180 ( $\pm$ SE) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRM			Parameter estimates of various PRM				
	a	b	r <sup>2</sup>	a	B	c	d	r <sup>2</sup>
Temp	104.25 $\pm$ 3.96	- 0.06 $\pm$ 0.16 <sup>ns</sup>	1.4	133.41	- 5.43 $\pm$ 8.79	0.30 $\pm$ 0.41	- 0.01 $\pm$ 0.006	22
RH	102.55 $\pm$ 6.51	0.004 $\pm$ 0.10	0	180	-313.31	20.94 $\pm$ 10.49	-0.34 $\pm$ 0.18	0.002 $\pm$ 0.001
Temp & SR	104.69 $\pm$ 5.22	b1=- 0.02 $\pm$ 0.37 <sup>ns</sup> ; b2=- 0.01 $\pm$ 0.05 <sup>ns</sup>	1.6					
THI	105.45 $\pm$ 8.09	- 0.04 $\pm$ 0.11 <sup>ns</sup>	0.01	305.24	- 9.95 $\pm$ 32.35	0.16 $\pm$ 0.48	- 0.0008 $\pm$ 0.002	10.5
THIadj	104.96 $\pm$ 8.62	- 0.03 $\pm$ 0.11 <sup>ns</sup>	0.63	330.4	- 10.49 $\pm$ 36.74	0.16 $\pm$ 0.51	- 0.001 $\pm$ 0.002	7.7

**Table 70. Regression of BW270 ( $\pm$ SE) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRM			Parameter estimates of various PRM				
	a	b	r <sup>2</sup>	a	B	c	d	r <sup>2</sup>
Temp	140.24 $\pm$ 6.13	- 0.30 $\pm$ 0.25 <sup>ns</sup>	13	202.03	- 10.15 $\pm$ 14	0.55 $\pm$ 0.66	- 0.01 $\pm$ 0.01	26
RH	170.07 $\pm$ 7.70	-0.35 $\pm$ 0.12 <sup>**</sup>	43.33	155.02	0.84 $\pm$ 15.85	-0.03 $\pm$ 0.27	0.0002 $\pm$ 0.001	
Temp & SR	132.08 $\pm$ 6.70	b1=- 0.57 $\pm$ 0.47 <sup>ns</sup> ; b2=0.11 $\pm$ 0.06 <sup>*</sup>	39.88					
THI	136.65 $\pm$ 12.88	- 0.15 $\pm$ 0.18 <sup>ns</sup>	6.5	2041.04	- 87.78 $\pm$ 33.32	1.34 $\pm$ 0.49	- 0.01 $\pm$ 0.002	65
THIadj	135.68 $\pm$ 13.66	- 0.18 $\pm$ 0.18 <sup>ns</sup>	8.7	2399.58	- 98.59 $\pm$ 38.89	1.42 $\pm$ 0.54	- 0.01 $\pm$ 0.003	62

**Table 71. Regression of BW365 ( $\pm$ SE) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRM			Parameter estimates of various PRM				
	a	b	r <sup>2</sup>	a	B	c	d	r <sup>2</sup>
Temp	196.73 $\pm$ 8.13	- 0.03 <sup>ns</sup>	0.0007	322.39	- 19.65 $\pm$ 18.75	0.96 $\pm$ 0.89	- 0.01 $\pm$ 0.01	14
RH	208.50 $\pm$ 12.65	-0.19 $\pm$ 0.19	0	8.09	10.55 $\pm$ 25.94	-0.19 $\pm$ 0.44	0.001 $\pm$ 0.002	11.69
Temp & SR	182.84 $\pm$ 7.49	b1= -1.47 $\pm$ 0.53*; b2=0.2 $\pm$ 0.07**	50.53					
THI	200.46 $\pm$ 16.51	- 0.06 $\pm$ 0.23 <sup>ns</sup>	0.007	2512.32	- 105.01 $\pm$ 55.83	1.57 $\pm$ 0.82	- 0.01 $\pm$ 0.004	36
THIadj	201.12 $\pm$ 17.53	- 0.07 $\pm$ 0.23 <sup>ns</sup>	0.008	3055.95	- 122.57 $\pm$ 61.91	1.73 $\pm$ 0.86	- 0.01 $\pm$ 0.004	37

**Table 72. Regression of BW450 ( $\pm$ SE) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRM			Parameter estimates of various PRM				
	a	b	r <sup>2</sup>	a	b	c	d	r <sup>2</sup>
Temp	243.64 $\pm$ 7.30	- 0.03 $\pm$ 0.30 <sup>ns</sup>	0.001	200.9	5.65 $\pm$ 18.06	- 0.22 $\pm$ 0.85	0.003 $\pm$ 0.01	4.6
RH	264.02 $\pm$ 10.36	-0.30 $\pm$ 0.16*	26.96	-3.44	12.88 $\pm$ 20.50	-0.21 $\pm$ 0.35	0.001 $\pm$ 0.002	33.99
Temp & SR	229.04 $\pm$ 6.15	b1=- 1.48 $\pm$ 0.40**; b2=0.22 $\pm$ 0.05**	66.76					
THI	246.77 $\pm$ 13.91	- 0.03 $\pm$ 0.21 <sup>ns</sup>	0.2	1147.47	- 43.11 $\pm$ 54.71	0.68 $\pm$ 0.80	- 0.004 $\pm$ 0.004	26
THIadj	247.29 $\pm$ 14.10	- 0.04 $\pm$ 0.21 <sup>ns</sup>	0.3	1470.9	- 54.91 $\pm$ 60.45	0.81 $\pm$ 0.84	- 0.004 $\pm$ 0.004	28

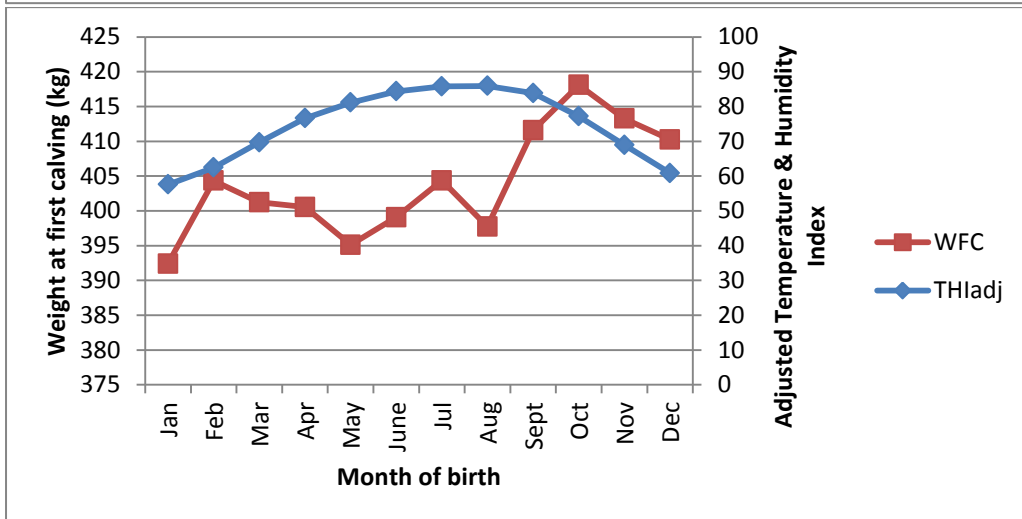
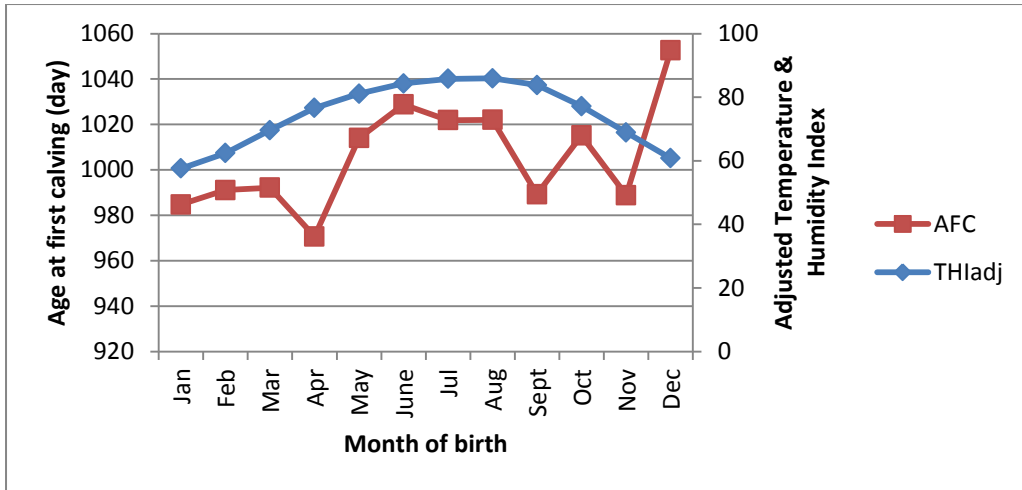
**Table 73. Regression of BW540 ( $\pm$ SE) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRM			Parameter estimates of various PRM				
	a	b	r <sup>2</sup>	a	B	c	d	r <sup>2</sup>
Temp	290.74 $\pm$ 7.35	- 0.05 $\pm$ 0.30	0.003	256.7	4.55 $\pm$ 17.91	- 0.18 $\pm$ 0.85	0.002 $\pm$ 0.01	3.1
RH	310.45 $\pm$ 10.34	-0.28 $\pm$ 0.16*	24.75	128.91	8.71 $\pm$ 21.09	-0.14 $\pm$ 0.36	0.001 $\pm$ 0.002	27.79
Temp & SR	277.25 $\pm$ 6.12	B1=- 1.35 $\pm$ 0.44**; b2=0.20 $\pm$ 0.06*	59.15					
THI	293.19 $\pm$ 14.89	- 0.02 $\pm$ 0.21	0.07	1132.13	- 40.00 $\pm$ 55.50	0.63 $\pm$ 0.82	- 0.003 $\pm$ 0.004	21
THIadj	293.61 $\pm$ 15.82	- 0.02 $\pm$ 0.21	0.1	1362.46	- 47.94 $\pm$ 61.96	0.71 $\pm$ 0.87	- 0.003 $\pm$ 0.004	22

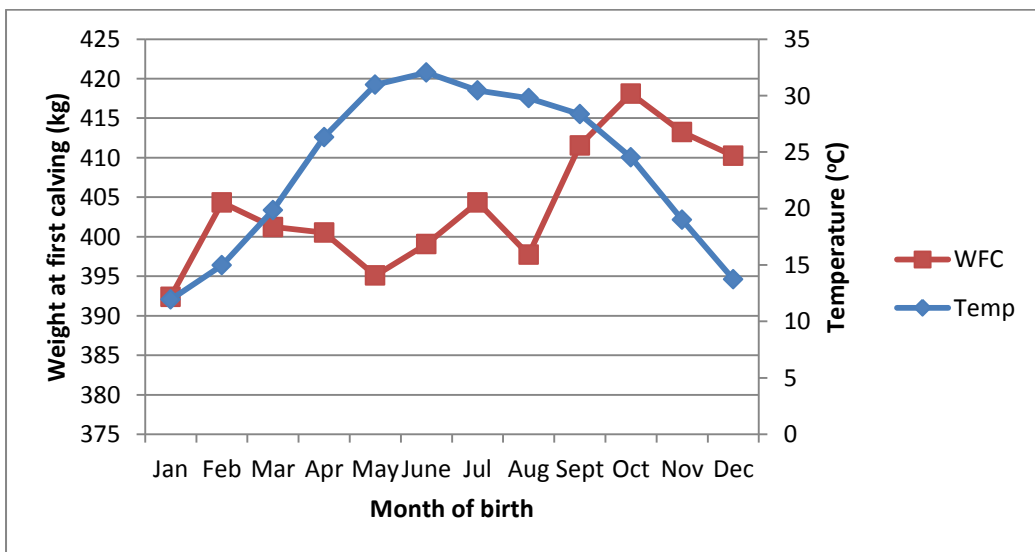
#### 4.18.2. Relationship of meteorological factors with AFS, AFC and WFC

The monthly least square means for AFS, AFC and WFC and corresponding monthly least square means of meteorological factors and their combinations during thirty two years (1985-2016) are presented in Table 74. High average AFS (765.71 days) was found in the month of December but the average lowest AFS (675.67 days) was observed in the month of April. In December, the average Temp, RH, SR, THI, and THIadj were estimated as 13.75 °C, 73.01%, 138.48 W/m<sup>2</sup>, 56.86 unit and 60.83 unit, respectively; but for month of April the corresponding values were 26.33 °C, 46.89%, 291.14 W/m<sup>2</sup>, 72.82 unit and 76.62 unit, in that order. The highest average AFC of crossbred cattle was found as 1052.61 days in the month of December. In the month of December, the average Temp, RH, THI, SR and THIadj were 13.75 °C, 73.01%, 138.48 W/m<sup>2</sup>, 56.86 units and 60.83 unit, in that order. The average AFC (970.65 days); however was observed in the month of April. The average Temp, RH, THI, SR and THIadj in the month of April were 26.33 °C, 46.89%, 291.14 W/m<sup>2</sup>, 72.82 units and 76.62 units, correspondingly. The average highest (418.10 kg) and lowest (392.40 kg) WFC were observed in the months of September and January, respectively. In the month of September, the Temp, RH, SR, THI, and THIadj averaged 28.36 °C, 74.57%, 247.74 W/m<sup>2</sup>, 79.46 unit and 83.84 unit, respectively whereas the corresponding values in the month of January were 11.94 °C, 77.53%, 142.50 W/m<sup>2</sup>, 54.00 unit and 57.56 unit, in that order.

In contrast to the present finding, Parveen (2017) reported the highest and lowest average age at first calving in the month of August and January, respectively. The results revealed that crossbred cows born in the months with lower average Temp, SR, THI, and THIadj and relatively high RH values had higher AFS and AFC than those born in the month with moderate meteorological factor values. It meant that crossbred cows born in the months (Feb-Apr) with moderate meteorological factor values reached AFS and AFC earlier than those born in the months with higher and lowest Temp, RH, SR, THI and THIadj values (table 74; Fig. 29-30).



**Fig. 29. Association of monthly THIadj and AFC and WFC over months of birth**



**Fig. 30. Association of monthly Temp and WFC over months of birth**

However the body weight at age first calving (WFC) was found to be continuously higher for crossbred cows which born in the month (Oct-Jan) with low to moderate average Temp, THI, SR and THIadj and RH values than those born in the months with higher and lowest Temp, RH, SR, THI and THIadj values (table 74; Fig. 29-30).

**Table 74. Month wise least square means of meteorological factors and corresponding AFS, AFC and WFC traits in crossbred cattle during the study period (1985-2016)**

MOB	Temp	RH	SR	THI	THIadj	AFS	AFC	WFC
Jan	11.94	77.53	142.50	54.00	57.56	685.68	984.75	392.40
Feb	14.98	73.42	190.96	58.79	62.42	687.53	991.13	404.34
Mar	19.86	66.39	241.81	65.84	69.64	696.32	992.16	401.23
Apr	26.33	46.89	291.14	72.82	76.62	675.67	970.65	400.53
May	30.97	41.58	302.94	77.91	81.12	716.21	1014.01	395.10
Jun	32.04	54.17	290.67	81.33	84.32	726.05	1028.84	399.07
Jul	30.46	74.46	253.30	82.57	85.77	749.44	1021.91	404.35
Aug	29.78	77.63	245.64	82.09	85.91	721.97	1022.06	397.73
Sep	28.36	74.57	247.74	79.46	83.84	693.47	989.25	411.57
Oct	24.53	64.05	214.00	72.54	77.16	713.67	1015.16	418.10
Nov	19.00	64.38	171.62	64.54	68.93	687.54	988.83	413.25
Dec	13.75	73.01	138.48	56.86	60.83	765.71	1052.61	410.24

#### 4.18.2.1. Effects of meteorological factors on AFS, AFC and WFC

The parameter estimates for the effects of meteorological variables and their combination on AFS, AFC and WFC traits under various linear and polynomial regression models are presented Table 75-77. The effects of Temp, THI and THIadj on AFS, AFC and WFC were found to be non-significant ( $P>0.05$ ). The underlined reasons for insignificant influence observed in our study might be the animals were maintained under the loose sheds and proper feeding and watering management. Temp, THI and THIadj negatively affected WFC; but positively influenced AFS and AFC traits. The average AFS increased by  $0.76\pm 1.17$ ,  $0.61\pm 0.81$  and  $0.58\pm 0.82$  days due to per a unit increase in Temp, THI and THIadj values, respectively, while average AFC increased by  $0.59\pm 1.0$ ,  $0.45\pm 0.7$  and  $0.43\pm 0.71$  days per a unit increase in Temp, THI and THIadj values, in that order. Whilst the average WFC showed a decline by  $-0.11\pm 0.34$ ,  $-0.03\pm 0.24$  and  $-0.003\pm 0.24$  kg for every 1 unit rise Temp, THI and ATI, correspondingly.

The influences of THI on age at first calving observed in the current study were in line with the finding of Teke and Akdag (2012) who found non-significant

effect of THI on AFC in different months in Jersey cows. However significant effects of THI on AFC in different months were reported by Zadeh *et al.* (2013) and Parveen (2017) for Sahiwal cattle. According to Parveen (2017), the average age at first calving was increased by 3 days with per unit increase in THI value.

According to polynomial regression analysis (table 75-77), the average AFS increased, decreased and increased by  $31.41\pm 63.74$ ,  $-1.80\pm 3.01$  and  $0.03\pm 0.05$  days for 1 °C rise in average ambient temperature;  $189.25\pm 206.90$ ,  $-2.94\pm 3.04$ , and  $0.02\pm 0.01$  days for a unit increase in THI; and  $211.30\pm 238.97$ ,  $-3.09\pm 3.34$  and  $0.015\pm 0.02$  days for a unite increase in THIadj, correspondingly whereas the average AFC increased, decreased and increased by  $0.04\pm 0.04$ ,  $-2.24\pm 2.47$  and  $41.22\pm 52.23$  days for 1 °C rise in average ambient temperature;  $143.70\pm 183.56$ ,  $-2.24\pm 2.70$  and  $0.01\pm 0.01$  days for a unit increase in THI and  $161.31\pm 210.53$ ,  $-2.36\pm 2.94$  and  $0.01\pm 0.01$  days for a unite increase in THIadj, respectively. By  $9.69\pm 16.24$ ,  $-0.32\pm 0.77$  and  $0.003\pm 0.01$  kg for 1 °C rise in average ambient temperature, the WFC increased, decreased and increased; but the values of the same trait increased, decreased and increased by  $50.99\pm 61.40$ ,  $-0.70\pm 0.90$  and  $0.003\pm 0.004$  kg for a unit increase in THI and  $58.59\pm 69.56$ ,  $-0.77\pm 0.97$  and  $0.003\pm 0.004$  kg for a unite increase in THIadj, in that order.

**Table 75. Regression of AFS (days) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRM			Parameter estimates of various PRM				
	a	b	r <sup>2</sup>	A	B	c	d	r <sup>2</sup>
Temp	692.05±28.73	0.76±1.17 <sup>ns</sup>	4.06	536.96	31.41±63.74	- 1.80±3.01	0.03±0.05	24
RH	685.16±47.16	0.38±0.71	2.8	1670.37	-50.33±96.46	0.85±1.62	0.005±0.01	6.09
Temp & SR	727.25±32.72	b1= 4.41±2.31 <sup>ns</sup> ; b2= -0.53±0.30 <sup>ns</sup>	29					
THI	667.18±58.18	0.61±0.81 <sup>ns</sup>	5.24	- 3307.52	189.25±206.90	- 2.94±3.04	0.02±0.01	32
THIadj	666.7±61.98	0.58±0.82 <sup>ns</sup>	4.75	- 4057.49	211.30±238.97	- 3.09±3.34	0.015±0.02	28

**Table 76. Regression of AFC (days) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRM			Parameter estimates of various PRM				
	a	b	r <sup>2</sup>	A	B	c	d	r <sup>2</sup>
Temp	992.09±24.52	0.59±1.0 <sup>ns</sup>	3.37	766.79	41.22±52.23	- 2.24±2.47	0.04±0.04	29
RH	991.26±40.41	0.22±0.61	1.34	1562.21	-29.63±83.41	0.51±1.40	-0.003±0.01	2.94
Temp & SR	1022.19±27.87	b1=3.71±1.97 <sup>ns</sup> ; b2=-0.45±0.25 <sup>ns</sup>	29					
THI	974.42±49.82	0.45±0.7 <sup>ns</sup>	3.94	- 2039.16	143.70±183.56	- 2.24±2.70	0.01±0.01	26
THIadj	974.04±53.04	0.43±0.7 <sup>ns</sup>	3.6	- 2630.28	161.31±210.53	- 2.36±2.94	0.01±0.01	22

**Table 77. Regression of WFC (kg) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRM			Parameter estimates of various PRM				
	a	b	r <sup>2</sup>	a	B	c	d	r <sup>2</sup>
Temp	406.55±8.31	- 0.11±0.34 <sup>ns</sup>	10.20	321.56	9.69±16.24	- 0.32±0.77	0.003±0.01	39
RH	395.67±13.36	0.13±0.20	3.85	823.45	-24.82±18.20	0.47±0.31	-0.003±0.002	58.79
Temp & SR	415.92±9.71	b1=0.86±0.69 <sup>ns</sup> ; b2=-0.14±0.09 <sup>ns</sup>	23					
THI	406.23±17.0	- 0.03±0.24 <sup>ns</sup>	18.20	- 809.68	50.99±61.40	- 0.70±0.90	0.003±0.004	26
THIadj	404.24±18.09	- 0.003±0.24 <sup>ns</sup>	19.10	- 1057	58.59±69.56	- 0.77±0.97	0.003±0.004	24

#### 4.18.3. Relationships of meteorological factors and reproduction traits

The monthly least square means for reproduction traits and corresponding monthly least square means of meteorological factors and their combinations during twenty eight years (1991-2018) are presented in Table 78. High average NSPC (2.59) days was found in the month of May but the average lowest NSPC (2.14) was observed in the month of March. In May, the average Temp, RH, SR, THI and THIadj were estimated as 31.19 °C, 40.44%, 300.87 W/m<sup>2</sup>, 78.0213 units and 81.1926 units, respectively; but for month of March, the corresponding values were 20.003 °C, 66.65%, 241.60 W/m<sup>2</sup>, 66.05 units, 69.89 units, in that order. The highest average PP of crossbred cattle was found as 279.07 days in the month of March. In the month of March, the average Temp, RH, SR, THI and THIadj were 20.003 °C, 66.65%, 241.60 W/m<sup>2</sup>, 66.05 units, and 69.89 units, in that order. The lowest average PP (274.87 days), however, was observed in the month of August. The average Temp, RH, SR, THI and THIadj in the month of August were 29.84 °C, 78.11%, 242.54 W/m<sup>2</sup>, 82.25 units and 86.06 units, correspondingly. The average highest (193.71 days) and lowest (161.43 days) SP were observed in the months of March and November, respectively. In the month of March, Temp, RH, SR, THI, and THIadj were 20.003 °C, 66.65%, 241.60 W/m<sup>2</sup>, 66.05 units, and 69.89 units, respectively whereas the corresponding values in the month of November were 19.02 °C, 64.84%, 167.44 W/m<sup>2</sup>, 64.60 units and 68.98 units, in that order. The highest (469.04 days) and lowest (439.80 days) monthly average CI were seen in the month of July and January, in that order. In the month of July and January, the average of Temp, RH, SR, THI and THIadj were 30.54 °C, 78.32%, 252.20 W/m<sup>2</sup>, 82.79 units and 85.98 units; 11.84 °C, 74.97%, 138.82 W/m<sup>2</sup>, 53.82 units and 57.35 units, correspondingly.

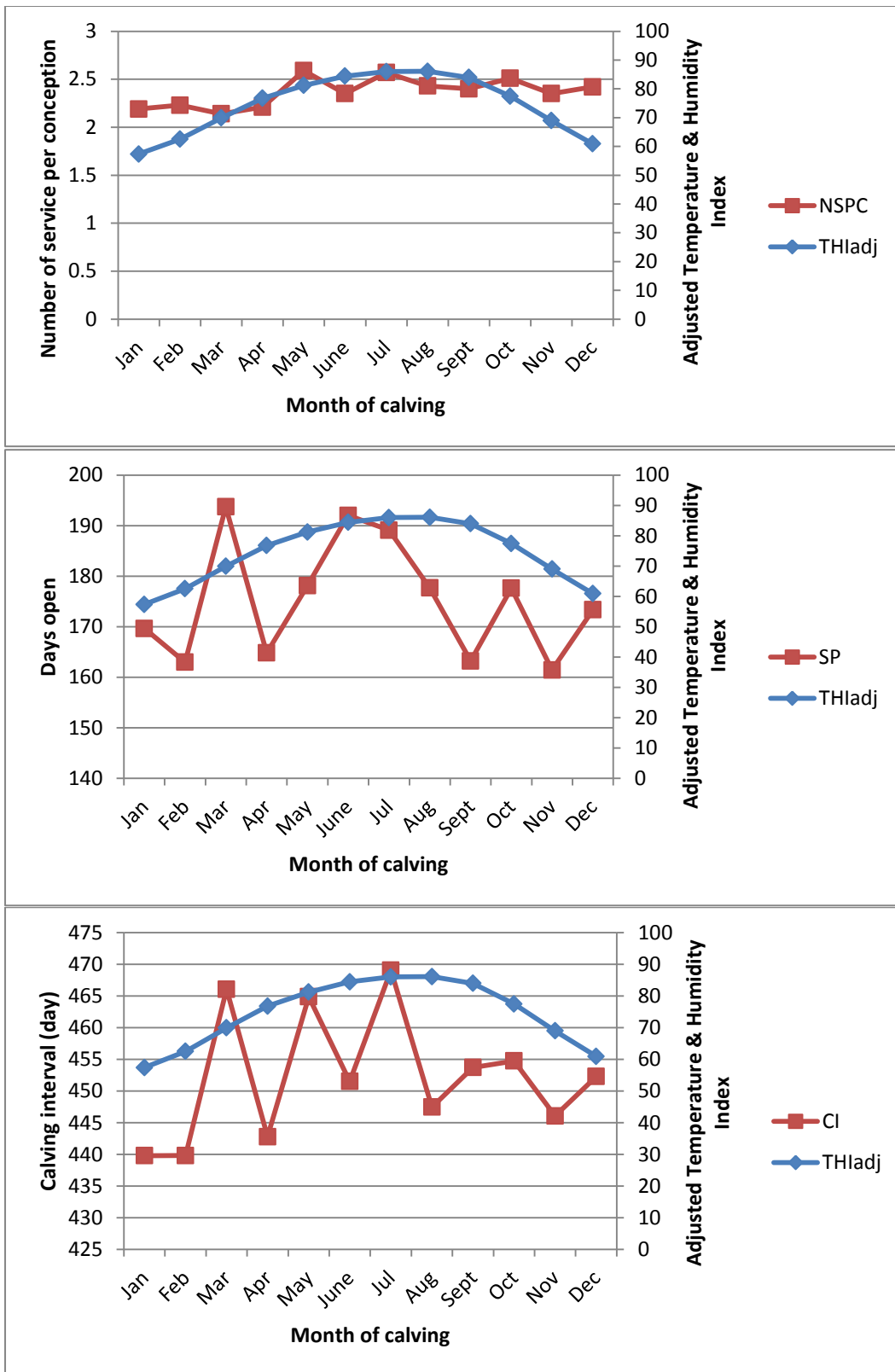
**Table 78. Month wise least square means of various meteorological factors and corresponding reproduction traits during the study period (1991-2018)**

<b>MOC</b>	<b>Temp</b>	<b>RH</b>	<b>SR</b>	<b>THI</b>	<b>THIadj</b>	<b>NSPC</b>	<b>PP</b>	<b>SP</b>	<b>CI</b>
Jan	11.84	78.32	138.82	53.82	57.35	2.19	278.20	169.64	439.80
Feb	15.03	73.9	188.15	58.87	62.51	2.23	276.81	162.97	439.82
Mar	20.00	66.65	241.60	66.05	69.89	2.14	279.07	193.71	466.06
Apr	26.44	46.77	289.09	72.95	76.76	2.21	276.92	164.81	442.79
May	31.19	40.44	300.87	78.02	81.19	2.59	275.55	178.11	464.86
Jun	31.98	55.01	288.34	81.39	84.41	2.35	275.96	192.03	451.51
Jul	30.54	74.97	252.20	82.79	85.98	2.57	276.36	189.11	469.04
Aug	29.84	78.11	242.54	82.25	86.06	2.43	274.87	177.66	447.46
Sep	28.34	75.4	244.72	79.55	83.94	2.40	274.88	163.21	453.70
Oc	24.64	64.83	210.15	72.77	77.43	2.51	277.47	177.62	454.74
Nov	19.02	64.84	167.44	64.60	68.98	2.35	278.88	161.43	446.06
Dec	13.77	73.25	135.90	56.88	60.91	2.42	277.70	173.36	452.28

On the contrary to the present finding, Parveen (2017) reported the highest and lowest average calving interval in the month of August and March, respectively. The results (table 78; Fig. 31) revealed that crossbred cows calved in the months with moderate average Temp, SR, THI, and THIadj and relatively high Hum values had lower NSPC than those calved in the month with higher meteorological factor values. The average values of PP was found to be lower for crossbred cows calved in the months with highest Temp, RH, SR, THI and THIadj than those calved in the months with low to moderate meteorological values. The average values of SP and CI were observed to be lower for crossbred cows calved in the months with lower Temp, RH, SR, THI and THIadj; but the higher average SP and CI were obtained in crossbred cows calved in the months with moderate and highest Temp, RH, SR, THI and THIadj, respectively.

#### **4.18.3.1. Effects of meteorological factors on reproduction traits**

The parameter estimates for the effects of meteorological factors and their combination on reproduction traits under various linear and polynomial regression models are presented Table 79-82. The effects of Temp, THI and THIadj on NSPC and PP were found to be negative and significant ( $P > 0.05$ ). However SP and CI were not significantly ( $P > 0.05$ ) influenced by Temp, THI and THIadj. The underlined reasons for insignificant influence seen in our study might be the animals were maintained under the loose sheds and proper feeding and watering management.



**Fig. 31. Association of monthly THIadj and NSPC, SP and CI over months of calving in crossbred cattle**

Temp, THI and THIadj negatively affected PP; but positively influenced NSPC, SP and CI traits. The average NSPC increased by  $0.01\pm 0.01$ ,  $0.01\pm 0.004$ ,  $0.01\pm 0.004$  due to per a unit increase in Temp, THI and THIadj values, respectively, while average PP decreased by  $0-0.14\pm 0.04$ ,  $-0.10\pm 0.03$ , and  $-0.10\pm 0.03$  days per a unit increase in Temp, THI and THIadj values, in that order. The average SP showed an increase by  $0.64\pm 0.46$ ,  $0.44\pm 0.32$  and  $0.42\pm 0.33$  days for every 1 unit rise Temp, THI and THIadj, correspondingly. A unit rise in Temp, THI and THIadj resulted in an increase by  $0.66\pm 0.38$ ,  $0.46\pm 0.26$  and  $0.46\pm 0.27$  days for CI, in that order.

The influences of THI on calving interval observed in the present study were in line with the finding of Teke and Akdag (2012) who found non-significant effect of THI on CI in different months in Jersey cows. However significant effects of THI on CI in different months were reported by Zadeh *et al.* (2013) and Parveen (2017) for Sahiwal cattle. According to Parveen (2017), the average CI was increased by 2 days with per unit increase in THI value. Similar to the present finding for PP, high temperatures and high temperature-humidity index decrease the pregnancy rate during the first 30 days of the breeding season (Amundson *et al.*, 2005). Moreover many workers reported the negative influences of heat stress on various reproduction traits in dairy cattle (West, 2003; Hansen, 2007; Verwoerd *et al.* 2006). About 20-27% drop in conception rates (Lucy, 2002) or decrease in 90-day non-return rate to the first service in lactating dairy cows (Al-Katanani *et al.*, 1999) can occur in summer. In these situations the calving interval is longer, the birth rate is lower and farm milk yield per year can be reduced. Heat stress does not prevent the occurrence of normal estrus cycles. It does, however, amplify the problem of heat detection by reducing the length of the estrus period, from 18 hours down to about 10 hours, and lowering the intensity of estrus behavior (Shearer and Beede, 1990; De Rensis and Scaramuzzi, 2003).

According to polynomial regression analysis (table 79-82), the average NSPC decreased, increased and increased by  $-0.01\pm 0.32$ ,  $6.3\times 10^{-5}\pm 0.02$  and  $9.4\times 10^{-6}\pm 0.0002$  for  $1^{\circ}\text{C}$  rise in average ambient temperature; however the average value of the same trait decreased, increased and decreased by  $-0.13\pm 1.06$ ,  $0.002\pm 0.02$  and  $-0.0001\pm 0.0001$  for a unit increase in THI; and  $-0.15\pm 1.18$ ,  $0.002\pm 0.02$  and  $-0.0008\pm 0.0001$  for a unit increase in THIadj, correspondingly.

Whilst the average PP increased, decreased and increased by  $2.45 \pm 2.15$ ,  $-0.11 \pm 0.10$  and  $0.001 \pm 0.002$  days for  $1^\circ\text{C}$  rise in average ambient temperature;  $5.97 \pm 7.01$ ,  $-0.08 \pm 0.10$  and  $0.0004 \pm 0.001$  days for a unit increase in THI and  $3.32 \pm 1.18$ ,  $0.0002 \pm 0.0001$  and  $-0.04 \pm 0.02$  for a unite increase in THIadj, respectively. The average SP increased by 25.18, 1.24, and 0.02 days for  $1^\circ\text{C}$  rise in average ambient temperature; however the average value of the same trait increased, decreased and increased by  $54.35 \pm 89.05$ ,  $-0.81 \pm 1.31$  and  $0.004 \pm 0.01$  days for a unit increase in THI; and  $36.20 \pm 1.43$ ,  $-0.51 \pm 0.01$  and 0.002 days for a unit increase in THIadj, correspondingly. By  $18.74 \pm 21.90$ ,  $-0.84 \pm 1.03$  and  $0.01 \pm 0.02$  days for  $1^\circ\text{C}$  rise in average ambient temperature, the CI increased, decreased and increased; but the values of the same trait increased, decreased and increased by  $38.07 \pm 74.67$ ,  $-0.54 \pm 1.10$  and  $0.003 \pm 0.01$  days for a unit increase in THI and  $33.14 \pm 83.55$ ,  $-0.44 \pm 1.67$  and  $0.002 \pm 0.01$  days for a unite increase in THIadj, in that order.

**Table 79. Regression of NSPC ( $\pm$ SE) (no.) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b	r <sup>2</sup>	A	b	C	d	r <sup>2</sup>
Temp	2.09 $\pm$ 0.13	0.01 $\pm$ 0.01*	32	2.31	- 0.01 $\pm$ 0.32)	5.3 $\times 10^{-5}$ $\pm$ 0.02	9.4 $\times 10^{-6}$ $\pm$ 0.0002	35
RH	2.47 $\pm$ 0.25	-0.002 $\pm$ 0.004	1.81	12.89	-0.53 $\pm$ 0.41	0.01 $\pm$ 0.01	-4.6 $\times 10^{-5}$ $\pm$ 0	22.59
Temp & SR	2.28 $\pm$ 0.09	b1=0.03 $\pm$ 0.01**; b2=0.003 $\pm$ 0.001**	61					
THI	1.79 $\pm$ 0.25	0.01 $\pm$ 0.004*	33	5.41	- 0.13 $\pm$ 1.06	0.002 $\pm$ 0.02	- 0.0001 $\pm$ 0.0001	35
THIadj	1.75 $\pm$ 0.27	0.01 $\pm$ 0.004*	33	5.9	- 0.15 $\pm$ 1.18	0.002 $\pm$ 0.02	- 0.0008 $\pm$ 0.0001	35

\*P<0.05; \*\*<0.01; NS: non-significant

**Table 80. Regression of PP ( $\pm$ SE) (days) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b	r <sup>2</sup>	A	b	C	d	r <sup>2</sup>
Temp	280.2 $\pm$ 1.06	- 0.14 $\pm$ 0.04 **	52	261.14	2.45 $\pm$ 2.15*	- 0.11 $\pm$ 0.10*	0.001 $\pm$ 0.002*	67
RH	276.29 $\pm$ 2.41	0.009 $\pm$ 0.04	0.63	299.83	-1.60 $\pm$ 3.32	0.03 $\pm$ 0.06	-0.0002 $\pm$ 0	32.44
Temp & SR	279.75 $\pm$ 1.33	b1=0.19 $\pm$ 0.10*; b2=0.01 $\pm$ 0.01*	54					
THI	283.95 $\pm$ 2.10	- 0.10 $\pm$ 0.03**	53	137.76	5.97 $\pm$ 7.01	- 0.08 $\pm$ 0.10	0.0004 $\pm$ 0.001	69
THIadj	284.34 $\pm$ 2.26	- 0.10 $\pm$ 0.03**	53	190.39	3.32 $\pm$ 1.18	- 0.04 $\pm$ 0.02	0.0002 $\pm$ 0.0001	69

\*P<0.05; \*\*<0.01; NS: non-significant

**Table 81. Regression of SP ( $\pm$ SE) (days) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b	r <sup>2</sup>	A	b	c	d	r <sup>2</sup>
Temp	160.26 $\pm$ 11.59	0.64 $\pm$ 0.46 <sup>ns</sup>	16	8.59	25.18	1.24	0.02	31
RH	181.84 $\pm$ 19.42	-0.10 $\pm$ 0.29	1.15	112.21	2.45 $\pm$ 34.65	-0.02 $\pm$ 0.59	3.85 $\times 10^{-5}$	5.16
Temp & SR	157.33 $\pm$ 14.85	b1=0.31 $\pm$ 1.03 <sup>ns</sup> ; b2=0.05 $\pm$ 0.13 <sup>ns</sup>						
THI	143.98 $\pm$ 24.03	0.44 $\pm$ 0.32 <sup>ns</sup>	16	- 1030.08	54.35 $\pm$ 89.05	- 0.81 $\pm$ 1.31	0.004 $\pm$ 0.01	22
THIadj	143.68 $\pm$ 25.74	0.42 $\pm$ 0.33 <sup>ns</sup>	15	- 676.52	36.20 $\pm$ 1.43	- 0.51 $\pm$ 0.01	0.002	17

**Table 82. Regression of CI ( $\pm$ SE) (days) on various meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b	r <sup>2</sup>	A	b	C	d	r <sup>2</sup>
Temp	436.74 $\pm$ 7.46	0.66 $\pm$ 0.38 <sup>ns</sup>	24	314.71	18.74 $\pm$ 21.90	- 0.84 $\pm$ 1.03	0.01 $\pm$ 0.02	30
RH	462.43 $\pm$ 16.62	-0.15 $\pm$ 0.25	3.67	1335.36	-46.20 $\pm$ 25.40	0.78 $\pm$ 0.43	-0.004 $\pm$ 0.002	32.17
Temp and SR	436.07 $\pm$ 9.31	b1=0.59 $\pm$ 0.86 <sup>ns</sup> ; b2=0.01 $\pm$ 0.1 <sup>ns</sup>	24					
THI	419.62 $\pm$ 15.64	0.46 $\pm$ 0.26 <sup>ns</sup>	24	- 446.04	38.07 $\pm$ 74.67	- 0.54 $\pm$ 1.10	0.003 $\pm$ 0.01	27
THIadj	417.93 $\pm$ 16.99	0.46 $\pm$ 0.27 <sup>ns</sup>	23	- 386.11	33.14 $\pm$ 83.55	- 0.44 $\pm$ 1.67	0.002 $\pm$ 0.01	26

ns: non-significant

#### 4.18.4. Relationship of meteorological factors and milk production traits

##### 4.18.4.1. Effects of meteorological factors on daily milk yield

The least square means along with standard error for daily milk yield of crossbred cattle across different factors are presented in Tables 83-85 and Annex-table 8-10. The effects of month of calving, period of calving, THI, THIadj, Temp, RH and SR on DMY were found to be highly significant ( $P<0.01$ ). Cows calved in February and March had better ( $P<0.01$ ) milk yield per day than cows calved in other months of the whole twenty eight years of the study period. However crossbred dairy cows calved in August had the lowest daily milk yield. Higher daily milk yield was observed for cows calved in POC5 followed by POC4 and POC7; but dairy cows calved within POC1 and POC2 had significantly ( $P>0.05$ ) lower daily milk yield. Lower daily milk yield was found for cows in THI9 followed by THI8 and THI7; but the daily milk yield of cows under THI4 was higher ( $P<0.01$ ) next to cows under THI5. Similarly dairy cows in THIadj5 had significantly higher ( $P<0.01$ ) daily milk yield; but the cows under THIadj1 produced lesser daily milk yield. Temp4 followed by Temp5 was comfortable temperature range as better daily milk production was observed under them. However lower daily milk yield was recorded for cows under Temp1. Dairy cows under RH7 and SR7 produced significantly higher daily milk yield; but milk yield of dairy cows in RH2 and SR1 were lower. The influences of month of calving and THI on daily milk yield observed in the present study was similar to the report of Parveen (2017) who found higher daily milk yield in the month of February and March. He also found higher daily milk yield in the THI range of 63-68 units which is in agreement with the present finding. However on the same study, lower daily milk yield was observed in the month of October and under THI range of 74.00-79.00 units. However, cows in THI range of 30-40 had the greatest amounts of milk and the cows in THI range of 81-90 had lower milk (Ghavi *et al.*, 2012).

**Table 83. Least squares means ( $\pm$ SE) for DMY (kg) of crossbred cattle (THI in the model)**

Sources	N	DMY
Overall mean	281698	12.57 $\pm$ 0.01
<b>Month of calving</b>		**
April	23817	13.28 $\pm$ 0.06 <sup>c</sup>
August	23795	11.17 $\pm$ 0.07 <sup>k</sup>
December	23580	12.92 $\pm$ 0.06 <sup>e</sup>
February	21815	13.49 $\pm$ 0.06 <sup>b</sup>
January	23508	13.19 $\pm$ 0.06 <sup>d</sup>

July	23792	11.73±0.07 <sup>h</sup>
June	23430	12.50±0.07 <sup>f</sup>
March	24467	13.51±0.06 <sup>a</sup>
May	24439	12.84±0.06 <sup>e</sup>
November	23022	11.83±0.06 <sup>g</sup>
October	23335	11.47±0.06 <sup>i</sup>
September	22698	11.27±0.07 <sup>j</sup>
<b>Period of calving</b>		**
POC1	29071	9.24±0.05 <sup>g</sup>
POC2	48869	9.62±0.05 <sup>f</sup>
POC3	38490	11.15±0.05 <sup>e</sup>
POC4	32262	12.58±0.05 <sup>d</sup>
POC5	41525	15.54±0.05 <sup>b</sup>
POC6	45641	15.92±0.05 <sup>a</sup>
POC7	45840	12.99±0.05 <sup>c</sup>
<b>THI sub-classes</b>		**
THI1	252	12.45±0.33 <sup>c</sup>
THI2	5192	12.46±0.09 <sup>cb</sup>
THI3	30320	12.44±0.06 <sup>c</sup>
THI4	39505	12.47±0.05 <sup>b</sup>
THI5	36167	12.65±0.04 <sup>a</sup>
THI6	40078	12.46±0.03 <sup>cb</sup>
THI7	59056	12.41±0.03 <sup>d</sup>
THI8	69113	12.40±0.04 <sup>d</sup>
THI9	2015	12.39±0.12 <sup>d</sup>

\*P<0.05; \*\*P<0.01; NS: non-significant

**Table 84. Least squares means (±SE) for DMY (kg) of crossbred cattle (THIadj in the model)**

Sources	N	DMY
Overall mean	281698	12.57±0.01
<b>Month of calving</b>		**
April	23817	13.22±0.06 <sup>c</sup>
August	23795	11.09±0.07 <sup>k</sup>
December	23580	12.89±0.06 <sup>e</sup>
February	21815	13.48±0.06 <sup>b</sup>
January	23508	13.17±0.06 <sup>d</sup>
July	23792	11.66±0.07 <sup>h</sup>
June	23430	12.43±0.06 <sup>f</sup>
March	24467	13.50±0.05 <sup>a</sup>
May	24439	12.77±0.06 <sup>e</sup>
November	23022	11.82±0.06 <sup>g</sup>
October	23335	11.42±0.06 <sup>i</sup>
September	22698	11.19±0.07 <sup>j</sup>
<b>Period of calving</b>		**
POC1	29071	9.20±0.05 <sup>g</sup>
POC2	48869	9.58±0.05 <sup>f</sup>
POC3	38490	11.10±0.05 <sup>e</sup>
POC4	32262	12.54±0.05 <sup>d</sup>

POC5	41525	15.49±0.05 <sup>b</sup>
POC6	45641	15.88±0.05 <sup>a</sup>
POC7	45840	12.95±0.05 <sup>c</sup>
<b>THIadj sub-classes</b>		**
THIadj1	247	12.18±0.33 <sup>f</sup>
THIadj2	4499	12.22±0.09 <sup>e</sup>
THIadj3	25036	12.29±0.06 <sup>d</sup>
THIadj4	39808	12.40±0.05 <sup>c</sup>
THIadj5	34766	12.60±0.04 <sup>a</sup>
THIadj6	40260	12.49±0.03 <sup>b</sup>
THIadj7	59234	12.42±0.03 <sup>c</sup>
THIadj8	73629	12.41±0.04 <sup>c</sup>
THIadj9	4219	12.35±0.09 <sup>d</sup>

\*P<0.05; \*\*P<0.01; NS: non-significant

**Table 85. Least squares means (±SE) for DMY (kg) of crossbred cattle (Temp, RH & SR in the model)**

Sources	N	DMY
Overall mean	281698	12.57±0.01
<b>Month of Calving</b>		**
April	23817	13.37±0.07 <sup>c</sup>
August	23795	11.01±0.07 <sup>k</sup>
December	23580	12.76±0.07 <sup>e</sup>
February	21815	13.29±0.07 <sup>b</sup>
January	23508	12.99±0.07 <sup>d</sup>
July	23792	11.60±0.07 <sup>h</sup>
June	23430	12.49±0.07 <sup>i</sup>
March	24467	13.47±0.06 <sup>a</sup>
May	24439	12.95±0.07 <sup>e</sup>
November	23022	11.80±0.07 <sup>g</sup>
October	23335	11.41±0.07 <sup>i</sup>
September	22698	11.16±0.07 <sup>j</sup>
<b>Period of calving</b>		**
POC1	29071	9.18±0.06 <sup>g</sup>
POC2	48869	9.53±0.05 <sup>f</sup>
POC3	38490	11.07±0.06 <sup>e</sup>
POC4	32262	12.50±0.06 <sup>d</sup>
POC5	41525	15.46±0.05 <sup>b</sup>
POC6	45641	15.84±0.05 <sup>a</sup>
POC7	45840	12.93±0.05 <sup>c</sup>
<b>Temperature</b>		**
Temp1	356	12.19±0.28 <sup>e</sup>
Temp2	15905	12.32±0.07 <sup>d</sup>
Temp3	49451	12.33±0.06 <sup>cd</sup>
Temp4	42588	12.57±0.05 <sup>a</sup>
Temp5	43181	12.43±0.04 <sup>b</sup>
Temp6	90403	12.29±0.04 <sup>d</sup>
Temp7	38860	12.37±0.05 <sup>c</sup>
Temp8	954	12.34±0.18 <sup>cd</sup>
<b>Humidity</b>		**
RH1	1878	12.18±0.13 <sup>c</sup>
RH2	12603	12.10±0.08 <sup>e</sup>
RH3	21805	12.11±0.07 <sup>d</sup>
RH4	22268	12.26±0.06 <sup>c</sup>

RH5	56383	12.31±0.05 <sup>b</sup>
RH6	87179	12.57±0.05 <sup>b</sup>
RH7	53977	12.59±0.05 <sup>a</sup>
RH8	22201	12.57±0.06 <sup>b</sup>
RH9	3404	12.54±0.10 <sup>b</sup>
<b>Solar Radiation</b>		**
SR1	19950	12.44±0.06 <sup>b</sup>
SR2	30443	12.30±0.06 <sup>de</sup>
SR3	51949	12.23±0.05 <sup>f</sup>
SR4	51978	12.37±0.05 <sup>c</sup>
SR5	47613	12.26±0.05 <sup>e</sup>
SR6	42184	12.33±0.05 <sup>de</sup>
SR7	36496	12.56±0.06 <sup>a</sup>
SR8	1085	12.36±0.17 <sup>dc</sup>

\*P<0.05; \*\*P<0.01; NS: non-significant

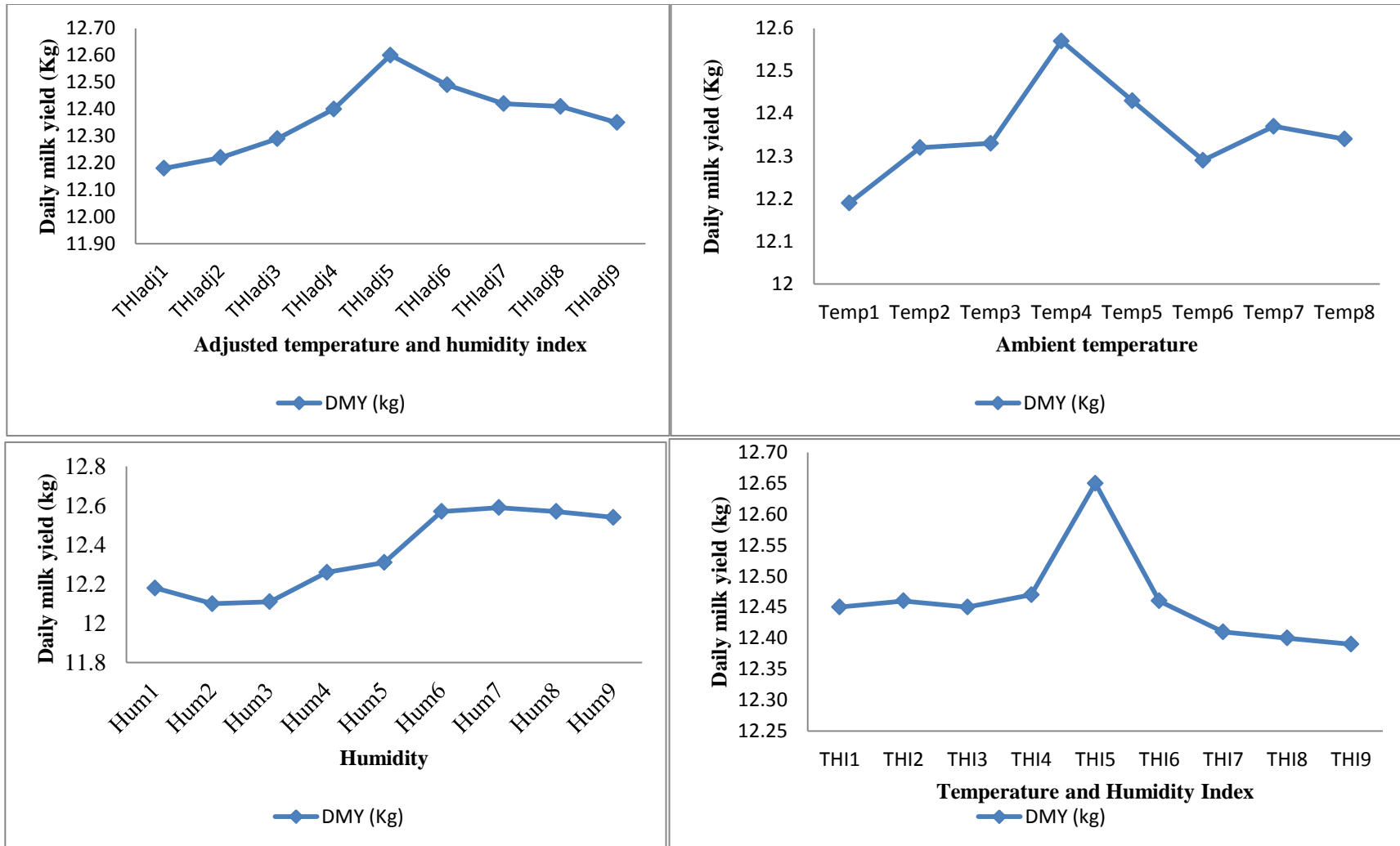
#### 4.18.4.2. Threshold Temp, RH, THI, SR and THIadj for DMY

The results of the study revealed that decrease in the daily milk yield was observed when an increase in Temp >21°C, RH>75%, THI >68 Units, SR > 316 W/m<sup>2</sup> and THIadj exceeded 71 units (table 83-85; Fig. 32). The threshold THI value (68 units) for DMY was observed in the present study was comparable with previous findings reported by various workers. Collier *et al.* (2009) reported that the DMY decreased around 2.2 kg/day when the THI values > 65 to 73. Bouraoui *et al.* (2002) observed a decrease DMY when the THI index exceeded from 68 to 78 for Tunisian dairy cattle whereas Parveen (2017) found a sudden reduction in DMY when THI rose from 63-68 units. However the present finding was higher as compared to reports of Bohmanova *et al.* (2007) who indicated a THI of > 65 as an upper critical THI for lactating cows and Brugemann *et al.* (2012) showed a THI of 60 as an upper critical THI for lactating HF cows. It was but lower as compared to Könyves *et al.* (2017) who reported > 25°C for temperature and >72 for THI as threshold of heat stress. In the present study, daily milk yield was found to be decreasing in short range of THI (>63-68) as compared with THIadj (>66-71).

Linear regression of DMY on different meteorological variables in crossbred cattle is presented in Table 106. The effects of Temp, Temp and SR, THI and THIadj on DMY were found to be significant (P<0.01). DMY declined by 0.07 kg for every 1 °C increase in average air Temp from threshold (21 °C), by 0.054 kg for a unit increase in THI from threshold (68 units) and 0.06 kg for a unit rise in THIadj from threshold (71 units). The reduction in DMY in our study (0.054 kg per a THI unit rise from 68) was lower than previous findings reported by various workers [E.g. Milk Yield decrease per a unit of THI rise was 0.2 kg (Ravagnolo and Misztal, 2000); 0.88

kg West (2003); 0.32 (Ingraham *et al.*, 1979); 0.18 to 0.36 kg (Herbut and Angrecka, 2012); 0.13 kg (Collier *et al.*, 2009); 3.98 kg per a unit rise THI>68-78 (Bouraoui *et al.*, 2002); 4 kg per a unit THI>72 (Falta *et al.*, 2008)]. In line with our finding, Brügemann *et al.* (2012) found milk yield decline by 0.08 kg per a THI unit and by 0.046 kg per a unit THI (Könyves *et al.*, 2017).

The heat stress reduced daily milk yield by 1.32 kg or 9.46%, by 0.92 kg or 9.62% and by 1.27 kg or 9.48% as the THI values went from 64 in the spring, from 66 in the autumn and from 42.34 in the winter periods to 79 in the summer period (Könyves *et al.*, 2017).



**Fig. 32. Relationship of DMY with THIadj, Temp, RH and THI sub classes in crossbred cattle**

Kohli *et al.* 2014 found that high yielding cows shows a significant decrease ( $p < 0.05$ ) in milk yield when THI was above 80 (severe stress zone) in the month of June to October and milk production decrease from an average of  $18 \pm 1.4$  to  $10.9 \pm 0.92$  kg whereas in November-December when THI declines in the zone of comfort the milk yield did not show significant rise.

#### **4.18.4.3. Association of meteorological factors and milk production traits**

The monthly least square means for TLMY, 305\_DMY, LL, DP, and DPY during twenty eight years (1991-2018) and corresponding monthly least square means of meteorological factors and their combinations are presented in Table 86. The highest and lowest monthly least square means for TLMY, 305\_DMY and PY were 4775.20, 4278.90; 4051.46, 3586.93 and 24.21, 20.07 kg, respectively. The highest means for these traits were observed in the month of February whereas the lowest values were found in July. In the month of February, the Temp, RH, THI, SR and THIadj averaged  $15.03$  °C, 73.90%, 58.87 units,  $138.32$  W/m<sup>2</sup> and 60.91 units, respectively whereas the corresponding values in the month of July were  $30.54$  °C, 74.97%, 82.79 units,  $252.20$  W/m<sup>2</sup> and 85.98 units, respectively. High average LL (399.66) was found in the month of April but the average lowest LL was observed in the month of May. In April, the average Temp, RH, THI, SR and THIadj were estimated as  $26.44$  °C, 46.77%, 72.95 unit,  $289.09$  W/m<sup>2</sup> and 76.76 unit, respectively; but for month of May the corresponding values were  $31.19$  °C, 40.44%, 78.02 unit,  $300.87$  W/m<sup>2</sup> 81.1 and 9 unit, in that order. The highest average dry period of HF crossbred cattle was found as 96.06 days in the month of June. In the month of June, the average Temp, RH, THI, SR and THIadj were  $31.98$  °C, 55.01%, 81.39 unit,  $288.34$  W/m<sup>2</sup> and 84.41 unit, in that order. The average lowest dry period (87.75 days), however, was observed in the month of November. The average Temp, RH, THI, SR and THIadj in the month of November were  $19.02$  °C, 64.84%, 64.60 units,  $167.44$  W/m<sup>2</sup> and 68.98 units, correspondingly. The average highest (54.51 days) and lowest (39.40 days) DPY were observed in the months of October and June, respectively. In the month of October, the Temp, RH, THI, SR and THIadj averaged  $24.64$  °C, 64.83%, 72.77 unit,  $210.15$  W/m<sup>2</sup> and 77.43 unit, respectively whereas the corresponding values in the month of June were  $31.98$  °C, 55.01%, 81.39 unit,  $288.34$  W/m<sup>2</sup> and 84.41 unit, in that order. The influences of meteorological factors (Temp, RH, and SR) and their combinations (THI and THIadj) on milk yield traits obtained in the current study were in line the results of Parveen (2017) who found lower and

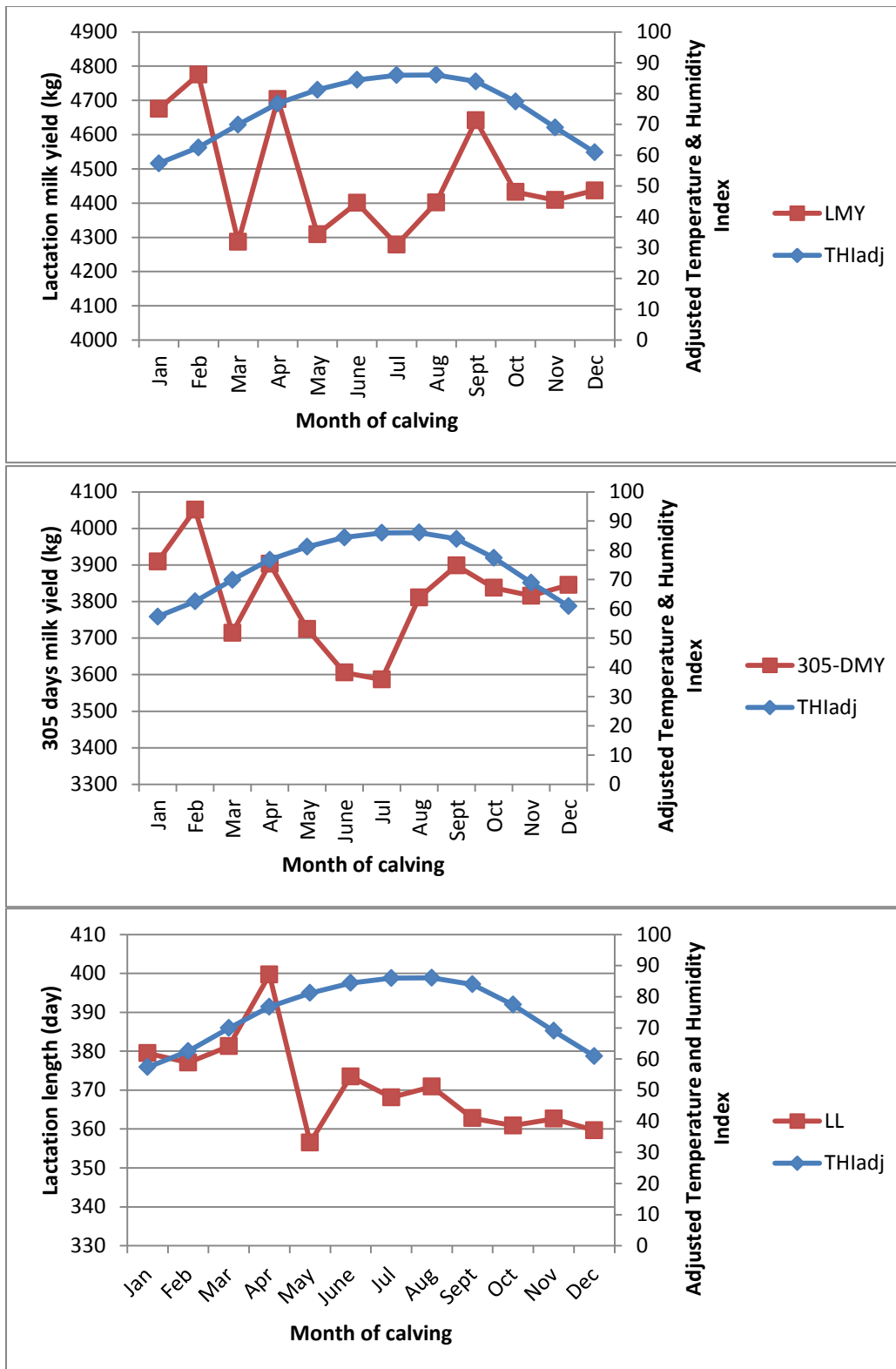
higher 305 days milk yield in the month of July and January, in that order for Sahiwal cows. In contrast to the present finding, the same author reported highest and lowest average LL in the month of February and August, respectively. We can learnt from the study (table 86; Fig. 33-34) that crossbred cows calved in the months with lower average Temp, THI, SR and THIadj and relatively high RH values had consistently higher TLMY, 305\_DMY, PY and DPY until a certain threshold. However the LL was found to be continuously higher for crossbred cows which calved in the month with moderate average Temp, THI, SR and THIadj and low RH values and average DP was observed as continuously higher for crossbred cows calved in the month with high average Temp, THI SR and THIadj and low RH values.

**Table 86. Month wise least squares means of various meteorological factors and milk production traits during the study period (1991-2018)**

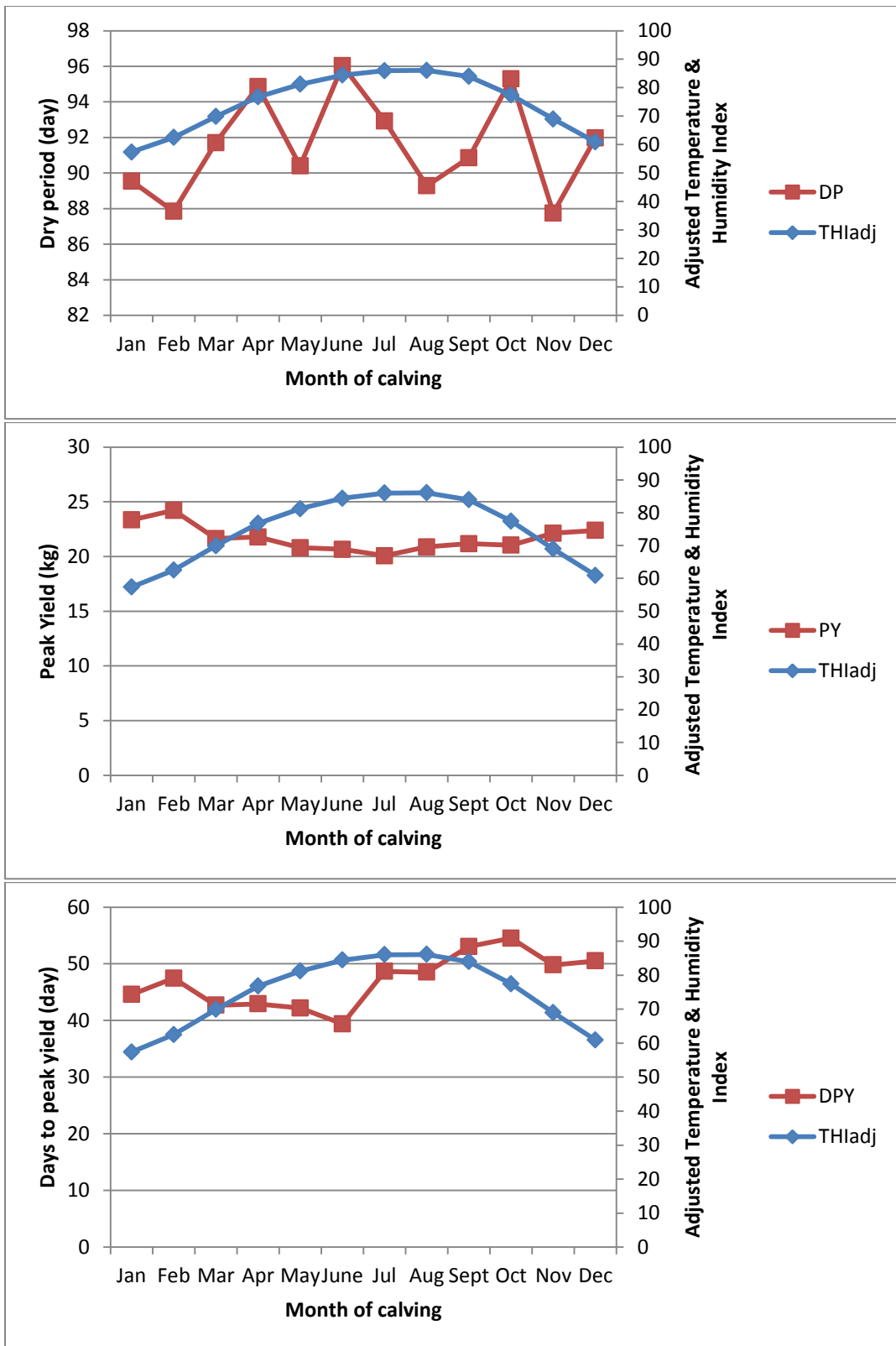
Month	Temp	THI	THIadj	RH	SR	LMY	305_DMY	LL	DP	PY	DPY
Jan	11.84	53.82	57.35	78.32	138.82	4675.08	3909.57	379.45	89.55	23.34	44.58
Feb	15.03	58.87	62.51	73.9	188.15	4775.2	4051.46	377.07	87.85	24.21	47.46
Mar	20	66.05	69.89	66.65	241.6	4286.81	3714.56	381.26	91.71	21.64	42.69
Apr	26.44	72.95	76.76	46.77	289.09	4703.71	3903.38	399.66	94.86	21.78	42.93
May	31.19	78.02	81.19	40.44	300.87	4309.3	3725.28	356.49	90.4	20.8	42.19
June	31.98	81.39	84.41	55.01	288.34	4400.64	3605.75	373.48	96.04	20.65	39.4
Jul	30.54	82.79	85.98	74.97	252.2	4278.9	3586.93	368.13	92.93	20.07	48.67
Aug	29.84	82.25	86.06	78.11	242.54	4401.97	3810.98	370.86	89.28	20.88	48.51
Sep	28.34	79.55	83.94	75.4	244.72	4641.75	3898.49	362.79	90.86	21.17	53.04
Oct	24.64	72.77	77.43	64.83	210.15	4432.64	3837.69	360.88	95.29	21.03	54.51
Nov	19.02	64.6	68.98	64.84	167.44	4408.9	3815.89	362.62	87.75	22.13	49.8
Dec	13.77	56.88	60.91	73.25	135.9	4437.2	3845.16	359.65	91.97	22.39	50.52

#### 4.18.4.4. Effects of meteorological factors on milk production traits

The parameter estimates for the effects of meteorological variables and their combination on milk production traits under various linear and polynomial regression models in crossbred cattle are presented in Table 87-93. The effects of Temp, Temp and SR, THI and THIadj on DMY were found to be significant ( $P < 0.01$ ). DMY declined by 0.07 kg for every 1 °C increase in average air Temp from threshold (21 °C), by 0.054 kg for a unit increase in THI from threshold (68 units) and 0.06 kg for a unit rise in THIadj from threshold (71 units). The effects of Temp, Temp and SR, THI and THIadj on TLMY, 305\_DMY, and DP was found to be non-significant ( $P > 0.05$ ); but significant ( $P < 0.01$ ) on PY. LL and DPY were significantly ( $P < 0.05$ ) influenced by combined effect of Temp and SR; however Temp, THI and THIadj had insignificant ( $P > 0.05$ ) effects on them.



**Fig. 33. Relationship of monthly THIadj and LMY, 305\_DMY and LL over months of calving during the study periods (1991-2018)**



**Fig. 34. Relationship of monthly THIadj and DP, PY and DPY over months of calving in crossbred cattle**

The underlined reasons for insignificant influence seen our study might be the animals were maintained under the loose sheds and proper feeding and watering. Temp, THI and THIadj negatively affected TLMY, 305\_DMY, LL and PY but positively influenced DP, whilst the DPY was negatively influenced by Temp and THI but positively influenced by THIadj. The average TLMY decreased by 8.47, 6.06, and 6.023 kg due to per a unit increase in Temp, THI and THIadj values, respectively, while average 305\_DMY decreased by 8.68, 5.72 and 5.59 kg per a unit increase in Temp, THI and THIadj values, in that order. The average LL also showed a decline by 0.11, 0.11, - 0.13 days for every 1 unit rise Temp, THI and THIadj, correspondingly. A unit rise in Temp, THI and THIadj resulted in an increase in DP by 0.16, 0.102 and 0.10 days, respectively. The average peak yield significantly decreases by 0.13, 0.10 and 0.10 Kg due to rise in Temp, THI and THIadj, in that order. The effects of Temp alone, and THI resulted in a decrease in average DPY by 0.10 days but THIadj resulted in an increase to the average DPY by 0.10 day for per unit increase in them.

The likely reasons for the negative and significant effects of Temp, THI and THIadj DMY and PY could be negative energy balance caused by high energy requirement of milk outputs aggravated by decrease feed intake due to thermal stress. Under feeding during early and mid-lactation will result in excessive mobilization of body reserves and impaired productive and reproductive performance. During early lactation, energy intake lags behind milk energy output a situation that is aggravated during summer when feed intake is also depressed by heat stress. Thus this combined effect of these two suppresses the milk production as well as alters the composition of milk. The energy density of the diet therefore would be of critical importance especially in deciding about the feeding management of high yielding animals through early and mid-stages of lactation during summer season (April to September).

According to polynomial regression analysis (table 87-93), the average TLMY decreased, increased and decreased by 642.43 kg, 30.29 kg and 0.46 kg for 1 °C rise in average ambient temperature; 1680.31 kg, 24.58 kg and 0.12 kg for a unit increase in THI and 1592.11 kg, 21.98 kg and 0.001 kg for a unite increase in THIadj, correspondingly whereas the average 305\_DMY decreased, increased and decreased by 411.48 kg, 19.41 kg and 0.30 kg for 1 °C rise in average ambient temperature; 573.62 kg, 8.22 kg, and 0.04 kg for a unit increase in THI and 361.42 kg , 4.74 kg and 0.02 kg for a unite increase in THIadj, respectively. The average length of lactation

period also decreased, increased and decreased by 19.13 days, 0.96 days and 0.02 days for 1 °C rise in average ambient temperature; 36.47 days, 0.56 days and 0.003 days for a unit increase in THI and 51.55 days, 0.74 days and 0.004 days for a unit increase in THIadj, respectively. By 1.21 kg, 0.05 kg and 0.0006 kg for 1 °C rise in average ambient temperature the average daily pick yield decreased, increased and decreased; but the values of the same trait increased, decreased and increased by 3.04, 0.05 and 0.0003 kg for a unit increase in THI and 4.08, 0.06 and 0.0003 kg for a unit increase in THIadj, in that order. The average length of dry period decreased, increased and decreased by 4.37, 0.23 and 0.004 days for 1 °C rise in average ambient temperature; 23, 0.35 and 0.004 days for a unit increase in THI and 30.17, 0.43 and 0.002 days for a unit increase in THIadj, respectively. Whilst the average number of days to attend pick yield decreased, increased and decreased by 9.42, 0.50 and 0.01 days for 1 °C rise in average ambient temperature but the value of the trait increased, decreased and decreased by 10.88, 0.16 and 0.001 days for a unit increase in THI and 23.01, 0.32 and 0.002 for a unit increase in THIadj, correspondingly.

Similar to these results, Ganesh, 2015 observed that increase in THI resulted decreased in PY. The same author reported that the third degree Polynomial model best fit with regression coefficient  $a= 17.943\pm 0.397$ ,  $b= -4.157\pm 0.519$ ,  $c=1.420\pm 0.193$ ,  $d=-0.167\pm 0.021$  which is useful for prediction of PY at specific given THI (Ganesh, 2015). Temp, THI and THIadj had negative and insignificant influences on TLMY, 305\_DMY, and LL whereas DMY and PY were significantly as well as negatively influenced by Temp, THI and THIadj. The combined effect of Temp and SR on LL and DPY were significant ( $P<0.05$ ). The effects of THI on 305 days milk yield and lactation length under various linear regression models were found to be lower as compared with the report of Parveen (2017). He reported higher decrease per a unit increase in THI from 63-68 units for 305 days milk yields (14.74 kg). In consistence with the present investigation for 305\_DMY, the influence of THI on 305 days milk yield was non-significant in HF X Gir crossbreds (Ganesh, 2015). He also obtained higher increase for lactation length (2 days) due to per a unit increase in THI as compared as the present finding for the same trait. Ganesh (2015) and Chauhan and Ghosh (2017) reported non-significant influences of THI, RH, Sunshine and WS on LL in Deoni cattle in line with the present results for the same trait but Chauhan and Ghosh (2017) observed significant effect of maximum temperature on it. Similar with the present results observed for LMY, Kendall *et al.* (2007) in HF cows and Ganesh

(2015) in the in HF X Gir crossbreds reported that the influence of THI on lactation milk yield was non-significant. However, significant effect of THI on LMY was observed by Maust *et al.* (1972) in HF cows, Kohli *et al.* (2014) in high yielding cattle and Thorat *et al.* (2014) in Deoni cattle and Chauhan and Ghosh (2017). LMY was not significantly influenced by Temp, Sunshine and WS (Chauhan and Ghosh, 2017). Similar with present result, Ganesh (2015) reported the non-significant effect of THI on dry period but in contrary to the present finding, he reported non-significant effect of THI on PY in HF X Gir halfbreds.

**In general**, the effects of Temp, THI and THIadj on PP, DMY and PY are negative and significant; but positive and significant on NSPC. Furthermore, from April to September, it was observed that Temp, THI and THIadj indicated high tendencies to increase beyond the thermal comfort zones ( $\leq 21^{\circ}\text{C}$  for Temp,  $\leq 68$  Units for THI, and  $\leq 71$  units for THIadj) of the cattle. Even though the shed where the animals are kept reduces heat accumulation from solar radiation, there is no effect on reduction of air temperature or relative humidity. Thus these could call up mitigation measures to be taken to combat the negative impacts of thermal stress on dairy crossbred cattle whenever the estimates of these variables go beyond the thermal comfort zone ( $\leq 21^{\circ}\text{C}$  for Temp,  $\leq 68$  Units for THI, and  $\leq 71$  units for THIadj). Integrated heat stress management measures considering cost effective cooling system, balanced diets, free water access and breeding for heat tolerance as one package may be used for lactating cows in early and mid-lactations and pregnant animals to mitigate the negative impacts of heat stress. Upper body sprinkling followed by forced air ventilation (Berman *et al.*, 1985) and evaporative cooling system (Ryan *et al.*, 1992) were found to be effective means to reduce body temperature and improve animal performance. Balanced diets containing high energy feeds along with bypass protein ( $>18\%$  crude protein), vitamins (C, E and A) and mineral such (zinc) could be used from April to September (Amaral-Phillips, 2016).

#### **4.19. Future Climate Scenario and Its Influence on Milk Production**

The minimum annual milk production losses at herd level in Directorate of Livestock Farm (DLF) due to rise of temperature, temperature and humidity index (THI) and adjusted temperature and humidity index (THIadj) from threshold (21 °C for Temp, 68 Units for THI and 71 units for THIadj) which are observed from Apr to Sept, were found to be 1489.25 kg, 1063.75 kg and 1276.50 kg, in that order. The corresponding economic losses in terms of rupees were 81,908.75, 58,506.25 and 70,207.50, respectively. By 2050, the ambient temperature, relative humidity, temperature and humidity index (THI) and adjusted temperature and humidity index (THIadj) may increase by 0.78 °C, 2.19%, 1.23 units and 1.29 units, respectively but the wind speed and solar radiation may decrease by 015 m/s and 28.62 w/m<sup>2</sup>, respectively whereas the milk production losses by the same year due to stresses caused by temperature, temperature and humidity index (THI) and adjusted temperature and humidity index (THIadj) at herd level (155 cows) when increasing beyond the comfort zone may be 44,677.50 kg, 51,615 kg and 31,912.50 kg, correspondingly and the corresponding economic losses in terms of rupees may be 2,457,262.50, 2,838,825 and 1,755,187.50, respectively.

**Table 87. Regression of DMY (kg) on meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b	r <sup>2</sup>	a	b	c	d	r <sup>2</sup>
Temp	14.07±0.04	-0.07±0.03**	33	4.33	1.443±2.02**	-0.075±0.095**	0.0012±0.0014**	0.276
RH	14.26±1.41	-0.03±0.02	16	17.76	-0.20±2.57	0.003±0.04	-1.4×10 <sup>-5</sup>	15.93
Temp & SR	13.85±0.09	b1:0.045±0.002** b2:0.053±0.008**	87					
THI	16.29±0.07	-0.054±0.02**	42	61.85	-2.256±6.390**	0.035±0.094**	-0.0002±0.0005**	0.353
THIadj	16.59±0.08	-0.06±0.02**	43	94.99	-3.601±6.747**	0.053±0.094**	-0.0003±0.0004**	0.418

\*P<0.05; \*\*P<0.01; NS: non-significant

**Table 88. Regression of LMY ( $\pm$ SE) (kg) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b (ns)	r <sup>2</sup>	A	b (ns)	c (ns)	d (ns)	r <sup>2</sup>
Temp	4679.56 $\pm$ 171.30	-8.47 $\pm$ 6.97	13	8831.51	-642.43 $\pm$ 354.40	30.29 $\pm$ 16.75	-0.46 $\pm$ 0.25	38
RH	4321.13 $\pm$ 288.70	2.40 $\pm$ 4.30	3.0	-5200.17	517.31 $\pm$ 481.01	-8.99 $\pm$ 8.14	0.05 $\pm$ 0.04	18.81
Temp & SR	4578.37 $\pm$ 212.40	b1= 0.76 $\pm$ 15.33; b2 =1.63 $\pm$ 1.96	19					
THI	4909.72 $\pm$ 346.47	-6.06 $\pm$ 4.84	14	42476.77	-1680.31 $\pm$ 1272.13	24.58 $\pm$ 18.70	-0.12 $\pm$ 0.09	29
THIadj	4929.60 $\pm$ 369.34	-6.023 $\pm$ 4.91	13	42675.35	-1592.11 $\pm$ 1458.21	21.98 $\pm$ 20.36	-0.001 $\pm$ 0.09	25

\*P<0.05; \*\*P<0.01; NS: non-significant

**Table 89. Regression of 305-DMY ( $\pm$ SE) (kg) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b (ns)	r <sup>2</sup>	a	b (ns)	c (ns)	d (ns)	r <sup>2</sup>
Temp	4013.11 $\pm$ 124.12	-8.68 $\pm$ 5.05	23	6629.27	-411.48 $\pm$ 26719	19.41 $\pm$ 12.62	-0.30 $\pm$ 0.19	41
RH	3627.52 $\pm$ 217.48	2.74 $\pm$ 3.24	6.69	4328.66	-23.51 $\pm$ 390.16	0.27 $\pm$ 6.61	-0.001 $\pm$ 0.04	9.44
Temp & SR	4044.95 $\pm$ 158.62	b1= -5.12 $\pm$ 11.45; b2= 0.51 $\pm$ 1.47	24					
THI	4213.62 $\pm$ 256.06	-5.72 $\pm$ 3.58	20	17132.81	-573.62 $\pm$ 1014.35	8.22 $\pm$ 14.91	-0.04 $\pm$ 0.07	24
THIadj	4226.23 $\pm$ 274.37	-5.59 $\pm$ 3.64	19	13020.2	-361.42 $\pm$ 1145.04	4.74 $\pm$ 14.91	-0.02 $\pm$ 0.07	22

**Table 90. Regression of LL ( $\pm$ SE) (days) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b	r <sup>2</sup>	A	b (ns)	c (ns)	d (ns)	r <sup>2</sup>
Temp	373.48 $\pm$ 12.90	-0.11 $\pm$ 0.52	0.4	491.45	-19.13 $\pm$ 30.54	0.96 $\pm$ 1.44	-0.02 $\pm$ 0.021	7.6
RH	379.21 $\pm$ 20.43	-0.12 $\pm$ 0.30	1.62	-920.04	67.92 $\pm$ 28.38*	-1.15 $\pm$ 0.48*	0.006 $\pm$ 0.003*	42.79
Temp & SR	353.56 $\pm$ 11.88	B1=-2.33 $\pm$ 0.86*; b2=0.32 $\pm$ 0.11	49					
THI	378.79 $\pm$ 26.13	-0.11 $\pm$ 0.37	0.9	1158.85	-36.47 $\pm$ 103.93	0.56 $\pm$ 1.53	-0.003 $\pm$ 0.007	4.4
THIadj	380.47 $\pm$ 27.74	-0.13 $\pm$ 0.30	1	1557.58	-51.55 $\pm$ 115.05	0.74 $\pm$ 1.61	-0.004 $\pm$ 0.007	5.44

**Table 91. Regression of DP ( $\pm$ SE) (days) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b (ns)	r <sup>2</sup>	A	b (ns)	c (ns)	d (ns)	r <sup>2</sup>
Temp	87.71 $\pm$ 2.69	0.16 $\pm$ 0.11	18	115.69	-4.37 $\pm$ 6.29	0.23 $\pm$ 0.30	-0.004 $\pm$ 0.005	26
RH	97.49 $\pm$ 4.34	-0.09 $\pm$ 0.06	16.28	-94.09	9.48 $\pm$ 6.53	-0.15 $\pm$ 0.11	0.09 $\pm$ 0.001	42.87
Temp & SR	86.35 $\pm$ 3.37	b1=0.01 $\pm$ 0.24; b2=0.02 $\pm$ 0.03	22					
THI	84.33 $\pm$ 5.58	0.102 $\pm$ 0.08	15	588.26	-23.00 $\pm$ 20.19	0.35 $\pm$ 0.30	-0.002 $\pm$ 0.001	32
THIadj	88.84 $\pm$ 5.93	0.10 $\pm$ 0.09	15	782.89	-30.17 $\pm$ 21.66	0.43 $\pm$ 0.30	-0.002 $\pm$ 0.001	37

**Table 92. Regression of PY ( $\pm$ SE) (kg) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b	r <sup>2</sup>	A	b	c	D	r <sup>2</sup>
Temp	24.64 $\pm$ 0.81	-0.13 $\pm$ 0.03**	60	32.62	-1.21 $\pm$ 1.88*	0.05 $\pm$ 0.09*	-0.0006 $\pm$ 0.001*	64
RH	19.81 $\pm$ 1.93	0.03 $\pm$ 0.03	8.80	27.93	-0.38 $\pm$ 3.50	0.01 $\pm$ 0.06	-3.6 $\times$ 10 <sup>-5</sup>	9.0
Temp & SR	24.67 $\pm$ 1.04	b1=-0.12 $\pm$ 0.07**; b2=-0.0005 $\pm$ 0.01**	60					
THI	27.73 $\pm$ 1.70	-0.10 $\pm$ 0.024**	56.52	-35.84	3.04 $\pm$ 6.19	-0.05 $\pm$ 0.09	0.0003 $\pm$ 0.0004	65
THIadj	28.16 $\pm$ 1.79	-0.10 $\pm$ 0.02**	57.27	-63.07	4.08 $\pm$ 6.78	-0.06 $\pm$ 0.09	0.0003 $\pm$ 0.0004	66

**Table 93. Regression of DPY ( $\pm$ SE) (days) on different meteorological factors in crossbred cattle**

Model Factors	Parameter estimates of various LRMs			Parameter estimates of various PRMs				
	a	b	r <sup>2</sup>	a	b	c	d	r <sup>2</sup>
Temp	49.06 $\pm$ 4.92	-0.10 $\pm$ 0.20	2	103.38	-9.42 $\pm$ 10.63	0.50 $\pm$ 0.50	-0.01 $\pm$ 0.01	24
RH	33.30 $\pm$ 6.57	0.21 $\pm$ 0.10*	31.06	298.18	-14.03 $\pm$ 10.56	-0.001 $\pm$ 0.001	0.25 $\pm$ 0.18	46.24
Temp & SR	56.76 $\pm$ 4.48	b1=0.77 $\pm$ 0.32*; b2= - 0.12 $\pm$ 0.04	51.0					
THI	47.81 $\pm$ 10.09	-0.011 $\pm$ 0.14	0.06	-197.9	10.88 $\pm$ 40.67	-0.16 $\pm$ 0.60	0.001 $\pm$ 0.003	0.01
THIadj	57.27 $\pm$ 10.73	0.01 $\pm$ 0.14	0.02	-491.28	23.01 $\pm$ 44.68	-0.32 $\pm$ 0.62	0.002 $\pm$ 0.003	3.52

\*P<0.05; \*\*P<0.01; NS: non-significant

## CHAPTER V

### SUMMARY AND CONCLUSIONS

There is a great need to evaluate the performance of Sahiwal and its crosses with Jersey, Holstein Friesian and Red Dane at organized dairy farm (Garima, 2006) along with influences of meteorological factors. Genetic and phenotypic evaluation is important to assess genetic improvement program progress, to make adjustments aiming to optimize genetic gain, and to increase farm profitability in the future (Silva *et al.*, 2001) whereas assessing of the effects of meteorological factors are important for considering the findings of meteorological variables in selection program, recommending the optimum temperature, humidity, solar radiation, THI and THIadj values for optimum milk production, and developing good heat stress management practices.

The present studies were undertaken with **four objectives**: (1) to assess the effect of genetic and non-genetic factors on different production and reproduction traits (2) to analyze the growth and lactation curves across fixed factors (3) to estimate the genetic and phenotypic parameters for performance traits and (4) to establish the relationship of THI with different production and reproduction traits in crossbred cattle. The performance data on crossbred cattle pertaining to growth, reproduction and milk production traits were collected from Dairy Livestock Farm, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana whereas the meteorological data were obtained from School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. The traits considered were growth traits (birth weight (BW0), body weight at 90 days (BW90), body weight at 180 days (BW180), body weight at 270 days (BW270), body weight at 365 days (BW365), body weight at 450 days (BW450), and body weight at 540 days (BW540)), reproduction traits (age at first service (AFS), age at first calving (AFC), weight at first calving (WFC), Number of service per conception (NSPC), pregnancy period (PP), Service period (SP) and calving interval (CI)) and milk production traits (Daily milk yield (DMY), 305 days lactation milk yield (305\_DMY), Total lactation milk yield (LMY), Lactation length (LL), dry period (DP), peak yield (PY), and days to attend peak yield (DPY)), whilst meteorological factors included Temperature (Temp), Relative Humidity (RH), Wind speed (WS), Solar Radiation (SR), Temperature and Humidity Index (THI) and Adjusted Temperature and Humidity

Index (THIadj). The statistical analysis was carried out by classifying the whole performance data into two data sets. Data set one included data of all first lactation performance traits whereas data set two consisted of data of performance traits from all/pooled lactations. Phenotypic data of both first and all lactation performance traits were analyzed using Multi-traits General Linear Model (MTGLM) Procedure of SAS version 9.3 (SAS institute Inc. 2011. Cary, NC, USA) to estimate the effects of fixed and random factors; though the model components differed from traits to traits. Restricted Maximum Likelihood (REML) under Univariate Mixed Model Equation (UMME) for first lactation performance traits and univariate repeatability model (URM) with REML for data of performance traits from all lactations was involved to estimate genetic and phenotypic parameters for each trait. Mixed model equation (MME) (back solution) were used to estimate genetic trends whereas Least Square Method (Harvey, 1990), REML (Meyer, 1998) and MIVQUE0 were applied to estimate genetic merits of the sires. The non-linear (NLIN) procedure of SAS was used to fit non-linear models to average lactation and growth curves. Both simple linear and polynomial regression models were fitted to analyze the association of performance data with meteorological data.

The overall least square means for BW0, BW90, BW180, BW270, BW365, BW450, BW540, AFS, AFC, WFC, FLNSPC, FLPP, FLSP, FCI, FL305\_DMY, FLMY, FLL, FLDP, FLPY and FLDPY were 29.40±0.18 kg, 59.42±0.45 kg, 102.77±0.76 kg, 146.80±1.17 kg, 195.49±1.44 kg, 243.88±1.49 kg, 291.57±1.57 kg, 712.05±9.24 days, 1008.01±9.52 days, 404.55±2.09 kg, 2.34±0.06 no., 276.96±0.27 days, 177.52±5.18 days, 454.21±5.22 days, 4323.53±73.83 kg, 3646.92±48.38 kg, 370.74±4.41 days, 93.32±1.53 days, 20.70±0.29 kg and 47.49±1.15 days, , respectively, whilst ALNSPC, ALPP, ALSP, ALCI, AL305\_DMY, ALMY, ALL, ALDP, ALPY and ALDPY were averaged as 2.37±0.04 no., 276.98±0.18 days, 173.91±3.17 days, 451.44±3.24 days, 4478.64±47.99 kg, 3813.69±32.43 kg, 370.12±2.91 days, 91.36±0.97 days, 21.72±0.20 kg and 47.48±0.74 days, in that order.

The influences of season of birth on BW0, BW270, BW365, BW450, and BW540 were found to be highly significant (P<0.01) but significant (P<0.05) for BW90. Average BW0, BW270, BW365, BW450, and BW540 varied highly and significantly (P<0.01) across periods of birth. Average BW270 and BW90 were also significantly influenced by period of birth at (P<0.05). Genetic group exerted

significant ( $P < 0.01$ ) influences only on BW180. Highly significant ( $P < 0.01$ ) influences of sire on all growth traits were found. Season of birth exerted highly significant ( $P < 0.01$ ) influences on WFC but it did not have significant influences on AFS and AFC. Period of birth had highly significant ( $P < 0.01$ ) influences on AFS, and AFC but its effect on WFC was observed to be non-significant ( $P > 0.05$ ). Insignificant ( $P > 0.05$ ) differences were seen among crossbred cows for AFS, AFC and WFC across genetic groups. Highly significant ( $P < 0.01$ ) influences of sire on AFS, AFC and WFC were found. Except for FLPP, period of birth did not significantly influence FLNSPC, FLSP and FCI. There were no significant variations among crossbred cows for FLNSPC, FLPP, FLSP and FCI over season of calving. Significant ( $P < 0.05$ ) effects of period of calving were observed on FLNSPC, FLSP and FCI but average FLPP did not vary significantly ( $P > 0.05$ ) among crossbred cows over period of calving. Genetic group had significant ( $P < 0.05$ ) and highly significant ( $P < 0.01$ ) effects on FLNSPC and FLPP, in that order. However it had insignificant influences on FLSP and FCI. Average FLPP, FLSP and FCI were significantly ( $P < 0.05$ ) affected by sire but non-significant effect of sire was found on FLNSPC.

The effects of period of birth was significant ( $P < 0.05$ ) only on FLDP. Only FLDPY was significantly affected by season of calving out of all first lactation milk production traits. Period of calving was found to have significant ( $P < 0.05$ ) effects on FLMY, FL305\_DMY and FLL in the crossbred cattle. Genetic groups had highly significant influences ( $P < 0.01$ ) on FLMY, and FL305\_DMY and significant one ( $P < 0.05$ ) FLPY; but its influences were insignificant ( $P > 0.05$ ) on FLL, FLDP, and FLDPY. FLMY and FL305\_DMY was highly significantly ( $p < 0.01$ ) influenced by sire but no significant influence of the sire on FLL, FLDP, FLPY and FLDPY. Age at calving was able to constitute significant ( $P < 0.05$ ) sources of variation in FLDP and FLPY but not in FLMY, 305\_DMY, FLL, and FLDPY. FLMY, FL305\_DMY, FLDP and FLPY were significantly ( $P < 0.05$ ) influenced by WAC. However there were no significant influences of WAC on FLL and FLDPY.

The effects of period of birth on ALSP and ALCI were found to be significant ( $P < 0.05$ ) and highly significant ( $P < 0.01$ ), correspondingly but non-significant ( $P > 0.05$ ) on ALNSPC and ALPP. Season of calving did not significantly ( $P > 0.05$ ) influenced ALNSPC, ALSP, ALPP and ALCI. The period of calving significantly ( $p < 0.05$ ) influenced the ALNSPC and ALSP in crossbred cattle but it did have insignificant influence on ALPP and ALCI. The random influences of sire were

highly significant ( $P < 0.01$ ) on ALPP and ALCI, significant on ALSP but non-significant on ALNSPC. Age at calving exerted highly significant ( $P < 0.01$ ) influences on ALNSPC and ALCI; but significant ( $P < 0.05$ ) and non-significant influences of the same factor were found on ALPP and ALSP, respectively. The effects of WAC on ALNSPC, ALSP and ALCI were found to be highly significant ( $P < 0.01$ ) but ALPP was not significantly ( $p > 0.05$ ) influenced by WFC.

The influence of period of birth were found to be highly significant ( $P < 0.01$ ) on ALMY, AL305\_DMY and ALPY but significant for ALL. Season of calving exerted highly significant influences on ALPY and ALDPY; however the effects of SOC on ALMY, AL305\_DMY, ALL, and ALDP were non-significant ( $P > 0.05$ ). Period of calving highly and significantly ( $p < 0.01$ ) influenced ALDPY in the crossbred cattle. However insignificant ( $P > 0.05$ ) influences of POC were found on ALMY, AL305\_DMY, ALL, ALDP and ALPY. ALMY and AL305\_DMY varied highly and significantly ( $p < 0.01$ ) among crossbred cows across the different genetic groups. However ALPY varied only significantly ( $p < 0.05$ ). ALL, ALDP, and ALDPY were not significantly ( $p > 0.05$ ) influenced by the genetic group. Sires had highly significant ( $P < 0.01$ ) influences on all milk production traits from all lactation except ALDP. ALMY, AL305\_DMY and ALPY were highly and significantly ( $P < 0.01$ ) affected by age at calving but effects of AAC was non-significant ( $P > 0.05$ ) on ALL, ALDP and ALDPY. The influences of WAC on AL305\_DMY and ALPY were highly significant ( $P < 0.01$ ) but on ALDPY, it was significant ( $P < 0.05$ ). ALMY, ALL, and ALDP were not significantly ( $P > 0.05$ ) influenced by WAC.

The heritability estimates of crossbred cattle for growth traits were intermediate to high with reasonably low to intermediate standard errors, whereas they were very low to intermediate with relatively low to intermediate high standard errors for first lactation reproduction traits. In other hands, the the heritability estimates for first lactation milk production traits were low to intermediate high with reasonably low to intermediate high standard error estimates. The overall heritability values for BW0, BW365, BW540, WFC, AFC, FLPP, FLSP, FCI, FLMY, FL305\_DMY and FLL were  $0.37 \pm 0.11$ ,  $0.58 \pm 0.09$ ,  $0.56 \pm 0.09$ ,  $0.45 \pm 0.10$ ,  $0.37 \pm 0.11$ ,  $0.13 \pm 0.13$ ,  $0.28 \pm 0.13$ ,  $0.28 \pm 0.13$ ,  $0.35 \pm 0.12$ ,  $0.40 \pm 0.10$ , and  $0.17 \pm 0.13$ , respectively. The heritability estimates of crossbred cattle for reproduction traits from all lactation were in general very low to low but low to intermediate for all lactation milk production traits with reasonable low to intermeadiate standard errors. The

intermediate to high heritability values observed for growth traits indicated that there are good additive genetic variances in all growth traits which can give high opportunities to the breeder for undertaking genetic improvement through individual selection.

The estimates of repeatability of crossbred cows for all lactation milk production and reproduction traits are in general low to intermediate. The repeatability estimates for ALMY, AL305\_DMY, ALPY, ALSP and ALCI were estimated as 0.30, 0.28, 0.16, 0.22 and 0.23, correspondingly. The moderate repeatability estimates observed for ALMY, AL305\_DMY, ALSP and ALCI indicated that selection of dairy cattle for the traits based on early performance records is reliable.

The genetic correlations among BW270 and BW365, BW270 and BW450, BW365 and BW450, BW365 and BW540, BW450 and BW540, FCI and FLSP and FL305\_DMY and FLMY were positive, higher and significant while the genetic correlations among BW0 and BW450, BW270 and BW540, WFC and FLDPY, FLMY and FLPY and FL305\_DMY and FLPY were positive, intermediate and significant. When using data of all available lactations, the genetic correlation between ALSP and ALCI, ALMY and AL305\_DMY, ALMY and ALL, ALMY and ALPY and AL305\_DMY and ALPY were positive, high and significant whereas the genetic correlation between ALCI and ALPY, AL305\_DMY and ALL and ALL and ALPY were positive, intermediate and significant. Low, negative and significant correlation were observed in ALSP and ALL, and ALSP and ALPY. The positive and strong genetic correlations observed in the present study indicate the evidence of common genetic and physiological mechanisms controlling those traits which in turn indicates that improvement of one trait has positive impact on the other trait.

The estimates of genetic trends for growth traits varied from  $-0.08 \pm 0.10$  kg/yr (BW365) to  $1.36 \pm 0.23$  kg per year (WFC). The trends were negative for all growth traits except BW180 and WFC, which might be actually expectable for dairy animals which were subjected for subsequent selection for improvement of milk production. The estimates of genetic trends for reproduction traits varied from  $-0.49 \pm 0.49$  days/yr (AFC) to 0 days per year (NSPC). The trends were negative for all reproductive traits except NSPC. In general, there was an annual genetic decline of  $0.68 \pm 2.91$  kg,  $0.89 \pm 1.94$  kg,  $0.12 \pm 0.05$  days and  $0.002 \pm 0.01$  kg in LMY, 305\_DMY, DP and PY, respectively, but LL and DPY increased by  $0.02 \pm 0.07$  days and  $0.003 \pm 0.01$  days, in

that order (table 1; Fig. 1-6). The estimates of phenotypic trends were very close to the environmental trends (Fig. 2-7), implying that the major variation in phenotypic values of milk production traits may be caused by the environment. The low and negative genetic trends observed on LMY, 305\_DMY and PY traits might be due to the aid of selection (phenotypic selection) used to select replacement heifers and sires or less genetic variation within the herd which might in turn be small herd size (inbreeding) and breeding system practiced (upgrading type crossbreeding). The selection criteria, the type and method of selection should be reconsidered and new breed should be introduced in the herd to increase genetic variance.

The result revealed that sire number 26 for ALL and ALMY and 43 for AL305\_DMY had the highest merit computed by LSM, REML and MIVQUE0. The results of the present investigation revealed that REML and MIVQUE0 are considered to be the good methods with no genetic variation between them and good precision estimates for ranking sires based on both first and pooled lactation traits. There were changes in the rank of first few top sires by different methods of sire evaluation. In ranking of sires for selected growth and reproduction traits, LSM would be considered as an option next to REML and MIVQUE0.

The Polynomial regression model gave highest fit to the daily milk yield data of crossbred cattle with  $R^2$ , MSE, AIC and CV values of 98.10%, 0.08, -743.31 and 2.37 %, respectively. The Inverse Polynomial Model have also best fitted the observed daily milk yield data with predicted daily milk yield data with highest  $R^2$  (98.05%), lower MSE (0.089), low AIC (-735.90) and lower CV (2.40%) values. The fitting of observed daily milk yield data with predicted ones were also found to be higher in the Mixed Log Function, and Gamma-Type Function. The  $R^2$ , MSE, AIC and CV estimates observed for Mixed Log Function and Gamma-Type Function were 96.46%, 0.16, -558.16 and 3.21%; 95.85%, 0.190,-505.24 and 3.50%, respectively. However IPM and GTF are chosen with corresponding developed equations for predicting daily milk production from calving to 305 days in milk of crossbred cattle managed under DLF of GADVASU because IPM and GTF curves were standard typical curves for the cattle. The Quadratic model gave highest fit to the weight-age data of crossbred cattle with  $R^2$ , MSE, AIC and CV values of 100%, 0.000011, -144.52 and 0.002%, respectively. The Gompertz model have also best fitted the observed weight-age data with predicted weight-age data with highest  $R^2$  (100%), lower MSE (6.88), low AIC (24.96) and lower CV (1.83) values. The fitting of

observed weight-age data with predicted ones were also found to be higher in the Cubic (Fig. 18), Logistic Richard (Fig. 20) and Von Bertalanffy models. Four models with namely Quadratic, Gompertz, Cubic and Logistics are selected for estimating later live weight from early age live weight between births to 1008 days.

The results indicated that crossbred cows born in the months with low to moderate average Temp, SR, THI, and THIadj and relatively low RH values had high body weights for all growth traits considered in this study. Temp, THI and THIadj had negative and insignificant influences on all growth traits. The combined effect of Temp and SR on BW365, BW450 and BW540 were significant ( $P < 0.05$ ); however BW90, BW180 and BW270 were not significantly influenced by the combined effects of Temp and SR. The effects of Temp, THI and THIadj on AFS, AFC and WFC were found to be non-significant ( $P > 0.05$ ). Temp, THI and THIadj negatively affected WFC; but positively influenced AFS and AFC traits. The average AFS increased by  $0.76 \pm 1.17$ ,  $0.61 \pm 0.81$  and  $0.58 \pm 0.82$  days due to per a unit increase in Temp, THI and THIadj values, respectively, while average AFC increased by  $0.59 \pm 1.0$ ,  $0.45 \pm 0.7$  and  $0.43 \pm 0.71$  days per a unit increase in Temp, THI and THIadj values, in that order, whilst the average WFC showed a decline by  $-0.11 \pm 0.34$ ,  $-0.03 \pm 0.24$  and  $-0.003 \pm 0.24$  kg for every 1 unit rise Temp, THI and THIadj, correspondingly.

The effects of Temp, THI and THIadj on NSPC and PP were found to be negative and significant ( $P > 0.05$ ); however SP and CI were not significantly ( $P > 0.05$ ) influenced by Temp, THI and THIadj. The average SP showed an increase by  $0.64 \pm 0.46$ ,  $0.44 \pm 0.32$  and  $0.42 \pm 0.33$  days for every 1 unit rise Temp, THI and THIadj, correspondingly. A unit rise in Temp, THI and THIadj resulted in an increase by  $0.66 \pm 0.38$ ,  $0.46 \pm 0.26$  and  $0.46 \pm 0.27$  days for CI, in that order; but average PP decreased by  $0 - 0.14 \pm 0.04$ ,  $- 0.10 \pm 0.03$ , and  $- 0.10 \pm 0.03$  days per a unit increase in Temp, THI and THIadj values, in that order.

The effects of month of calving, period of calving, THI, THIadj, Temp, RH and SR on DMY were found to be highly significant ( $P < 0.01$ ). The results of the study revealed that sudden decrease in the daily milk yield was observed when an increase in Temp  $> 21$  °C, THI  $> 68$  Units and THIadj exceeded 71 units. DMY declined by 0.07 kg for every 1 °C increase in average air Temp from threshold (21 °C), by 0.054 kg for a unit increase in THI from threshold (68 units) and 0.06 kg for a unit rise in THIadj from threshold (71 units); however the effects of Temp, Temp and SR, THI and THIadj on LMY, 305\_DMY, and DP was found to be non-significant

( $P > 0.05$ ); but significant ( $P < 0.01$ ) on PY. LL and DPY were significantly ( $P < 0.05$ ) influenced by combined effect of Temp and SR; however Temp, THI and THIadj had insignificant ( $P > 0.05$ ) effects on them. The average 305\_DMY decreased by 8.68, 5.72 and 5.59 kg per a unit increase in Temp, THI and THIadj values, in that order whereas The average peak yield decrease by 0.13, 0.10 and 0.10 Kg due to rise in Temp, THI and THIadj, in that order. By 2050, the Temp, RH, THI and THIadj may increase to 0.78 °C, 2.19%, 1.23 units and 1.29 units, respectively but the WS and SR may decrease by 0.15 m/s and 28.62 w/m<sup>2</sup>, respectively.

**The following conclusions were drawn from the study**

1. The milk production efficiency of crossbred dairy cattle is within the range of the standard records; however the reproduction efficiency is fair.
2. Season of birth significantly influenced all growth traits except BW180 but it had no significant influences on AFS and AFC.
3. The influences of period of birth on all growth traits except BW180 and WFC and on AFS, AFC, FLPP, FLDP, ALSP, ALCI, AL305\_DMY, ALMY and ALPY were found to be significant.
4. All milk production and reproduction traits under the study except FLDPY, ALPY and ALDPY were not significantly influenced by season of calving.
5. Period of calving had significant influences on FLNSPC, FLSP, FCI, FLMY, FL305\_DMY, FLL, ALNSPC, ALSP and ALDPY.
6. Genetic groups exerted significant influences on BW180, FLNSPC, FLPP, FL305\_DMY, FLMY, FLPY, AL305\_DMY, ALMY and ALPY.
7. The random influences of sire on all growth traits, many reproduction traits (AFS, AFC, FLPP, FLSP, FCI, ALPP, ALSP, and ALCI) and some milk production traits (FL305\_DMY, FLMY, AL305-DMY, ALMY, ALL, ALPY and ALDPY) were observed to be significant.
8. FLDP, FLPY, ANSPC, ALCI, AL305\_DMY, ALMY and ALPY were significantly affected by age at calving.
9. Body weight at calving significantly influenced FL305\_DMY, FLMY, FLDP, FLPY, ALNSPC, ALSP, ALCI, AL305\_DMY, ALPY and ALDPY.
10. The heritability estimates of crossbred cattle for growth traits were intermediate to high whereas the heritability of first lactation reproduction and milk production traits ranged from low to intermediate.

11. The heritability estimates of crossbred cattle for reproduction traits from all lactation were low but low to intermediate for all lactation milk production traits. The high heritability observed for BW365, BW540, and WFC and intermediate heritability for FLMY, FL305\_DMY, ALMY and AL305\_DMY indicated that there are good additive genetic variances which can give opportunities to the breeder for undertaking genetic improvement through mass selection/combined with family or pedigree selection.
12. The genetic correlation of AFC with growth traits was negative and low to high.
13. The low and static genetic trends observed on LMY, 305\_DMY, and PY might be due to the aid of selection (phenotypic selection) used to select replacement heifers and sires or less genetic variation within the herd which might in turn be small herd size (inbreeding) and breeding system practiced (upgrading type crossbreeding).
14. Both REML and MIVQUE0 methods could be considered as good methods for ranking of sires for milk production traits with high efficiency. In ranking of sires for selected growth and reproduction traits, LSM would be considered as an option next to REML and MIVQUE0.
15. The Quadratic and Gompertz models followed by Cubic and Logistic models gave best fit and reliable description to the growth curve characteristics of crossbred dairy cattle.
16. PRM model and IPM models followed by MLF and GTF showed best fit and reliable description to the average lactation curve pattern and characteristics of crossbred dairy cattle.
17. Temp, THI and THIadj had negative and insignificant influences on all growth traits but positively influenced AFS and AFC traits.
18. The influences of Temp, THI and THIadj on NSPC and PP were found to be negative and significant ( $P>0.05$ ) but positive and non-significant on SP and CI.
19. The effects of Temp, Temp and SR, THI and THIadj on TLMY, 305\_DMY, and LL was found to be negative and non-significant ( $P>0.05$ ); but significant ( $P<0.01$ ) on PY and DMY.
20. The milk productions are susceptible to the negative impacts of heat stress when Temp, THI and THIadj are  $> 21$  °C, 68 Units and 71 units, respectively.

21. From April to September, climate variables increased beyond the thermal comfort zones (<21 °C for Temp, <75% for RH, <68 Units for THI, <316 w/m<sup>2</sup> for SR and <71 units for THIadj).
22. The underlined reasons for insignificant influences meteorological factors on all performance traits except DMY, PY, NSPC, and PP observed in our study might be the animals were maintained under the loose sheds and proper feeding and watering management.
23. Both THI and THIadj are useful and practical tools to measure the level of heat stress in crossbred dairy cattle.

### **5.1. Recommendations**

1. Period of calving, genetic group, weight at calving and age at calving should be considered under the herd management practices.
2. Individual selection could be used for improving all the growth traits except BW0 and BW270, whereas FL305\_DMY, FLMY, AL305\_DMY and ALMY may be improved viz mass selection approach along with pedigree or progeny selection. However improvement of reproduction traits should rely on good husbandry management than genetic approach.
3. Estimated breeding value as prior selection criteria and selection index as method of selection should be used to select replacement heifers and AI bulls so as to improve the genetic progress for milk yield traits (305\_DMY, TLMY and PY). New germplasm may also be introduced in the herd to increase the genetic variability and thereby the genetic gain.
4. Sire selection should be kept on giving higher attention as its effects in almost all performance traits are highly significant.
5. REML and MIVQUE0 methods could be considered as good methods for ranking of sires for milk production traits with high efficiency. In ranking of sires for growth and reproduction traits, LSM would be considered as an option next to REML and MIVQUE0.
6. Lactation and growth curves may be considered as criteria for selection.
7. Integrated heat stress management measures considering cost effective cooling system, balanced diets, free water access and breeding for heat tolerance as one package may be used for pregnant animals and lactating cows in early and mid-lactations to mitigate the heat stress from April to September.

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## ANNEXTURES

**Annex-table 1. Analysis of variance of different growth traits in crossbred cattle**

Sources of variance	DF	MSS Values						
		BW0	BW90	BW180	BW270	BW365	BW450	BW540
Season of birth	4	59.53**	207.96*	490.69 <sup>ns</sup>	3873.58**	3446.31**	1691.65**	1589.08**
Period of birth	7	14.84**	205.42*	212.88 <sup>ns</sup>	1168.78*	2984.48**	4114.38**	3485.73**
Genetic groups	3	11.29 <sup>ns</sup>	69.45 <sup>ns</sup>	700.28**	1160.80 <sup>ns</sup>	998.19 <sup>ns</sup>	1742.79 <sup>ns</sup>	1317.82 <sup>ns</sup>
Sire	124	31.74**	186.39**	520.17**	933.19**	1530.06**	1622.81**	1819.47**
Residual errors		20.01 (626)	114.74 (622)	339.95 (613)	683.08 (613)	888.01 (612)	922.83 (611)	1057.74 (611)

\*P<0.05; \*\*P<0.01; Numbers in the parenthesis is degree of freedom for residual errors

**Annex-table 2. Analysis of variance for different first lactation reproductive traits in crossbred cattle (AFS, AFC and WFC)**

Source of Variance	DF	MSS values		
		AFS	AFC	WFC
Season of birth	4	33291.82 <sup>ns</sup>	24151.67 <sup>ns</sup>	7529.67**
Period of birth	7	400484.73**	379219.50**	2012.26*
Genetic group	3	42174.36 <sup>ns</sup>	38917.03 <sup>ns</sup>	1956.09 <sup>ns</sup>
Sire	122	59572.21**	68303.13**	3390.10**
Residual error	613	39714.85	44344.97	2246.55

\*P<0.05; \*\*P<0.01; ns: Non-significant; Numbers in the parenthesis is degree of freedom for residual error

**Annex-table 3. Analysis of variance for various first lactation reproductive traits in crossbred cattle (FLNSPC, FLPP, FLSP and FLCI)**

Source of Variance	DF	MSS Values			
		FLNSPC	FLPP	FLSP	FCI
Period of birth	7	3.27	168.95**	20749.16 <sup>ns</sup>	21078.57 <sup>ns</sup>
Season of calving	4	0.77 <sup>ns</sup>	62.80 <sup>ns</sup>	15831.74 <sup>ns</sup>	15706.05 <sup>ns</sup>
Period of calving	6	6.75*	23.68 <sup>ns</sup>	29995.28*	29230.38*
Genetic group	3	7.02*	210.84**	10016.98 <sup>ns</sup>	9612.64 <sup>ns</sup>
Sire	110	2.99 <sup>ns</sup>	62.53*	16911.81*	17029.84*
Residual error (DF)		2.57 (619)	51.06 (619)	12715.97 (395)	12908.51 (395)

\*P<0.05; \*\*P<0.01; ns= non-significant; Numbers in the parenthesis is degree of freedom for residual error

**Annex-table 4. Analysis of variances for different reproductive traits considering all lactation in crossbred cattle**

Source of Variance	DF	MSS Values			
		ALNSPC	ALPP	ALSP	ALCI
Period of birth	7	2.84 <sup>ns</sup>	64.40 <sup>ns</sup>	20892.96*	32724.80**
Season of calving	4	0.91 <sup>ns</sup>	44.50 <sup>ns</sup>	9345.31 <sup>ns</sup>	9184.09 <sup>ns</sup>
Period of calving	6	5.06*	46.66 <sup>ns</sup>	27267.96*	16260.12 <sup>ns</sup>
Genetic group	3	16.93**	321.20**	2365.19 <sup>ns</sup>	14133.34 <sup>ns</sup>
Sire	124	2.62 <sup>ns</sup>	81.47**	14695.92*	18551.27**
Age at calving	9	16.26**	78.29 <sup>ns</sup>	22361.98*	32023.83**
Weight at calving	8	12.15**	39.38 <sup>ns</sup>	33952.18**	34978.96**
Residual error		2.35 (1573)	52.14 (1573)	11712.64 (1094)	12068.63 (1094)

\*P<0.05; \*\*P<0.01; ns= non-significant; Numbers in the parenthesis are degree of freedom for residual error

**Annex-table 5. Analysis of variance of various first lactation milk production traits in crossbred cattle**

Source of Variance	DF	MSS Values					
		FLMY	FL305_DMY	FLL	FLDP	FLPY	FLDPY
Period of birth	7	1826585.7 <sup>ns</sup>	875062.9 <sup>ns</sup>	8278.09 <sup>ns</sup>	3251.0091*	42.734661 <sup>ns</sup>	483.77 <sup>ns</sup>
Season of calving	4	921129.4 <sup>ns</sup>	376990.4 <sup>ns</sup>	4524.53 <sup>ns</sup>	1011.18 <sup>ns</sup>	38.84 <sup>ns</sup>	2353.78*
Period of calving	6	3904989.8*	2101443.8*	16346.69*	1562.82 <sup>ns</sup>	89.78 <sup>ns</sup>	1448.92 <sup>ns</sup>
Genetic group	3	14484242.8**	9094166.0**	7653.80 <sup>ns</sup>	966.94 <sup>ns</sup>	130.25*	111.96 <sup>ns</sup>
Sire	121	4808129.1**	2014277.7**	16269.57 <sup>ns</sup>	1598.25 <sup>ns</sup>	52.15 <sup>ns</sup>	972.71 <sup>ns</sup>
Age at calving	5	2973922.1 <sup>ns</sup>	781854.3 <sup>ns</sup>	12114.72 <sup>ns</sup>	5109.36**	123.535362*	737.86 <sup>ns</sup>
Weight at calving	8	5321902.6*	2555942.0*	18967.68 <sup>ns</sup>	2436.48*	85.25*	1171.06 <sup>ns</sup>
Residual error	595	3148923	1252357	13756.37 <sup>ns</sup>	1609.84	55.68	901.45

\*P<0.05; \*\*P<0.01; ns= non-significant; Numbers in the parenthesis are degree of freedom for residual error

**Annex-table 6. Analysis of variances for different milk production traits from all lactations in crossbred cattle**

Source of Variance	DF	MSS Values					
		ALMY	AL305_DMY	ALL	ALDP	ALPY	ALDPY
Period of birth	7	11810596.30**	5053285.90**	27719.15*	2296.61ns	184.46**	667.14ns
Season of calving	4	3324964.50ns	1213136.10ns	19002.88ns	1742.87ns	196.05**	2580.14**
Period of calving	6	2066427.70ns	1834606.00ns	10977.41ns	1685.50ns	9.63ns	1455.67**
Genetic group	3	15998543.00**	7549728.90**	22561.66ns	623.59ns	167.88*	570.23ns
Sire	124	5616536.60**	2463651.10**	19919.32**	1782.95ns	77.22**	1073.08**
Age at calving	9	24813094.70**	16835593.30**	9785.17ns	1894.83ns	488.62**	750.74ns
Weight at Calving	8	4851391.10ns	3601484.60**	3029.83ns	2008.31ns	125.68*	1537.12*
Residual error	1573	3123640	1327594	14053.20	1555.66	58.28	820.00

\*P<0.05; \*\*P<0.01; ns= non-significant; Numbers in the parenthesis are number of observations

**Annex-table 7. Analysis of variance for meteorological factors**

Source of Variance	DF	MSS Values					
		Temp	RH	THI	WS	SR	THIadj
Month	11	83.84**	2000.79**	165.28**	2.30**	40993.66**	192.64**
Year	33	55125.36**	153397.46**	112819.08**	159.56**	3319737.75**	110582.07**
Residual errors	12397	5.93	102.50	10.88	0.37	2124.19	11.96

\*\*P<0.01

**Annex-table 8. Analysis of Variance for DMY of crossbred cattle (THI in the model)**

Source of Variance	DF	MSS Values
Month of calving	11	12019.72**
Period of calving	6	281357.00**
THI	8	269.30**
Residual	281672	26.75

\*P<0.05; \*\*P<0.01

**Annex-table 9. Analysis of variance for DMY of crossbred cattle (THIadj in the model)**

Source of Variance	DF	MSS values
Month of calving	11	11650.77**
Period of calving	6	281628.58**
THIadj	8	205.96**
Residual	281672	26.76

\*P<0.05; \*\*P<0.01

**Annex-table 10. Analysis of variance for DMY of crossbred cattle (Temp, RH & SR in the model)**

Sources of variance	DF	MSS Values
Month of calving	11	8451.78**
Period of calving	6	272472.91**
Temperature	7	288.06**
Humidity	8	391.98**
Solar Radiation	7	330.34**
Error	281658	26.74

\*P<0.05; \*\*P<0.01

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