Associations of Milk Yield, Lameness, and Digital Dermatitis with Claw and Foot Traits in Holstein Dairy Cows

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SUMMARY

This study investigated the effects of lameness, milk yield, and digital dermatitis (DD) on claw and foot traits in Holstein dairy cows, with a focus on traits measured from the heel region. A total of 184 lactating cows from a single herd were categorized by DD status (DD+ or DD-) and, lameness score (LS), and milk yield. The results showed that cows with DD, particularly those with low milk yield, had significantly higher heel width and oblique heel length compared to high milk yield cows. In contrast, high milk yield cows without DD had higher axial heel height and heel angle measurements, indicating that high productivity independently contributes to claw stress. Furthermore, significant differences in pastern width were observed between low and high milk yield cows in DD+ groups, with low milk yield cows exhibiting more pronounced foot alterations. Lameness further exacerbated claw deformities, particularly in high milk yield cows with mild lameness (LS1). These findings emphasize the complex interplay between milk yield, DD, and lameness in influencing claw and foot traits, highlighting the need for early intervention and management strategies to prevent claw disorders and improve herd performance. The results also suggest that DD and lameness affect claw morphology differently depending on the productivity level of the cow, and that even mild lameness may lead to structural changes in claw traits. The significant alterations observed in heel region measurements suggest that this area may be a sensitive indicator of claw health, particularly in the presence of DD. As such, measuring claw traits from the heel region in the milking parlor may provide a practical, non-invasive approach to monitoring foot health. Future studies should explore the role of additional claw diseases and management practices in shaping claw health and welfare, particularly in the context of early detection, treatment strategies, and long-term prevention plans aimed at sustaining both productivity and animal well-being.

KEY WORDS

Cattle, Claw, Digital dermatitis, Foot, Lameness, Milk yield.

INTRODUCTION

Claw health and foot conformation are one of the important cornerstones to maintain in dairy farms, as they directly impact the farm economy along with productivity, and welfare of dairy cows. Claw lesions and lameness are among the most prevalent issues, with studies estimating that 70-80% of dairy cows experience claw lesions at some point (Manske et al., 2002; Somers et al., 2003). These problems are influenced by various factors, including breed, lactation stage, production systems, and environmental conditions (Ayalp et al., 2008; Baird et al., 2009; Telezhenko et al., 2009; Demirkan et al., 2018). The introduction of loose-housing systems and the increased use of concrete floors have exacerbated claw and locomotory issues, as these surfaces accelerate horn growth, increase wear, and contribute to claw malformations (Somers et al., 2005). Modern dairy farms predominantly use free-stall housing with concrete alleyways, a practice linked to poorer claw health malformations compromises the locomotor system, making claws vulnerable to mechanical injuries and infections (Sadiq et al., 2020). Changes in claw conformation are closely associated with claw lesions such as digital dermatitis and white line disease and lameness in previous studies (Somers et al., 2005; Laven, 2007; van der Linde et al., 2010). Pain and discomfort caused by claw diseases further disrupt normal growth and wear patterns, altering both external and internal claw structures (Flower and Weary, 2009; Bicalho et al., 2009). Lameness and claw conformation changes not only affect cow well-being but also lead to decreased productivity, prompting the growth of the claw trimming industry to restore locomotion and maintain claw health (Manske et al., 2002; Ouweltjes et al., 2009). However, therapeutic trimming often focuses on cows with visible lameness, neglecting those with claw lesions that do not present overt symptoms (Offer et al., 2000; Fjeldaas et al., 2011). This is particularly evident in cases of digital dermatitis (DD) and skin disorders, where severe lesions typically coincide with significant alterations in claw shape, such as «*square*» feet with

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overgrown heels and shortened claws. While DD's effects during advanced stages are well-documented, its impact on claw conformation in earlier stages remains unclear.
To address these challenges, this study aimed to investigate the effects of lameness, milk yield, and digital dermatitis (DD) on claw and foot traits in Holstein dairy cows, with a particular focus on traits measured specifically from the heel region of the foot.

MATERIALS AND METHODS

Animals and Housing

A total of 184 lactating cows from a herd of 289 Holstein cattle from a single farm located in Aydin, TÜRKİYE were included. The study was conducted between January and March 2025. The cows were housed in a free-stall barn with grooved concrete floors and straw bedding. A 1 cm thick flat rubber mat covered the 3.50 m alley adjacent to the feed bunk, and alleys were cleaned 8 times per day with an automatic scraper. Cows had *ad libitum* access to feed and water and were milked twice daily (06:00 and 18:00) in a double milking parlor. The diet consisted of 45% concentrate (soybean meal, cornmeal, cottonseed, and canola) and 55% forage (wheat straw, alfalfa hay, haylage, and corn silage). Routine claw trimming was last performed five months before the study by a professional trimmer during the dry-off period, according to farm records. The footbath was located outside of the milking parlor and dimensions were 100×200×10 cm (length×width×height) and consist of combination of 4% formalin and 5% copper sulphate solution and renewed every 3 days. Each cows record related to days in milk, and milk yield were obtained from farm record. Milk yield data were categorized into two groups: low (average daily milk yield≤20 kg) and high (average daily milk yield>20 kg).

Digital Dermatitis Examination

During the study period, no farm records indicated cows diagnosed or treated for claw diseases. In the milking parlor, the cows' feet were washed and visually examined for signs of digital dermatitis, and the presence or absence of the disease was recorded. Following the examination, each cow's hindlimbs were photographed from the rear using a digital camera (Nikon D3200) positioned 30 cm away. A plastic ruler was used as a reference, placed near the feet in contact with the floor (Figure 1a). Lesions were not staged according to severity; instead, the inclusion criterion was the presence of any visible plantar DD lesion. Accordingly, cows were classified as DD+ if at least one lesion was detected on the plantar surface or DD- if no lesion was observed.

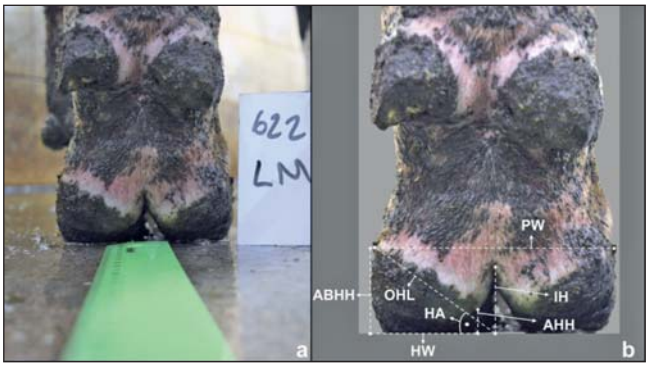

Figure 1 - The obtained photograph of a cows' hindlimb and determined foot areas of interest.
HW: Heel width; OHL: Oblique heel length; ABHH: Abaxial heel height; AHH: Axial heel height; HA: Heel angle; IH: Interdigital height; PW: Pastern width.

Claw and Foot Trait Measurements

Obtained photographs were transferred to a computer and processed digitally with *Image J* software program. Image J was calibrated to taking designates measurements on photographs by designating known distance for distance in pixel. In each photograph of hindlimbs of cows determined areas of interest [Heel width (HW); Oblique heel length (OHL); Abaxial heel height (ABHH); Axial heel height (AHH); Heel angle (HA)] of lateral-medial claws and foot areas [Interdigital height (IH); Pastern width (PW)] were measured (Figure 1b).

Lameness Evaluation

Lameness evaluations were performed on all cows after the morning milking as they were leaving the milking parlor through an alley. The scoring system was adapted from the Agriculture and Horticulture Development Board (AHDB) guidelines, where a score of 0 indicated no signs of lameness, while lameness scores (LS) ranged from 1 to 3, with LS1 representing mild lameness, LS2 moderate lameness, and LS3 severe lameness (Agriculture and Horticulture Development Board, 2020). All observations were performed by a single trained author (Y.A.O.) to ensure consistency and minimize inter-observer variability.

Statistical Analyses

The sample size for the general linear model was estimated based on a previous study (Gomez et al., 2015), including three predictors (milk yield, lameness score, digital dermatitis existence), with an assumed moderate effect size (f^2=0.07), =0.05, and 80% power, requiring a minimum of 120 dairy cows for 90% power. Morphometric measurement data was transferred into SPSS 22 (IBM Corp., Armonk, NY, USA) statistical package software program for statistical tests. Data normality was assessed using histograms, assessing kurtosis and skewness along with Shapiro-Wilk test. The differences between predictors (milk yield, lameness score, and digital dermatitis) and claw/foot measurements were analyzed using a general linear model (GLM) to assess the impact of these predictors on the measurements.

Table 1 - Number of cows by lameness score (LS), digital dermatitis (DD) status, and milk yield (n).

LS	DD	Yield		Total
		Low	High	
0	+	41	53	94
	-	11	18	29
	Total	52	71	123
1	+	19	15	34
	-	7	2	9
	Total	26	17	42
2	+	5	7	12
	-	1	1	2
	Total	6	8	14
3	+	2	-	2
	-	2	-	2
	Total	4	-	4
	Grand Total	88	96	184

When significant differences were found between the groups (milk yield, lameness score, and digital dermatitis), and their interactions, a Bonferroni-corrected post-hoc simple effects analysis was performed to further assess the differences in claw and foot measurements. Results are expressed as means±standard error of the mean (SEM), with statistical significance set at $P<0.05$.

RESULTS

The distribution of cows by lameness score, digital dermatitis (DD) status, and milk yield categories is presented in Table 1. Most cows had LS0 (66.8%), followed by LS1 (23.4%), LS2 (7.6%), and LS3 (2.2%). DD+ cows were more prevalent across all LS categories, particularly in LS0. High-yield cows were more frequent in LS0 and LS2, while low-yield cows had a slightly higher proportion in LS1 and LS3. The total number of cows in the study was 184, with a nearly equal distribution between milk yield groups.

Effects of Lameness Score, Milk Yield, and Digital Dermatitis on Claw Traits in Lateral Claws

Table 2 presents the effects of LS, milk yield, and DD on measured claw traits in lateral claws.

The measurement values of HW (P=0.003) and OHL (P=0.019) in DD+ cows with LS0 and low milk yield were significantly higher compared to those with high milk yield. In DD- cows, OHL (P=0.041), AHH (P=0.002), and HA (P=0.036) measurement values were significantly higher in LS1 high milk yield cows compared to low milk yield cows (Table 2).

AHH measurement values (P=0.003) were significantly higher in LS1 DD- cows compared to DD+ in high milk yield cows.

Table 2 - Measurement of Lateral Claw Traits in Dairy Cows Based on Lameness Scores, Presence of Digital Dermatitis (DD; exist, -: not exist), and Milk Yields (Mean±SEM).

Claw Traits	Yield	LS 0			LS 1			LS 2			LS 3		
		DD-	DD+	P	DD-	DD+	P	DD-	DD+	P	DD-	DD+	P
HW (mm)	Low	4.69±0.23	4.86±0.09	0.450	4.55±0.20	4.74±0.18	0.541	4.08±0.16	5.19±0.20	0.132	-	-	-
	High	4.70±0.17	4.45±0.09	0.172	5.11±0.15	4.51±0.20	0.243	3.89±0.15	4.75±0.26	0.234	4.16±0.56	4.22±0.08	0.935
	P	0.975	0.003		0.305	0.343		0.851	0.273		-	-	
OHL (mm)	Low	6.59±0.24	6.96±0.11	0.105	6.44±0.19	7.01±0.14	0.058	5.31±0.16	7.21±0.33	0.010	-	-	-
	High	6.66±0.12	6.63±0.10	0.896	7.54±0.69	6.69±0.09	0.094	6.70±0.50	6.77±0.27	0.924	6.72±0.33	5.94±0.59	0.241
	P	0.800	0.019		0.041	0.182		0.143	0.258		-	-	
ABHH (mm)	Low	3.45±0.21	3.84±0.09	0.071	3.57±0.25	3.88±0.20	0.275	3.64±0.24	4.30±0.29	0.338	-	-	-
	High	3.65±0.11	3.74±0.08	0.581	4.53±0.67	3.91±0.16	0.184	2.89±0.45	3.63±0.19	0.267	3.15±0.61	4.03±0.66	0.161
	P	0.406	0.479		0.057	0.890		0.398	0.072		-	-	
AHH (mm)	Low	1.39±0.17	1.58±0.06	0.163	1.40±0.13	1.45±0.11	0.783	2.15±0.12	1.57±0.12	0.192	-	-	-
	High	1.46±0.09[a]	1.55±0.05	0.460	2.45±0.06[b]	1.54±0.11	0.003	1.24±0.04	1.43±0.12	0.663	1.36±0.42	1.41±0.62	0.912
	P	0.637	0.656		0.002	0.533		0.115	0.569		-	-	
HA (°)	Low	29.80±1.11	32.35±0.48	0.027	29.83±1.40	31.02±0.80	0.432	35.03±1.21	32.18±1.59	0.445	-	-	-
	High	31.68±0.71	32.22±0.47	0.557	35.60±0.56	32.16±1.02	0.180	28.60±0.76	32.56±1.16	0.278	29.61±4.04	33.76±2.88	0.224
	P	0.148	0.850		0.036	0.331		0.183	0.849		-	-	

HW: Heel width, OHL: Oblique heel length, ABHH: Abaxial heel height, AHH: Axial heel height, HA: Heel angle, DD: Digital dermatitis, LS: Lameness score, SEM: Standard error of the mean; Superscript letters (a, b) indicate statistically significant differences (P<0.05) between subgroups (LS-Yield-DD).

Table 3 - Measurement of Medial Claw Traits in Dairy Cows Based on Lameness Scores, Presence of Digital Dermatitis (DD; exist, -: not exist), and Milk Yields (Mean±SEM).

Claw Traits	Yield	LS 0			LS 1			LS 2			LS 3		
		DD-	DD+	P	DD-	DD+	P	DD-	DD+	P	DD-	DD+	P
HW (mm)	Low	4.62±0.23	4.58±0.11	0.863	‘4.88±0.34	4.65±0.17	0.481	‘3.46±0.12	4.61±0.55	0.161	‘-	-	-
	High	4.69±0.11	4.65±0.10	0.838’	5.18±0.41	4.68±0.24	0.365’	4.04±0.40	4.61±0.24	0.476’	5.75±0.19	4.59±0.21	0.121
	P	0.815	0.655		0.925	0.583		0.583	0.999	‘	-	-	
OHL (mm)	Low	6.49±0.19	6.86±0.09	0.101	6.76±0.31[a]	6.59±0.12	0.569	4.94±0.28[b]	7.13±0.40	0.003	-	-	-
	High	6.68±0.18	6.74±0.09	0.755i	7.40±0.16	6.58±0.18	0.101	i5.70±0.15	7.01±0.22	0.068	6.65±0.49	6.85±0.26	0.758
	P	0.459	0.362		0.224	0.975		0.419	0.747		-	-	
ABHH (mm)	Low	3.40±0.22	3.72±0.10	0.125	3.41±0.21	3.59±0.13	0.519	4.13±0.18	3.98±0.08	0.830	-	-	-
	High	3.62±0.15	3.68±0.09	0.724	4.60±0.57	3.51±0.16	0.021	3.23±0.42	3.52±0.19	0.666	3.20±0.31	3.77±0.77	0.365
	P	0.354	0.733		0.018	0.709		0.307	0.201		-	-	
AHH (mm)	Low	1.36±0.13	1.53±0.06	0.193	1.57±0.08	1.54±0.10	0.847	1.56±0.03	1.61±0.13	0.910	-	-	-
	High	1.43±0.08[a]	1.55±0.05	0.254	2.22±0.03[b]	1.47±0.10	0.011	1.24±0.07	1.42±0.12	0.670	1.38±0.28	1.24±0.54	0.717
	P	0.642	0.822		0.037	0.622		0.558	0.395		-	-	
HA (°)	Low	30.64±0.21	31.08±0.61	0.742	29.43±1.54	30.12±0.83	0.686	35.90±1.23	32.13±1.29	0.378	-	-	-
	High	30.32±0.75	32.63±0.54	0.031	36.66±4.48	30.18±1.06	0.028	29.07±1.25	31.46±1.51	0.567	28.99±5.39	31.98±3.57	0.443
	P	0.829	0.057		0.022	0.968		0.217	0.767		-	-	

HW: Heel width, OHL: Oblique heel length, ABHH: Abaxial heel height, AHH: Axial heel height, HA: Heel angle, DD: Digital dermatitis, SEM: Standard error of the mean; superscript letters (a, b) indicate statistically significant differences ($P<0.05$) between subgroups (LS-Yield-DD).

Conversely, OHL measurements (P=0.010) in LS2 cows and HA measurement values (P=0.027) in LS0 DD+ cows were significantly higher compared to DD- cows. Additionally, AHH measurement values in LS1 DD- cows were significantly higher than in LS0 high milk yield DD- cows (P<0.001; Table 2).

Effects of Lameness Score, Milk Yield, and Digital Dermatitis on Claw Traits in Medial Claws

Table 3 presents the effects of LS, milk yield, and DD on measured claw traits in medial claws.

In high milk yield cows with LS0, HA measurement values were significantly higher in DD+ cows compared to DD- (P=0.031). In LS1 cows, ABHH (P=0.021), AHH (P=0.011), and HA (P=0.028) measurement values were significantly higher in DD- cows compared to DD+ cows (Table 3).

In low milk yield cows with LS2, OHL measurement values were significantly higher in DD+ cows compared to DD- (P=0.003). LS1 low milk yield DD- cows had significantly higher OHL measurement values compared to LS2 low milk yield DD- cows (P<0.001). LS1 high milk yield DD- cows had significantly higher AHH measurement values compared to LS0 high milk yield DD- cows (P<0.001; Table 3).

Effects of Lameness Score, Milk Yield, and Digital Dermatitis on Foot Traits

Table 4 presents the effects of LS, milk yield, and DD on measured foot traits.

PW measurements were significantly higher in low milk yield DD+ cows compared to high milk yield in both LS0 (P=0.012) and LS2 (P=0.001) DD+ cows (Table 4).

Effects of Milk Yield and Digital Dermatitis on Claw Traits in Lateral and Medial Claws

Table 5 presents the effects of milk yield and DD on measured claw traits in lateral and medial claws.

In lateral claws, HW (P=0.018) and OHL (P=0.003) measurement values were significantly higher in low milk yield cows compared to high milk yield cows in DD+ cows. Conversely, OHL measurement values were significantly higher in high milk yield cows compared to low milk yield cows in DD- cows (P=0.023; Table 5).

In medial claws, DD+ cows had significantly higher oblique heel length (OHL) measurements compared to DD- cows in low milk yield groups (P=0.004; Table 5).

Effects of Milk Yield and Digital Dermatitis on Claw Traits on Foot Traits

Table 6 presents the effects of milk yield and DD on measured claw traits in foot traits.

Low milk yield DD- cows had significantly higher PW measurement values compared to low milk yield DD- (P=0.038). Additionally, in DD+ cows, low milk yield cows had significantly

Table 4 - Measurement of Foot Traits in Dairy Cows Based on Lameness Scores, Presence of Digital Dermatitis (DD; exist, -: not exist), and Milk Yields (Mean±SEM).

Foot Traits	Yield	LS 0			LS 1			LS 2			LS 3		
		DD-	DD+	P	DD-	DD+	P	DD-	DD+	P	DD-	DD+	P
IH (mm)	Low	3.04±0.16	3.07±0.09	0.864	3.37±0.22	3.11±0.19	0.332	3.17±0.15	3.15±0.13	0.983	-	-	-
	High	3.19±0.14	3.10±0.08	0.578	3.60±0.03	3.12±0.16	0.283	2.91±0.14	3.20±0.10	0.658	2.62±0.56	2.22±0.83	0.508
	P	0.515	0.850		0.621	0.960		0.761	0.911		-	-	
PW (mm)	Low	11.34±0.29	11.70±0.14	0.168	11.59±0.34	11.67±0.15	0.803	11.01±0.29	12.53±0.33	0.070	-	-	-
	High	11.46±0.16	11.30±0.10	0.427	11.53±0.03	11.51±1.02	0.964	11.36±0.12	11.07±0.20	0.722	11.33±0.25	10.82±0.19	0.505
	P	0.679	0.012		0.934	0.543		0.746	0.001		-	-	

IH: Interdigital height, PW: Pastern width, DD: Digital dermatitis, LS: Lameness score, SEM: Standard error of the mean.

Table 5 - Measurement of Lateral and Medial Claw Traits in Dairy Cows Based on Presence of Digital Dermatitis (DD; exist, -: not exist), and Milk Yields (Mean±SEM).

Claw Traits	Yield	Lateral Claws			Medial Claws		
		DD		P	DD		P
		-	+		-	+	
HW (mm)	Low	4.61±0.15	4.85±0.08	0.077	4.66±0.19	4.60±0.09	0.343
	High	4.65±0.14	4.48±0.08	0.951	4.80±0.12	4.65±0.09	0.360
	P	0.936	0.018		0.124	0.931	
OHL (mm)	Low	6.47±0.17	6.99±0.09	0.001	6.51±0.18	6.80±0.08	0.004
	High	6.74±0.11	6.64±0.07	0.156	6.70±0.15	6.74±0.08	0.503
	P	0.023	0.003		0.112	0.718	
ABHH (mm)	Low	3.51±0.15	3.88±0.08	0.082	3.44±0.15	3.70±0.07	0.641
	High	3.65±0.13	3.77±0.06	0.298	3.65±0.14	3.63±0.07	0.861
	P	0.997	0.312		0.955	0.395	
AHH (mm)	Low	1.43±0.11	1.54±0.05	0.496	1.45±0.08	1.54±0.05	0.695
	High	1.53±0.09	1.53±0.04	0.382	1.49±0.08	1.51±0.04	0.359
	P	0.933	0.641		0.721	0.194	
HA (°)	Low	30.08±0.85	31.95±0.40	0.829	30.47±0.93	30.88±0.46	0.583
	High	31.70±0.71	32.28±0.39	0.360	30.70±0.83	32.03±0.46	0.853
	P	0.921	0.380		0.717	0.676	

HW: Heel width, OHL: Oblique heel length, ABHH: Abaxial heel height, AHH: Axial heel height, HA: Heel angle, DD: Digital dermatitis, SEM: Standard error of the mean.

Table 6 - Measurement of Foot Traits in Dairy Cows Based on Presence of Digital Dermatitis (DD; exist, -: not exist), and Milk Yields (Mean±SEM).

Foot Traits	Yield	DD		P
		-	+	
IH (mm)	Low	3.17±0.12	3.09±0.08	0.748
	High	3.16±0.12	3.09±0.07	0.491
	P	0.723	0.221	
PW (mm)	Low	11.41±0.21	11.76±0.11	0.038
	High	11.45±0.12	11.31±0.08	0.437
	P	0.779	<0.001	

IH: Interdigital height, PW: Pastern width, DD: Digital dermatitis, SEM: Standard error of the mean.

higher PW measurement values compared to high milk yield cows (P<0.001; Table 6).

Effects of Lameness and Milk Yield on Claw Traits in Lateral and Medial Claws

Table 7 presents the effect of LS and milk yield on claw traits. In lateral claws of LS1 cows, high milk yield cows had significantly higher AHH (P=0.002) and HA (P=0.021) measurement values compared to low milk yield cows. A significant difference was also found between LS0 and LS1 cows in high milk yield cows (P=0.016; Table 7).

In medial claws, high milk yield cows had significantly higher AHH (P=0.042), and HA (P=0.033) measurement values compared to low milk yield cows (Table 7).

Effects of Lameness and Milk Yield on Foot Traits

No statistically significant differences were found between milk yield and lameness categories for foot traits (P>0.05; Table 8).

Effects of Lameness and Digital Dermatitis on Claw Traits in Lateral and Medial Claws

Table 9 presents the effects of LS and DD on claw traits.

In lateral claws, DD+ cows had significantly higher HW measurement values in LS2 (P=0.048) and higher AHH measurement values in LS1 (P=0.016) compared to DD- cows. DD+ cows also had significantly higher HA measurement values in LS0 (P=0.037) compared to DD- cows. A significant difference was found between LS0 and LS1 AHH measurement values in DD+ cows (P=0.044; Table 9).

In medial claws, cows with digital dermatitis had significantly higher OHL measurement values in LS2 compared to DD- cows (P=0.001), while DD- cows had significantly higher AHH measurement values in LS1 (P=0.022) compared to DD+ cows. Additionally, a significant difference was found between LS0 and LS1 AHH measurement values in DD- cows (P=0.036; Table 9).

Table 7 - Measurement of Lateral and Medial Claw Traits in Dairy Cows Based on Lameness Scores, and Milk Yields (Mean±SEM).

Claw Traits	Yield	Lateral Claws					Medial Claws				
		LS					LS				
		0	1	2	3	P	0	1	2	3	P
HW (mm)	Low	4.83±0.08	4.69±0.14	5.01±0.25	-	0.749	4.59±0.10	4.71±0.15	4.42±0.49	-	0.239
	High	4.51±0.08	4.58±0.18	4.64±0.25	4.19±0.23	0.455	4.66±0.08	4.74±0.21	4.54±0.22	5.17±0.35	0.359
	P	0.165	0.570	0.552	-		0.675	0.618	0.611	-	
OHL (mm)	Low	6.88±0.10	6.85±0.12	6.89±0.41	-	0.405	6.79±0.08	6.63±0.12	6.76±0.39	-	0.232
	High	6.64±0.08	6.79±0.12	6.76±0.23	6.33±0.36	0.237	6.72±0.08	6.68±0.17	6.84±0.25	6.75±0.23	0.516
	P	0.367	0.176	0.355	-		0.830	0.269	0.533	-	
ABHH (mm)	Low	3.76±0.09	3.79±0.16	4.19±0.26	-	0.635	3.65±0.09	3.54±0.11	4.01±0.07	-	0.313
	High	3.72±0.06	3.98±0.16	3.54±0.19	3.59±0.45	0.088	3.66±0.07	3.63±0.17	3.48±0.17	3.49±0.38	0.277
	P	0.695	0.071	0.142	-		0.514	0.042	0.153	-	
AHH (mm)	Low	1.54±0.06	1.44±0.09	1.66±0.14	-	0.202	1.50±0.06	1.55±0.07	160±0.11	-	0.549
	High	1.53±0.04[a]	1.65±0.12[b]	1.41±0.10	1.39±0.31	0.016	1.52±0.04	1.56±0.10	1.39±0.10	1.31±0.25	0.066
	P	0.840	0.002	0.095	-		0.606	0.085	0.386	-	
HA (°)	Low	31.81±0.46	30.69±0.69	32.65±1.38	-	0.281	30.99±0.54	29.94±0.72	32.76±1.22	-	0.166
	High	32.08±0.39	32.56±0.97	32.06±1.12	31.69±2.36	0.427	32.05±0.46	30.94±1.13	31.16±1.34	30.49±2.78	0.508
	P	0.238	0.021	0.247	-		0.470	0.033	0.210	-	

HW: Heel width, OHL: Oblique heel length, ABHH: Abaxial heel height, AHH: Axial heel height, HA: Heel angle, LS: Lameness score, SEM: Standard error of the mean; superscript letters (a, b) indicate statistically significant differences (*P*<0.05) between subgroups (yield-LS).

Table 8 - Measurement of Foot Traits in Dairy Cows Based on Lameness Scores, and Milk Yields (Mean±SEM).

Foot Traits	Yield	LS				P
		0	1	2	3	
IH (mm)	Low	3.07±0.08	3.18±0.15	3.16±0.10	-	0.560
	High	3.12±0.07	3.17±0.14	3.16±0.10	2.42±0.36	0.088
	P	0.507	0.636	0.812	-	
PW (mm)	Low	11.63±0.13	11.65±0.14	12.28±0.37	-	0.787
	High	11.34±0.08	11.51±0.14	11.10±0.18	11.08±0.20	0.798
	P	0.397	0.752	0.341	-	

IH: Interdigital height, PW: Pastern width, LS: Lameness score, SEM: Standard error of the mean.

Table 9 - Measurement of Lateral and Medial Claw Traits in Dairy Cows Based on Presence of Digital Dermatitis (DD; exist, -: not exist) and Lameness Scores (Mean±SEM).

Claw Traits	DD	Lateral Claws					Medial Claws				
		LS					LS				
		0	1	2	3	P	0	1	2	3	P
HW (mm)	+	4.70±0.13	4.68±0.17	3.98±0.09	4.16±0.56	0.339	4.65±0.11	4.95±0.27	3.75±0.29	5.75±0.19	0.989
	-	4.63±0.07	4.64±0.13	4.93±0.18	4.22±0.08	0.314	4.62±0.07	4.66±0.14	4.61±0.26	4.59±0.21	0.040
	P	0.789	0.484	0.048	0.935		0.793	0.256	0.134	0.121	
OHL (mm)	+	6.63±0.11	6.68±0.24	6.01±0.69	6.72±0.33	0.226	6.61±0.13	6.90±0.26	5.32±0.38	6.65±0.49	0.162
	-	6.78±0.08	6.87±0.09	6.95±0.21	5.94±0.59	0.319	6.79±0.07[a]	6.58±0.10[a]	7.06±0.20[b]	6.85±0.26	0.015
	P	0.237	0.628	0.055	0.241		0.141	0.089	0.001	0.758	
ABHH (mm)	+	3.58±0.11	3.79±0.26	3.26±0.37	3.15±0.61	0.700	3.53±0.13	3.67±0.26	3.68±0.45	3.20±0.31	0.621
	-	3.79±0.06	3.89±0.13	3.91±0.18	4.03±0.66	0.172	3.70±0.06	3.55±0.10	3.71±0.13	3.77±0.77	0.258
	P	0.080	0.552	0.145	0.161		0.156	0.093	0.882	0.365	
AHH (mm)	+	1.44±0.08	1.63±0.18	1.69±0.45	1.36±0.42	0.776	1.40±0.07	1.72±0.11	1.40±0.16	1.38±0.28	0.723
	-	1.56±0.04[a]	1.49±0.08[b]	1.49±0.08	1.41±0.62	0.044	1.54±0.04[a]	1.51±0.07[b]	1.50±0.09	1.24±0.54	0.036
	P	0.121	0.016	0.527	0.912		0.085	0.022	0.705	0.717	
HA (°)	+	30.96±0.62	31.11±1.46	31.81±3.21	29.61±4.04	0.666	30.44±0.64	31.04±1.75	32.48±3.41	28.99±5.39	0.187
	-	32.28±0.33	31.52±0.63	32.40±0.90	33.76±2.88	0.535	31.95±0.41	30.15±0.65	31.74±1.00	31.98±3.57	0.392
	P	0.037	0.447	0.832	0.224		0.107	0.090	0.817	0.443	

HW: Heel width, OHL: Oblique heel length, ABHH: Abaxial heel height, AHH: Axial heel height, HA: Heel angle, DD: Digital dermatitis, LS: Lameness score, SEM: Standard error of the mean; superscript letters (a, b) indicate statistically significant differences ($P<0.05$) between subgroups (LS-DD).

Effects of Lameness and Digital Dermatitis on Foot Traits

No statistically significant differences were found in foot traits between lameness and digital dermatitis categories ($P>0.05$; Table 10).

DISCUSSION

Claw health and conformation are critical determinants of dairy cow productivity, welfare, and economic sustainability. This study investigated the effects of lameness, milk yield, and digital dermatitis (DD) on claw and foot traits in Holstein dairy cows, revealing intricate interactions between these factors and their impact on claw morphology. The findings underscore the importance of proactive management strategies aimed at mitigating claw disorders, which are essential for improving herd performance and sustaining dairy farm productivity. By examining how these factors influence claw health, the study provides novel insights into the complex interplay between disease, productivity, and claw morphology. Consistent with previous research, DD was associated with notable alterations in claw morphology, particularly in heel height, claw length, and foot angle (Somers et al., 2005; Laven, 2007; van der Linde et al., 2010). The inflammatory and mechanical effects of DD likely contribute to these changes by altering weight distribution and gait, leading to uneven claw wear and growth (Döpfer et al., 2012; Capion et al., 2008). In particular, the observed differences between DD+ and DD- cows emphasize the role of DD in claw deformation, which may be further influenced by milk yield and lameness severity. The significant impact of DD on lateral claws aligns with previous findings that highlight the greater weight-bearing function of the lateral claw in the hind limbs (Nuss and Paulus, 2006). These observations suggest that DD management should focus on mitigating its effects on weight distribution and claw wear to prevent long-term structural damage.

Lameness also emerged as a key factor influencing claw traits, with notable variations observed across different milk yield categories. Previous studies have linked lameness to abnormal hoof growth and wear, particularly in high-yielding cows (Manske et al., 2002; Kremer et al., 2007; Bicalho et al., 2009; Olechnowicz and Jaskowski, 2010; Sadiq et al., 2017). Even mild lameness appeared to induce detectable changes in claw morphology, reinforcing the importance of early detection and intervention. Regular claw trimming and lameness monitoring are essential strategies to maintain optimal claw health and prevent the progression of locomotion disorders, which can compromise both welfare and productivity (Sadiq et al., 2020). Milk yield further influenced claw and foot traits, reinforcing the association between high productivity and increased claw stress. Metabolic and mechanical demands in high-yielding cows may contribute

Table 10 - Measurement of Foot Traits in Dairy Cows Based on Presence of Digital Dermatitis (DD; exist, -: not exist) and Lameness Scores (Mean±SEM).

Foot Traits	DD	LS				P
		0	1	2	3	
IH (mm)	+	3.14±0.11	3.42±0.17	3.04±0.13	2.62±0.03	0.307
	-	3.07±0.06	3.11±0.13	3.18±0.08[a]	2.22±0.83[b]	0.221
	P	0.830	0.157	0.769	0.508	
PW (mm)	+	11.42±0.15	11.57±0.26	11.18±0.17	11.33±0.25	0.324
	-	11.47±0.08	11.60±0.11	11.68±0.28	10.82±0.19	0.933
	P	0.562	0.930	0.293	0.505	

IH: Interdigital height, PW: Pastern width, DD: Digital dermatitis, LS: Lameness score, SEM: Standard error of the mean; superscript letters (a, b) indicate statistically significant differences ($P<0.05$) between subgroups (LS-DD).

to excessive hoof wear and deformation, as previously suggested (Kremer et al., 2007; Olechnowicz and Jaskowski, 2010; Martin et al., 2024). Additionally, DD appeared to exacerbate these effects, particularly in low milk yield cows, suggesting that compromised foot health in this group may further contribute to alterations in claw morphology. The pathological effects of DD, including inflammation and swelling within the interdigital space, likely account for the observed differences in foot width (Döpfer et al., 2012; Robrics et al., 2023). These findings highlight the importance of integrating milk yield dynamics into lameness and DD management strategies to minimize the negative impact on claw and foot health.

While this study provides valuable insights into the relationships between claw traits, milk yield, lameness, and DD, several limitations should be acknowledged. First, the study was conducted on a single farm with a relatively small sample size, which minimized environmental variability (e.g., flooring type, footbath use, and trimming practices) but limited the generalizability of the findings. Future studies should include multiple herds under diverse management systems to better capture variability in claw health. Second, examinations were performed in the milking parlor from the caudal aspect of the hindlimbs, restricting the detection of DD lesions to the plantar surface. Interdigital or dorsal lesions, although less common, may have been overlooked. Moreover, lesions were classified only by presence or absence, without staging according to severity, which prevented a more detailed evaluation of lesion progression. Finally, lameness was assessed using the AHDB visual scoring system, which is inherently subjective. Although all evaluations were carried out by a single trained observer to minimize variability, observer bias cannot be completely excluded. These limitations highlight the need for future research that employs comprehensive lesion staging, chute-based examinations, and objective lameness detection technologies to provide a more complete understanding of claw health.

The hindlimbs, which bear approximately 60% of a cow's body weight and play a more significant role in lameness than the forelimbs (Pastell et al., 2010), should be the primary focus for data collection to ensure assessments are conducted in the most affected region. This is particularly relevant as DD predominantly affects the hindlimbs, altering claw traits through inflammation, weight redistribution, and gait changes (Salem et al., 2023; Holzhauer et al., 2024). Evaluating the impact of DD on claw morphology may be more efficiently performed by measuring heel traits in the milking parlor rather than restraining cows in a trimming chute. The methodology used in this study, which involved assessing claw traits from the caudal/heel aspect in the milking parlor, provides a more comprehensive view of both claws in their natural alignment. This approach contrasts with previous studies that measured claw traits from the axial and solar aspects (Gomez et al., 2015; Somers et al., 2005). By ensuring repeatable and standardized measurements across both claws, this method offers a more accurate assessment of load-bearing. Future research utilizing automated, camera-based systems positioned in the milking parlor may further enhance the accuracy and efficiency of this approach.

CONCLUSION

Early detection of lameness is critical, as even mild cases impact claw morphology. This study underscores the significant effects of milk yield, lameness, and digital dermatitis (DD) on claw health and morphology in Holstein dairy cows. DD exacerbates claw deformation, particularly in low milk yield cows, while high milk yield increases claw stress. The findings highlight the need for targeted management strategies, including regular claw monitoring and non-invasive disease detection systems, to prevent and mitigate claw disorders. Future research should explore the co-occurrence of other claw diseases and their collective impact on claw health.

Ethical Approval

This study protocol was approved by Aydin University Animal Experiments Local Ethics Committee on 05th Dec. 2024 (Approval No: 64583101/2024/130).

Author Contributions

YAO, HEB and IA conceived and designed the study. YAO and IA conducted data gathering. YAO and HEB performed statistical analyses. YAO, HEB and IA wrote the article.

Conflict of Interest Statement

The authors have nothing to declare.

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