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Welfare and Reproductive Performance of Rabbits Under Two Housing Models in the Egyptian Delta Region

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Abstract: Concerns about animal welfare due to climate change are growing in the rabbit industry and determining an animal's welfare status is important. So, it is necessary to consider housing conditions as one of the main management criteria. The goal of this study was to examine the preference of rabbits under two housing models of various roofing materials. Twenty-four doses and 6 bucks in a total of NZW rabbits were used in this study. Thermos-respiratory, some physiological responses, and reproductive performance were evaluated as being impacted by seasonal variables during the course of one year of production in two styles of housing. These mostly differed in terms of roofing style, wood roof (1st model), and single metal roof (2nd model). The results confirmed that 1st model accommodated more comfortable zone conditions in all seasons than the 2nd one. Rabbit kept in the 1st model showed the lowest values of rectal temperature and respiration rate and the highest values of hematocrit, hemoglobin, Triiodothyronine, and progesterone concentrations in comparison to the 2nd model. In the second model, the drop in all reproductive examined characteristics was more pronounced. Does raised during spring showed the highest values of litter size and weight in comparison to those in summer and showed higher values of milk yield in winter than in summer. According to the results, it can be concluded that the wooden roof in the 1st model provided a comfortable zone during razing ambient temperature that improved the reproductive performance of the rabbit.

Keywords: Blood, Housing, Performance, Rabbits, Seasons, Welfare

Introduction

The world faces substantial difficulties, such as providing food for an expanding population and addressing serious environmental issues such as the depletion of natural resources and the disastrous effects of climate change on the planet. Besides that, since the public's concern for animal welfare has increased during the past forty years, consumers, retailers, producers, legislators and other parties involved use the term "animal welfare" more and more when referring to livestock (García, 2020). The phrase "state of an animal as it attempts to cope with its environment" is generally regarded as the definition of animal well-being "welfare" (Patterson-Kane, 2018). The welfare is now included in the vast majority of the adverse effects of climate change (El Sabry *et al*., 2021; Bozzo *et al*., 2021).

Heat stress negatively impacts the welfare and adaptation, health condition, and reproduction performance of rabbits (Oladimeji *et al*., 2022). Due to their homoeothermic nature, rabbits should be able to maintain their body temperature within a certain range (Szendrő *et al*., 2018). Due to their absence of sweat glands, rabbits have very poor thermoregulation (Maya-Soriano *et al*., 2015), thus high Ambient Temperatures (AT) are extremely harmful to rabbits. The thick, insulating hair that covers the skin of rabbits further limits heat escape. Most likely, the physiology and reproductive processes of mammals will suffer greatly as a result of global warming (Liang *et al*., 2022; El-Ratel *et al*., 2023). There has long been research on how AT affects animal reproduction. Nowadays, more researchers are working in this field as a result of global warming (El Sabry *et al*., 2021). Some physiological characteristics of domestic rabbits have been impacted by the AT (Ondruska *et al*., 2011) and this affected the reproduction and production efficiency directly or indirectly (Marco Jiménez *et al*., 2017; El-Ratel *et al*., 2023).

It is necessary to establish housing conditions techniques that indicate a high standard of animal welfare through ensuring success because housing conditions typically harm animal welfare on several levels (García, 2020). The features of the animal and their responses to external temperature and humidity determine the design of the rabbit housing. In temperate zones, the exterior elements should provide good heat insulation (Abdelnour *et al*., 2022). In tropics and subtropics, adequate protection against heat is equally important (Schlolaut, 1985). When the interior temperature of the home is high, energy is lost by panting, but when the temperature is low, Metabolizable Energy (ME) is converted directly into sensible heat (Jimoh and Ewuola, 2018).

In rabbit houses, the roof needs the most attention and presents the most difficulty (Ashour *et al.*, 2017). They added that, in the subtropical zone, the rabbits' housing roof construction fulfills resistance to severe changes in indoor microclimate during cold winter and hot summer. The welfare of rabbits in hot locations would suffer due to the anticipated rise in the global surface temperature (Oladimeji *et al*., 2022). So, the primary goal of this study was to evaluate the impact of two housing models on rabbit does' performance during seasonal changes throughout one year of production. Thermo-respiratory, some hematological and hormonal profile responses of rabbits, were studied as indicators of rabbit’s welfare.

Materials and Methods

This study was carried out in the rabbitry in the delta zone, El-Gharbia Governorate, Egypt, in co-operation with animal, poultry, and fish production department, faculty of agriculture, Damietta University, throughout one year to cover four seasons of different environmental conditions. Four natural seasonal climate conditions are included in the experiment: June, July, and August are the severely hottest summer months, whereas December, January, and February are the coldest winter months. And the mild conditions in spring and autumn (March, April, and May) and (September, October and November), respectively.

Ethical Approval

All procedures and experimental protocols which carried out according to the animal care and use committee guidelines of the Damietta University, Damietta, Egypt (approval number: 03/2018/du.edu). The rabbits in the current study received appropriate care and treatment without needless suffering.

Housing Models Specifications

The rabbits were kept in two Housing Models (HM) that differed mainly in the roofing materials. The first house model is roofed by 5 cm thick wood. The walls were made of 13 cm thick common. The height of the house was 4.1 m. There were two windows, one large glass window (0.8 m height ×2.3 m width) on the northern side and another glass window (0.6 m height ×1.15 m width) on the western side. These two windows were located at 2.0 m above the ground level. There was one door made of 2.0 cm wood (2.0 m height and 1.3 m width). The second house model was roofed by only one layer of 0.5 cm thick corrugated iron sheet. The floor (4.0 mL ×3.6 m width) was cementing ground in both housing models. The walls, doors, and windows of the second house are similar to that of the first house.

Experimental Animals

A total of healthy 24 dogs and 6 bucks of NZW rabbits were used in this study. The parents were all adults at the beginning of the study, aged 5-6 months, and weighed 2.4-3.3 kg. The animals were split into two groups at random, each including 12 dogs and 3 bucks. Each group was housed randomly in one of both housing models throughout the whole experimental period. Does and bucks were kept in individual wire cages (60×40×35 cm), apart from one another. Five days before kindling, nest boxes (30 25 30 cm) were installed on the front edges of the cages; they were removed after 28 days of lactation (weaning age).

Animal Management

According to the National Research Council (1977), a commercial balanced pelleted ration with 18% crude protein, 14% crude fiber, and 2700 kcal/kg digestible energy was fed *ad libitum* to the rabbits. Water for drinking was offered without restriction. Every doe was moved to a buck’s cage for natural mating, then put back in her own cage after being palpated for pregnancy 14 days later. Does that didn’t get pregnant were transferred to the same mating buck to be remated within 12 h.

Metrological Data

Once a week, from 10-11 am (a moderate diurnal period) away from the hottest afternoon in summer and the coldest morning in winter and respectively in autumn and spring, the seasonal responses of rabbits were tested. Maximum and minimum AT (°C) were recorded daily. Seasonal AT and Relative Humidity (RH, %) of outdoor and indoor conditions were recorded at weekly intervals by using a thermometer and hygrometer, respectively. These conditions within both housing models were recorded simultaneously, at 10-11 am.

Thermo-Respiratory Responses

Rectal temperatures (RT, °C) were measured by using a digital thermometer. Respiration Rate (RR, breaths/min.) was determined by measuring how many flank motions there are each minute. The animal was kept as quiet as possible by taking all reasonable measures, which included counting the animal's breaths immediately before taking its body temperature. These measurements were twice a week recorded at 12:00 p.m.

Blood Parameters

Fourteen rabbit does (7 of each house) were used to collect blood samples all over the year round. Blood samples were collected post-mating weekly at 8-9 am. In clean, heparinized tubes from the ear's marginal vein and split into two separate subsamples. In the first one, hematological parameters including hemoglobin concentration (Hb, g/dl) determined by the cyanmethemoglobin according to the procedure described by the manufacturer by using a spectrophotometer and hematocrit value (Ht, %) which was measured using microhematocrit tubes and a hematocrit centrifuge that ran for 15 min at 3000 rpm.

Midway through the pregnancy, blood plasma was isolated from another subsample using a digital centrifuge (T32c; Janetzki, Wallhausen, Germany) and centrifugation (5000 rpm for 20 min) "according to Erwan *et al*. (2017; 2020), then stored in Eppendorf tubes (1.5 mL) at 20°C for hormonal assay. Triiodothyronine (T3, ng/mL) and Progesterone (P4, ng/mL) hormone concentrations in blood plasma were measured using the radioimmunoassay method and commercial kits (Medical Technology, USA). The manufacturer's recommended protocol was followed to ascertain the hormone levels.

Reproductive Performance

After kindling, litter size (total number of born), litter weight, and bunny weight of the rabbits were noted at birth, 14, and 28 (at weaning age). The amount of milk produced by each doe was determined by comparing the weight of the pups after and before nursing twice daily (every 12 h). Averages of daily milk yield at 3rd week of the sucking period were recorded. All reproductive performance traits are based on two parities per season.

Statistical Analysis

The statistical analysis model's general linear model's technique was used to examine the data using the least squares analysis of variance (SAS, 2012). The statistical model looked like this:

$$Yij = \mu + Hi + S_j + Hi\ S_j + e_{ij}$$

where,

Y_{ij} = The observation of the animals reared in the i^{th} housing at the j^{th} season
μ = Overall mean, common element to all observations
H_i = Effect of housing models (i = 1, 2, 3)
S_j = Effect of season (j = 1, 2, 3, 4)
$H_i\ S_j$ = Interaction effect between i^{th} housing models and j^{th} seasons
e_{ij} = Random error component assumed to be normally distributed

Results

Environmental Condition

The general averages of AT and RH during the experimental period (four seasons) and corresponding conditions as recorded inside both housing models consequently with the outdoor conditions are presented in Table 1. In the hot seasons, particularly in summer, the wood roof significantly ($p \le 0.05$) reduced the indoor temperatures; maximum and at the scheduled time (10.00 h), alongside the greatest differences between the outside and inside of housing models (Table 1). The differences between the indoor temperature at the scheduled time (10 am) in both housing models were 7.2, 12.9, 8.1 and 1.7°C in spring, summer, autumn, and winter, respectively. Relative humidity was significantly ($p \le 0.05$) lower in the 2nd model compared to the 1st model in the summer and winter seasons, while it was in the opposite trend in the spring and autumn seasons (Table 1).

Table 1: LSM ± S.E. of environmental Air Temperature (AT, °C) and Relative Humidity (RH, %) outdoors and indoors in the two housing models during different seasons of the year

Season	House		Maximum	SEM	In-out	Minimum	SEM	In-out	Temperature at 10.00 h	SEM	In-out	RH	SEM
Spring	Out		29.1^b	0.23		17.3^b	0.29		29.9^d	0.31		68.3^b	0.52
	In	1	26.8^c	026	-2.3	18.8^a	0.20	1.3	25.6^{ef}	0.27	-4.3	63.4^a	0.50
		2	39.1^a	0.28	10.0	16.0^{bc}	0.19	-1.9	32.8^c	0.27	+2.9	65.9^b	0.49
Summer	Out		36.3^b	0.27		22.2^a	0.22		40.0^b	0.28		68.1^a	0.48
	In	1	31.6^{bc}	0.26	-4.7	22.8^a	0.23	0.6	32.3^c	0.26	-7.7	63.8^c	0.51
		2	45.7^a	0.28	9.4	17.8^c	0.20	-4.4	45.2^a	0.28	+5.2	61.2^b	0.52
Autumn	Out		29.1^b	0.24		20.1^a	0.21		26.5^e	0.20		72.3^a	0.49
	In	1	27.3^{bc}	0.21	-1.8	18.5^b	0.18	-1.6	24.0^f	0.27	-2.5	67.0^a	0.46
		2	33.0^a	0.23	3.9	14.5^c	0.20	-5.6	32.1^c	0.31	+5.6	70.5^b	0.45
Winter	Out		17.7^b	0.20		9.4^b	0.17		20.4^g	0.24		75.8^b	0.35
	In	1	21.9^a	0.23	4.2	12.3^a	0.20	2.9	22.6^g	0.17	+2.2	71.7^a	0.31
		2	22.9^a	0.22	5.2	8.3^{bc}	0.21	-1.1	24.3^h	0.20	+3.9	66.8^c	0.38

a, b, c, d, e, f, g, h Means in the same column with different superscripts are significantly different ($p<0.05$)

Table 2: Thermo-respiratory responses in NZW rabbits as affected by two housing models during different seasons of the year

Items	Thermo-respiratory responses Rectal Temperature (RT, °C)	Respiration Rate (RR, pulse/minute)
Effect of Housing Models (HM):		
Model 1 (HM1)	39.470	129.37
Model 2 (HM2)	39.630	152.40
SEM	0.3900	0.62
p-value	0.0500	0.0401
Effect of seasons:		
Spring	39.56^{B}	158.3^{A}
Summer	39.71^{A}	164.6^{A}
Autumn	39.52^{C}	137.30^{B}
Winter	39.45^{D}	103.3^{C}
SEM	0.440	0.61
p-value	0.0090	0.0301
Effect of interaction (HM × Seasons):		
HM1× Spring	39.44^{d}	150.6^{c}
HM2× Spring	39.68^{ab}	166.0^{b}
HM1× Summer	39.52^{c}	145.5^{c}
HM2× Summer	39.89^{a}	183.7^{a}
HM1× Autumn	39.60^{b}	121.3^{d}
HM2× Autumn	39.44^{d}	153.4^{bc}
HM1× Winter	39.34^{e}	100.1^{e}
HM2× Winter	39.55^{c}	106.5^{e}
SEM	0.540	0.74
p-value	0.0001	0.0006

$^{a, b, c, d, e}$ Means in the same column with different superscripts are significantly different (p<0.05)
$^{A, B, C, D}$ Means in the same column with different superscripts are significantly different (p<0.05)

Physiological Reactions of Rabbit Does

Thermo-Respiratory Responses

Rectal temperature and respiration rate of NZW do show significantly ($p<0.05$) higher values in the 2nd model than those recorded in the 1st model (Table 2). These differences were clearly observed in the summer season in comparison to other seasons. Regarding season effect, RT and RR are significantly ($p\leq0.05$) improved during mild environmental conditions (autumn, spring, and winter seasons) than in hot ones (summer season). It is also evident from Table 2 that each of RT and RR was significantly ($p\leq0.05$) affected by housing model × season interaction and the highest values were by HM2× summer and the lowest ones were by HM1× winter.

Hematological Responses

Heamatocrit and Hb values for NZW were significant ($p\leq0.05$) and affected by housing models and seasons (Table 3). Results in Table 2 also show that the highest values of Ht and Hb were in 1st model followed by 2nd model throughout the four seasons. The significant increased differences between both models were clearly observed in the summer season; being +5.02 and +1.83 for Ht and Hb, respectively. The highest values for Ht and Hb were detected in rabbits in mild environmental conditions (autumn, spring, and winter seasons) compared to hot one (summer season).

Each of Ht and Hb were significantly ($p\leq0.01$) affected by HM × season interaction (Table 3). The highest and the lowest values of Ht were recorded in HM1× winter HM2× summer, and HM2× spring, respectively. It was also observed that insignificant differences were found among (HM1× winter), (HM1× spring), and (HM2× autumn) groups for Hb.

Triiodothyronine and Progesterone Concentrations

During the four seasons, all rabbits raised in 1st model had the highest values of T_3 and P_4 concentrations, followed by those kept in 2nd model. Rabbit does in 1st model showed higher values of T_3 and P_4 than those in 2nd model by +0.21 and +0.52; +0.31 and +2.03; +0.18 and +1.99 and +0.21 and +1.71 for spring, summer, autumn, and winter, respectively (Table 4).

The highest and lowest levels were obtained during the winter and summer seasons, respectively (Table 4). It is clear that the effect of housing models was more obvious in autumn and summer hot conditions compared to that of other seasons.

It is also evident from Table 4 that each of T_3 and P_4 high significantly ($p\leq0.01$) affected by housing model × season interaction and the highest values of T_3 were observed in HM1× spring, HM1× autumn, and HM1× winter. While the highest P_4 values were observed in HM1× autumn interaction in comparison to other interactions.

Table 3: Hematological responses in NZW rabbits as affected by two housing models during different seasons of the year

	Hematological responses	
Items	Hematocrit (HT %)	Hemoglobin (Hb, g/dl)
Effect of Housing Models (HM):		
Model 1 (HM1)	36.240	11.660
Model 2 (HM2)	32.010	10.370
SEM	0.3000	0.1900
p-value	0.0021	0.0001
Effect of seasons:		
Spring	34.73^{B}	11.03^{B}
Summer	33.01^{C}	10.09^{D}
Autumn	34.40^{B}	11.80^{A}
Winter	35.14^{A}	10.95^{C}
SEM	0.320	021
p-value	0.0419	0.0315
Effect of interaction (HM × Seasons):		
HM1× Spring	36.11^{b}	11.68^{b}
HM2× Spring	31.34^{e}	10.37^{e}
HM1× Summer	35.52^{c}	11.00^{c}
HM2× Summer	30.50^{e}	9.17^{d}
HM1× Autumn	36.18^{ab}	12.38^{a}
HM2× Autumn	32.61^{d}	11.59^{b}
HM1× Winter	37.13^{a}	11.56^{b}
HM2× Winter	33.15^{c}	10.33^{e}
SEM	0.290	0.170
p-value	0.0080	0.0003

$^{a, b, c, d}$ Means in the same column with different superscripts are significantly different ($p<0.05$)
$^{A, B, C, D}$ Means in the same column with different superscripts are significantly different ($p<0.05$)

Table 4: Some hormonal profile responses in NZW rabbits are affected by two housing models during different seasons of the year

	Hormonal profile responses	
Items	Triiodothyronine (T_3, ng/dl)	Progesterone (P_4, ng/dl)
Effect of Housing Models (HM):		
Model 1 (HM1)	1.5100	10.310
Model 2 (HM2)	1.2500	08.750
SEM	0.0900	0.4300
p-value	0.0426	0.0014
Effect of seasons:		
Spring	1.40^{A}	09.72^{B}
Summer	1.35^{B}	09.08^{D}
Autumn	1.42^{A}	10.04^{A}
Winter	1.41^{A}	09.37^{C}
SEM	0.06	0.380
p-value	0.0092	0.0191
Effect of interaction (HM × Seasons):		
HM1× Spring	1.50^{a}	11.68^{b}
HM2× Spring	1.29^{c}	10.37^{e}
HM1× Summer	1.50^{a}	11.00^{c}
HM2× Summer	1.19^{d}	09.17^{d}
HM1× Autumn	1.51^{a}	12.38^{a}
HM2× Autumn	1.33^{b}	11.59^{b}
HM1× Winter	1.51^{a}	11.56^{b}
HM2× Winter	1.30^{bc}	10.33^{e}
SEM	0.07	0.510
p-value	0.0001	0.0001

$^{a, b, c}$ Means in the same column with different superscripts are significantly different ($p<0.05$)
$^{A, B, C, D}$ Means in the same column with different superscripts are significantly different ($p<0.05$)

Table 5: Litter size at birth, 3rd week, and at weaning (4th week) in NZW rabbits under the two housing models during the seasons of the year

Items	Litter size at: At birth	3rd week	4th week (weaning)
Effect of Housing Models (HM):			
Model 1 (HM1)	6.9300	5.9800	5.3400
Model 2 (HM2)	4.9200	4.2000	3.7800
SEM	0.1300	0.1600	0.1000
p-value	0.0168	0.0091	0.0019
Effect of seasons:			
Spring	6.27^{A}	5.82^{A}	5.00^{A}
Summer	5.80^{C}	4.97^{C}	4.04^{C}
Autumn	6.17^{B}	5.06^{B}	4.61^{B}
Winter	5.75^{D}	4.51^{D}	4.61^{B}
SEM	0.12	0.14	0.12
p-value	0.0255	0.0171	0.0308
Effect of interaction (HM × Seasons):			
HM1× Spring	7.08^{a}	6.00^{a}	5.89^{a}
HM2× Spring	5.45^{c}	5.64^{c}	4.10^{d}
HM1× Summer	7.00^{a}	6.16^{a}	5.00^{b}
HM2× Summer	4.59^{d}	3.78^{e}	3.07^{e}
HM1× Autumn	6.88^{b}	5.88^{b}	5.23^{bc}
HM2× Autumn	5.45^{c}	4.23^{d}	3.99^{d}
HM1× Winter	6.78^{b}	5.89^{b}	5.25^{c}
HM2× Winter	4.71^{d}	3.13^{f}	3.97^{d}
SEM	0.15	0.13	0.11
p-value	0.0006	0.0001	0.0015

$^{a, b, c, d, e, f}$ Means in the same row with different superscripts are significantly different (p<0.05)
$^{A, B, C, D}$ Means in the same row with different superscripts are significantly different (p<0.05)

Reproductive Performance of Rabbit Does

Litter Size

Concerning the effect of the housing model, all rabbits reared in model 1 showed significantly ($p\leq0.05$) greater litter size at birth, 3rd week, and at weaning than those in the 2nd model (Table 5). The increased differences between the two models for LS at birth, 3rd week and at weaning of rabbits in 1st model than those in 2nd model, on averages, were 1.89, 1.78, and 1.56, respectively.

Regarding to the effect of season, showed the highest values of LS at weaning during spring and the lowest ones during summer. Values of LS at weaning decreased in the summer season than in spring by 23.8%.

As regards Table 5 the interaction effects were highly significant ($p\leq0.01$) on LS at birth, 3rd week, and at weaning (4th week) in NZW rabbit does where the highest values of LS at weaning were recorded in HM1 × spring in compared to other interactions.

Litter Weight

The litter weight was clearly affected by housing conditions throughout four seasons, the weight in the 2nd model was about half the value of that in the 1st model (Table 6). The increases (differences between the two models) in litter weight at birth, 3rd week, and at weaning of rabbits in model 1 than those in model 2, on average, were 138.5, 677.0, and 800.3 g, respectively.

Regarding to the effect of season, does showed the highest values of LW at weaning during spring and the lowest ones during summer. Summer average decreased than that of spring by 26.5%.

Concerning, HM × season interactions, it is clear that rabbit rear in HM1 led to insignificant differences between both of autumn and winter seasons for LW at weaning (Table 6). Moreover, the highest values of LW at weaning were found in HM1×spring and the lowest ones were by HM2× summer.

Bunny Weight

As regards the housing effect, bunny weight (BW, g) at successive ages in the 1st model recorded the highest values. In contrast, those kept in the 2nd model showed the lowest values (Table 7). Data found in the same Table also showed that BW at different ages in the two housing models was significantly ($p\leq0.05$) lower in the summer season compared to other seasons.

Table 7 also revealed that, HM × season interaction high significant effect ($p\leq0.05$) on means of bunny weight at birth, 3rd week, and at weaning (4th week). All these means were higher in HM1× autumn than in other interactions.

Table 6: Litter weight (LW, g) at birth, 3rd week, and at weaning (4th week) in NZW rabbits under the two housing models during the seasons of the year

Items	Litter weight at: At birth	3rd week	4th week (weaning)
Effect of Housing Models (HM):			
Model 1 (HM1)	400.85	1570.10	2009.84
Model 2 (HM2)	262.36	0893.11	1209.51
SEM	14.130	22.32	30.31
p-value	0.0001	0.0001	0.0001
Effect of seasons:			
Spring	344.55^{A}	1416.50^{A}	1831.73^{A}
Summer	307.78^{C}	1024.66^{C}	1346.31^{C}
Autumn	349.03^{A}	1300.00^{AB}	1641.01^{B}
Winter	325.09^{B}	1186.15^{B}	1619.80^{B}
SEM	11.340	22.13	29.32
p-value	0.0235	0.0119	0.0187
Effect of interaction (HM × Seasons):			
HM1× Spring	404.55^{a}	1639.00^{b}	2310.05^{a}
HM2× Spring	284.55^{c}	1194.10^{d}	1353.41^{d}
HM1× Summer	385.56^{b}	1325.14^{c}	1755.50^{c}
HM2× Summer	230.00^{e}	722.17^{f}	0937.11^{e}
HM1× Autumn	412.80^{a}	1670.90^{a}	1993.26^{b}
HM2× Autumn	285.25^{c}	926.92^{e}	1288.73^{d}
HM1× Winter	400.49^{a}	1643.01^{b}	1980.56^{b}
HM2× Winter	249.69^{d}	729.29^{f}	1258.80^{d}
SEM	14.050	25.180	27.34
p-value	0.0321	0.0001	0.0015

a, b, c, d, e, f Means in the same row with different superscripts are significantly different ($p<0.05$)
A, B, C Means in the same row with different superscripts are significantly different ($p<0.05$)

Table 7: Bunny weight at birth, 3rd week, and at weaning (4th week) in NZW rabbit does under the two housing models during the seasons of the year

Items	Bunny weight at: At birth	3rd week	4th week (weaning)
Effect of Housing Models (HM):			
Model 1 (HM1)	57.82	262.82	375.41
Model 2 (HM2)	51.86	213.73	318.84
SEM	0.410	1.32	30.31
p-value	0.0001	0.0001	0.0001
Effect of seasons:			
Spring	54.59^{B}	242.43^{C}	361.14^{A}
Summer	52.54^{C}	203.09^{D}	328.15^{D}
Autumn	56.17^{A}	251.61^{B}	352.06^{B}
Winter	56.07^{A}	255.97^{A}	347.16^{B}
SEM	1.110	6.87	13.55
p-value	0.0235	0.0119	0.0187
Effect of interaction (HM × Seasons):			
HM1× Spring	57.14^{b}	273.13^{b}	392.18^{a}
HM2× Spring	52.04^{d}	211.72^{e}	330.10^{c}
HM1× Summer	55.08^{b}	215.12^{d}	351.10^{bc}
HM2× Summer	50.00^{d}	191.05^{f}	305.19^{e}
HM1× Autumn	60.00^{a}	284.09^{a}	381.12^{ab}
HM2× Autumn	52.34^{cd}	219.13^{d}	322.99^{cd}
HM1× Winter	59.07^{a}	278.93^{b}	377.23^{b}
HM2× Winter	53.07^{c}	233.01^{c}	317.08^{d}
SEM	1.17	10.67	16.34
p-value	0.0500	0.0001	0.0015

a, b, c, d, e Means in the same row with different superscripts are significantly different ($p<0.05$)
A, B, C, D Means in the same row with different superscripts are significantly different ($p<0.05$)

Table 8: LSM ± S.E. of Milk Yield (MY, g/wk) in the third week (21st day) of lactation in NZW rabbits as affected by two housing models during different seasons of the year

Items	Milk Yield (MY, g) in 3rd week
Effect of Housing Models (HM):	
Model 1 (HM1)	632.60
Model 2 (HM2)	602.70
SEM	14.410
p-value	0.0001
Effect of seasons:	
Spring	601.0^{B}
Summer	580.7^{C}
Autumn	602.2^{B}
Winter	686.7^{A}
SEM	15.06
p-value	0.0035
Effect of interaction (HM × Seasons):	
HM1× Spring	615.6^{c}
HM2× Spring	586.4^{e}
HM1× Summer	600.1^{d}
HM2× Summer	561.3^{f}
HM1× Autumn	616.6^{c}
HM2× Autumn	587.8^{e}
HM1× Winter	698.0^{a}
HM2× Winter	675.3^{b}
SEM	13.71
p-value	0.0110

$^{a, b, c, d}$ Means in the same column with different superscripts are significantly different (p<0.05)
$^{A, B, C}$ Means in the same column with different superscripts are significantly different (p<0.05)

Milk Yield

Does reared in the 1st model recorded the highest values of MY in the 3rd week throughout four seasons (Table 8). In contrast, those reared in Model 2 showed the lowest values (Table 8). There were significant ($p \leq 0.05$) differences in MY levels among different seasons. The highest value for MY was detected in rabbits does rear in mild environmental conditions (autumn, spring, and winter seasons) compared to hot ones (summer season).

Housing model × season interaction had a significant ($p \leq 0.05$) effect on MY at 3rd week of rabbit does. Rabbit does in HM1 during the winter season had higher ($p \leq 0.05$) values of MY in 3rd week than the other interactions as shown in Table 8.

Discussion

As mentioned by Ashour *et al.* (2017) in the subtropical zone, the rabbits' housing roof construction fulfills resistance to severe changes in indoor microclimate during cold winter and hot summer. The current study proved that roofing with wood (the 1st model) was generally advantageous in providing better comfort conditions during all seasons studied than that in the second model, roofed by iron sheet. The prior privileges of the wood roof are clear in the temperature differences indoors (Table 1). So, the roofs of housing play an important role in regulating the temperature inside a building. This is due to their physical properties, which are particularly effective at reducing heat from solar radiation.

Heat flow from the outer surfaces of the wood sheet roof and iron roof to their inner surfaces is determined by the materials' conductivity, which in turn causes to distribute the heat within indoors by convection and radiation. In the case of the wood sheet, which has low thermal conductivity (K value = 0.10 Wm-1K-1) (CIBS, 1999) minimizes heat flow. According to similar results recorded by Ashour *et al.* (2005) in the study of thermodynamics in the model roofed by iron sheet. In this respect, Hatem *et al.* (2011) showed that the temperature differential and material thermal conductivity both affect how quickly heat moves through a material. Differences between both housing models can be attributed to the variations in the indoor AT (Table 3), as a reflection of climatic temperature alongside the intensity of solar radiation.

The highest values for either RT or RR in summer seasons compared to other seasons for rabbits reared in 2nd housing model (Table 2) may be due to its inadequate and ineffective sweat glands to remove extra heat (Ewuola *et al.*, 2022). These results matched the conclusions of Fabrizio *et al.* (2018). The increase in RT of heat stress may be caused by the animals' inability to prevent an increase in RT under conditions of high ambient temperature or by the animals' physiological systems' inability to manage the overheating caused by being exposed to high AT (Liang *et al.*, 2022). Oladimeji *et al.* (2022) showed that elevated AT above the Thermo-Neutral Zone (TNZ) causes a compromised homeostatic system in rabbits, impairing their welfare. In hot weather, the rabbit's ability to control body temperature is mostly dependent on respiratory evaporation. With respect to the effect of the housing model, it can be noticed that all rabbits kept in model 1 had significantly ($p<0.05$) lower RT and RR than those in model 2 throughout the year seasons, with one exception only for does' RR during winter. This is confirmed that model 1 achieved a TNZ during the four seasons for raising rabbits does than model 2 with a single metal roof. Variations in RR due to housing models can be explained as a result of variations in environmental conditions inside these models. During the hot season, the 1st housing model maintained an AT within the rabbit's comfort zone, so RR remained at the normal level. Contrary to the adverse environmental conditions (high AT) in model 2 which led to increased RR to increase heat loss throughout the evaporation of water as found by Ashour *et al.* (2017). The RR is the most sensitive physiological response to heat stress (Ashour and Shafie, 2002). Harkness reported that under normal conditions for rabbits, approximately 35% of the heat was dissipated by evaporation, 60% was lost through panting and 40% passively through the skin. Ashour *et al.* (2017) proved that the RR was significantly (p≤0.01) affected by the housing model.

The optimum thermoregulatory for rabbits in model 1 is due to that the AT was the lowest in this model as a result of the good insulation capacity of the wood roof.

As mentioned in Table 3, the values of these hematological traits were always low in-house no. 2 in compared to house no. 1 denoting that the thermal condition is much better in model 1. These differences are due to adverse environmental conditions in the 2nd housing model, which were under heat stress during summer. The increase in erythrocyte breakdown and hemodilution might be caused by the high temperature. Reduction in Ht and Hb could be a reaction to reduce oxygen uptake and hence, metabolic heat production (Ashour and Shafie, 2002). Heat stress can indirectly disrupt homeostasis by activating fibroblasts, leukocytes, and endothelial cells in acute infections (Abdelnour *et al*., 2020). These results may be due to increasing ambient temperature in 2nd model. There is also more heat dissipation in rabbits kept in the 1st housing model, than that kept in the 2nd model. Under hot conditions, an animal's first reaction is to increase skin temperature by vasodilating its blood vessels in order to transfer more heat from the body's center to the skin. The overall averages of T_3 and P_4 in the current study are within the ranges reported by Sharaf *et al*. (2021); Habeeb *et al*. (2019). Rabbits that have higher T_3 and P_4 concentrations in 1st model than those in 2nd model are another evidence that model 1 had a worse internal condition than the others. Similar results were investigated by Ashour *et al.* (2017).

The greater LS for NZW does in the 1st housing model is justified by the better thermal conditions than that in model 2. On the other hand, the drop in LS at the 3rd week and at weaning in model 2 may be attributed to the impact of various environmental factors on lactation capacity and mothering ability because of hypothermia. These results agree with the findings of Desouky (2021); El-Ratel *et al*. (2023). The increase in P_4 was accompanied by the increase in LS (Ashour and Abdel-Rahman, 2019).

The lower BW in the 2nd model of housing in comparison to the 1st model can be attributed to the reduction of milk yield of hyperthermic rabbits and stunted metabolic rate with the result of depressing embryonic weight at birth. Lower LW during weaning was noted by Liang *et al.* (2022) as a result of the heat stress. When the temperature was greater than 21°C, each individual's weaning weight was reduced by 14 g per degree. Rabbits raised in temperate areas typically have larger litter sizes and heavier litter than those raised in hot climates because heat stress causes energy metabolism and calorigenic hormones to decline, which lowers milk production and so the decrease of bunny weight.

In the present study increased MY in model 1 compared to the 2nd model could be attributed to an increase of T_3 which indicates to increased metabolic rate. Referring to the thermal characteristics of housing models, the 1st model secured ambient temperature within the comfort zone for the rabbits while the 2nd had a higher ambient temperature. These environmental conditions were reflected in the doe's performance. Besides that, as milk synthesis depends on prolactin, a lactogenic hormone (Abdel-Khalek *et al*., 2022) and because of the marked decrease of this hormone in adverse hot conditions as in model 2 (Ashour *et al*., 2017) MY decreased under model 2. In this respect, Pascual *et al.* (1996) concluded that MY off lactate decreased as temperature increased. According to Rafai and Pappu (1984), for every 1°C increase in AT above 20°C, daily MY decreases by 7.7 g. Lactating rabbit does appear to respond to greater AT extremely sensitively (Szendrő *et al*., 2018).

Conclusion

As found in current results, rabbits' housing roof construction is considered an influential factor through its integral action with both thermo-respiratory responses and the reproductive performance of rabbits. Also, the outcomes of the current assessment highlighted the possible welfare of rabbits in the wood roof housing model. The 1st model secured ambient temperature within the thermoneutral zone for the rabbits while the 2nd model had a higher ambient temperature. So, the wooden roof in the 1st model provided a comfortable zone during climatic change that could improve the reproductive performance of rabbits.

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Author's Contributions

Khaled Hassan El-Kholy: Written and reviewed the manuscript.

Abdel-Monem Abel-Rahman Sedki: Statistical analysis of data.

Hossam Zakaria Khalil: Farm and laboratory work.

Ibrahim Talat El-Ratel: Developed the concept of the manuscript.

Ethics

This article is original and has never been published before. The author has also confirmed to all authors involved in this study to read and agree to the contents of this article and that there are no ethical issues involved.

Competing Interests

There are no conflicts of interest, according to the authors.

Consent to Publication

All authors agreed to the public this original research work.

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