Strategies to reduce heat stress in sheep housing

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Abstract
Three experiments were carried out to assess the effects of ventilation regimens, shading and time of feeding on the welfare and production performance of lactating ewes in summer in a Mediterranean climate. In the first trial we tested the effects of three different ventilation regimens: low (33 m^3/h/head; LVR), moderate (66 m^3/h/head; MVR) and programmed (operating at 30 °C air temperature and 70% relative humidity; PROGR). In the sheep houses after LVR and MVR treatments were detected higher air concentrations of ammonia and carbon dioxide than after PROGR treatment and sheep of those groups showed higher respiration rate and rectal temperatures. Ewes under the LVR treatment also displayed impaired humoral immune responses and higher plasma cortisol levels than ewes under PROGR or MVR treatment. In the second trial, we tested the effects of two ventilation rates (35 vs 70 m^3/h per ewe), two air-speeds (2 vs 4 m/s) and two lengths of ventilation cycles (30 vs 60 min/cycle). Results suggest that proper air speed and length of ventilation cycles, aside from ventilation rate, are required to sustain welfare of housed sheep in summer.
When comparing the effects of providing shaded areas we found that sheep exposed to solar radiation displayed enhanced respiration rate and increased rectal temperature compared with animals protected from solar radiation. Exposure to solar radiation also depressed cellular immune response and adversely affected the hygienic quality of ewe milk In addition, sheep exposed to direct solar radiation exhibited an increase of inactive behaviours and showed high non-esterified fatty acids plasma concentrations .

Keywords : sheep welfare; heat stress; solar radiation; ventilation regimen.

Introduction
Wide areas of the Mediterranean basin, where dairy sheep are very common, have ambient temperatures in late spring and summer that often exceed the thermal neutral zone (5 to 25 °C) of sheep (Curtis, 1983). Hot climates may induce a rise in body temperature and breath rate, which increases energy requirements for maintenance by 7-25%. Feed intake decreases in heat stressed sheep (Abdalla et al., 1993), especially when they are offered low quality feed (Costa et al., 1992), due to both the effort of reducing heat production and the slower feed transit through the digestive tract. Under these conditions, body reserves of fat and nitrogen are used to supply energy through gluconeogenesis at the expense of the mammary gland, especially in early lactating animals (Amaral-Phillips et al., 1993). High ambient temperatures can also result in plasma mineral imbalance, especially due to reduction in sodium, potassium, calcium and phosphorus and increase in chloride concentrations (Kume et al., 1987; Schneider et al., 1988). Published evidence does not prove that ambient temperature is directly related to udder health, but indicates that it may interact with other predisposing conditions to exert an influence (Klastrup et al., 1987). Beede and Collier (1986) indicated protection from solar radiation and improvement of nutritional management as well as use and genetic development of heat-resistant breeds as the main strategies to improve

productivity in animals raised in hot climates. Ventilation is one of the most important factors in affecting the welfare and production performance of farmed animals, too. Inadequate ventilation systems cannot provide an efficient control of temperature and humidity in animal houses and can lead to increased airborne particulate and gaseous pollutant concentrations, which can represent a significant burden to the respiratory tract of humans and livestock (Rylander, 1986; Hartung, 1994). Previous experiments have shown that poor ventilation is responsible for increased aerial concentrations of viable microbes, ammonia and carbon dioxide, reduced feed efficiency and enhanced aggressive interactions in farmed animals. Three experiments were carried out to assess the effects of ventilation regimens, shading and changing time of feeding to late afternoon on the welfare and production performance of lactating ewes in summer in a Mediterranean climate.

Material and methods

The experiments were conducted at Segezia research station of the Italian Istituto Sperimentale per la Zootecnia (latitude: 41° 27' 6" and longitude: 15° 33' 5"). The climate of this area is Mediterranean, with a rainfall of about 500 mm, a mean temperature of 24.1 °C and a mean relative humidity of 59.4% during summer over the last 40 years. In the first trial 36 lactating Comisana ewes were divided into three groups of 12 and separately housed on straw litter in 8m x 3m and 3.5m high rooms of the same building. Each room was provided with a mechanical negative-pressure system of ventilation, in which 0.28 m^2 suction fans were placed at 2.5 m from the floor and two 0.36 m^2 air inlets were placed at the ground level on the opposite wall. Fan speed was kept constant at 4.6 m/s. The three groups were designed low (LVR), moderate (MVR) and programmed ventilation regimen (PROGR). In LVR and MVR rooms, fans provided 10 ventilation cycles of 12.5 and 25 min/h, respectively. In the PROGR room, the fan was connected to temperature and humidity sensors, which provided an on/off two stage control function switching power to the fan. Ventilation system was programmed to operate at 30 °C ambient temperature and 70% relative humidity. A mean ventilation rate of 33, 66 and 173 m^3/h per ewe was provided in LVR, MVR and PROGR rooms. The ambient temperature and the relative humidity inside each room were continuously monitored throughout the trial by means of thermo-hygrographs (LSI) placed at a height of 1.5 m from the floor. Air was sampled 0.6 m from the floor twice a week at 0900 (fans switched off in LVR and MVR rooms) and at 16.30 h (fans switched on in all rooms). The concentration of mesophilic micro-organims, coliforms and yeasts/moulds were sampled using a Surface Air System pump (PBI International, Milan, Italy). Air concentrations of total (∅ > 5 μm) and breathable (∅ = 2-5 μm) dust were recorded twice weekly, using Digit pumps (Zambelli, Bareggio-Milan, Italy). A Lippman cyclone was used for collecting breathable dust. Cellulose nitrate filters having a diameter of 37 mm and pore size of 0.8 μm were used for this purpose. Air concentrations of gaseous pollutants were also recorded twice a week using a Gas Detection Pump (Dräger, Sicherheitstechnik Gmbh, Lübeck, Germany), provided with carbon dioxide, hydrogen sulphide, ammonia and methane detection tubes. Respiration rate (RR) and rectal temperature (RT) were monitored in all animals throughout the trial. At 1430 RR was recorded by a trained observer by counting the rate of flank movement and soon after RT was measured with an electronic thermometer having an accuracy to 0.1 °C. Behavioral observations were recorded by two trained observers equipped with video cameras every 15 min from 0930 to 12.30 h once per week. The measurement criterion at each observation period was the number of animals engaged in each of two postures (standing or lying) and of seven behavioral categories, which were eating, drinking, ruminating, walking, self-grooming and idling. The phytohemagglutinin (PHA) skin test was performed to induce non-specific delayed-type hypersensitivity. At d 3, 20 and 40 of the experiment, 1 mg of PHA (Sigma-Aldrich Italia, Milan, Italy) dissolved in 1 mL of sterile saline solution was injected intra-dermally into the middle of two 2 cm wide circles stamped on shaved skin in the upper side of each shoulder. The skinfold thickness was determined before PHA injection and 24 h after with a caliper. At d 2 of the study, 6 mg of chicken egg albumin (Sigma-Aldrich Italia) dissolved in 1 ml of sterile saline solution and in 1 ml of incomplete Freund's adjuvant (Sigma Aldrich-Italia) were injected subcutaneously in both shoulders of each ewes. A second injection without adjuvant was repeated 9 days later. Antibody titer was determined in blood samples collected in heparinized vacuum tubes immediately before the first antigen injection (2 days) and then at 11, 21, 30 and 40 days of the study period. An ELISA was performed in 96-well U-bottomed microtiter plates. At d 37 ewes were intravenously injected with 2 IU porcine ACTH/kg body weight$^{0.75}$ (Sigma-Aldrich Italia). Blood samples (10 ml) for evaluation of cortisol concentrations were collected in vacuum tubes from the jugular vein immediately before and 1, 2 and 4 h after ACTH injection. Hormone concentration was determined by a radioimmunoassay specific for ovine cortisol. Ewes were milked twice daily (08.00 and 15.00 h) using pipeline milking machines. Milk yield was recorded daily by means of graduated measuring cylinders attached to individual milking units. Milk samples, consisting of proportional volumes of morning and evening milk, were individually collected weekly in 200 ml sterile plastic containers after cleaning and disinfection of teats (70% ethyl alcohol) and discharging the first streams of foremilk. Milk samples were carried in our laboratory by means of transport tankers at 4 °C. The following measurements were carried out in agreement to International Dairy Federation standards, unless otherwise indicated: pH, total protein, fat and lactose content using an i.r. spectrophotometer (Milko Scan 133B; Foss Electric, Hillerød, Denmark), casein content, somatic cell count (SCC) using a Foss Electric Fossomatic 90 cell counter and polymorphonuclear neutrophil leukocyte count (PMNLC), by means of direct microscopic count in milk smears stained with May-Grünwald-Giemsa, renneting characteristics (clotting time, rate of clot formation and clot firmness after 30 min) using a Foss Electric Formagraph. The milk coagulating index (CoI) was calculated as the clot firmness to clotting time + rate of clot formation ratio. At the beginning of the trial, and fortnightly during the study period, the following bacteriological analyses were carried out on milk, according to International Dairy Federation standards: enumeration of mesophilic bacteria, psychrotrophs on plate count agar, total and fecal coliforms. The body weights and body condition scores of the ewes (in a six-point scale with 0=thin and 5=fat) were recorded during the trial.

In the second trial 36 lactating Comisana ewes were divided into three groups of 12 and separately housed in three rooms of the same building as in the first trial. In all rooms, fans provided 10 ventilation cycles per day. Treatments were: low ventilation (LOV-30), moderate ventilation with short ventilation cycles at high air speed (MOV-30) and moderate ventilation with long ventilation cycles at low air speed (MOV-60). In the LOV-30 room 30 min ventilation cycles were provided at a fan speed of 2 m/s. In the MOV-30 room 30 min ventilation cycles were provided at a fan speed of 4 m/s, while in the MOV-60 room 60 min ventilation cycles were provided at a fan speed of 2 m/s. In all rooms, ventilation rate was checked daily by placing a hot wire anemometer (LSI, I-20090, Settala Premenugo, Milan, Italy) over the air outlet and converting readings to m^3/h per ewe. The fans provided a mean ventilation rate of 35 m^3/h per ewe in the LOV-30 room and 70 m^3/h per ewe in the MOV-30 and MOV-60 rooms. Measures taken on air, animals and milk were the same of the first trial.

In the third trial, 40 late-lactating Comisana ewes were divided into four groups of 10 each, which were separately kept in open 5m x 12m pens with mesh-fence boundaries. Shade was provided by 3m x 8m and 3.5 m high brickwork rooms adjacent to open pens. During the study, animals were either exposed (EXP; not offered shade) or protected from solar radiation (PRO; offered shade). For each solar radiation treatment, feed was offered either in the morning at 10.00 (EXPM and PROM groups) or in the afternoon at 16.00 (EXPA and PROA groups), and the animals had free access to the feed at all times thereafter. Refusals were collected and weighed daily at 10.00, 13.00, 16.00 and 19.00 h. Open pens in EXP groups and shaded rooms in PRO groups were provided with 2 mangers. Averages of daily DM intake were 2.41, 2.25, 2.39 and 2.28 kg/ewe in PROM, EXPM, PROA and EXPA groups, respectively. Water was available at any time for all groups from automatic drinking troughs. Ambient temperature and relative humidity in protected and exposed areas were monitored throughout the trial. Respiration rate (RR) and rectal temperature (RT) were measured in all animals twice weekly. The phytohemagglutinin (PHA) skin test was performed to induce non-specific delayed-type hypersensitivity at d 10, 20 and 32 of the experiment, as described in previous trials. Behavioral observations were recorded by trained observers equipped with video cameras every 15 min from 08.00 to 20.00 h once per week. Jugular blood samples were taken from all ewes at the beginning and at d 21 and 42 of the experiment. Blood sampling was carried out at 07.00 h. Samples were centrifuged for 20 min at 3,500 r.p.m. and plasma was stored at -20 °C, except for a sub-sample which was analyzed enzymatically for plasma concentrations of glucose immediately. The following metabolites and enzymes in plasma were determined within three days from blood sampling: total protein, albumin, bilirubin, NEFA, calcium, inorganic phosphorus, chloride and magnesium, using colorimetrical methods, and total cholesterol, urea N, creatinin, aspartate amino-transferase (AST/GOT), alanine amino-transferase (ALT/GPT), gamma-glutamiltransferase (γ-GT), lactate- dehydrogenase (LDH) and alkaline phosphatase (ALP), using enzymatical methods. Sodium and potassium were diluted in a lithium solution and measured by a TRIFLAMM flame photometer (Digiflame, 00100 Rome, Italy). Ewes were milked twice daily (08.00 and 15.00 h) using a pipeline milking machine. Daily milk yield was recorded and milk samples were analyzed as described in previous trials. The body weights and body condition of the ewes were recorded at the beginning and at d 21 and 42 of the study period, after the morning milking but before feeding. All data were subjected to an analysis of variance, using the GLM procedure for repeated measures in the SAS statistical software. When significant effects ($P < 0.05$) were found the Student's t test was used to locate significant differences between means.

Results

First trial. Significantly higher temperature and humidity ($P < 0.001$) were found in LVR than in PROGR room, while both LVR and MVR treatment resulted in higher NH_3 and CO_2 air concentrations than PROGR treatment ($P < 0.05$). LVR and MVR ewes had a higher RT than PROGR ewes ($P = 0.001$). LVR animals also exhibited higher idling compared to PROGR ($P < 0.01$) and lower feeding times than MVR ($P < 0.05$) and PROGR animals ($P < 0.01$). LVR ewes displayed significant lower antibody titers ($P = 0.07$) than PROGR animals (Figure 1) and higher plasma cortisol levels than PROGR ($P < 0.01$) and MVR ewes ($P < 0.05$) 60 min after ACTH injection (Figure 2). LVR treatment resulted in lower yields of milk ($P < 0.01$) and reduced feed efficiency ($P < 0.01$) than PROGR treatment.

Second trial. Averages of maximum THI were about 3 points higher in the LOV-30 and the MOV-30 than in the MOV-60 room, whereas no differences emerged in the air concentrations of dust, gaseous pollutants and microorganisms. Significant interactions of treatment x time ($P < 0.05$) were found for respiration rate, and for the time the ewes spent lying, idling and eating in the afternoon. Significant effects of ventilation regimen x time ($P < 0.05$) were also observed for milk yield and milk renneting parameters, the LOV-30 ewes giving smaller volumes of milk with a deteriorated coagulating behavior than those of the MOV-60 group during the second half of the trial. When the renneting parameters were gathered in the milk coagulating index (CoI), significant differences ($P < 0.05$) were found between the LOV-30 and the MOV-60 group (Figure 3). No significant differences emerged in ewe immune and endocrine responses.

Third trial. In exposed areas, weekly averages of maximum ambient temperatures were over 30 ^{0}C throughout the study period and often exceeded 35 °C. Maximum ambient temperatures and relative humidities were 3.9 to 6.8 °C and 6.3 to 12.3% lower in protected than in exposed areas. During daytime, averages of THI were always near or over 80 in exposed areas, whereas they only exceeded 75 during the second half of the trial. Solar radiation ($P < 0.00l$) and the interaction of solar radiation x time of feeding ($P = 0.01$) had significant effects on rectal temperatures (Figure 4). EXPM ewes had higher rectal temperatures than EXPA ewes, which in turn exhibited higher RT compared to PROM and PROA ewes. EXP groups also had significantly higher respiration rates ($P < 0.01$) than PRO groups. Immune response was lower ($P < 0.001$) in EXPM ewes at d 10 and in both EXPM, EXPA and PROM animals ($P < 0.05$) at d 20 compared to PROA ewes (Figure 5). Exposure to solar radiation resulted in decreased plasma concentrations ($P < 0.05$) of alanine amino-transferase (ALT/GPT) ($P < 0.05$), alkaline phosphatase (ALP) ($P < 0.05$), Potassium ($P < 0.05$), Magnesium ($P < 0.05$) as well as in increased levels of NEFA ($P < 0.01$) and aspartate amino-transferase (AST/GOT) ($P < 0.05$). Milk yield and composition were not changed by exposure to solar radiation and time of feeding, but the EXPM treatment resulted in lower yields of casein and fat ($P < 0.05$) and reduced clot firmness ($P < 0.05$) compared with the three other treatments. Milk SCC was similar across treatments, but PMNLC was higher ($P < 0.0l$) in EXPM than in PROM and PROA milk. EXPM animals also had the greatest amounts of total and fecal coliforms ($P <0.0l$) and of *Pseudomonadaceae* ($P < 0.05$) as well as the highest number of mastitis related pathogens in their milk.

Conclusions

Our results suggest that a fan ventilation system programmed to operate over upper critical temperature and humidity is not economically attractive in dairy sheep housing. In fact, it involved about a three fold greater energy cost and did not lead to remarkable improvements of ewe welfare and productivity compared to an intermittent regimen split in 25 min/h ventilation cycles during the warmest hours of the day. A further reduction of ventilation cycles to 12.5 min/h resulted in ewe displaying altered behaviour, immune and endocrine responses and giving lower yields of milk. Therefore, our findings indicate that a ventilation regimen, providing ventilation cycles during the warmest hours of the day and the night at a mean ventilation rate of 66 m^3/ewe per hour may adequately sustain the welfare and production performance of lactating ewes raised in Mediterranean climates during summer.

Doubling air speed from 2 to 4 m/s and ventilation rate from 35 to 70 m^3/h per animal did not lead to any significant improvement of ewe well-being and performance in the groups subjected to 30 min ventilation cycles. Instead, the ventilation rate being kept at 70 m^3/h per animal, the group subjected to short ventilation cycles displayed a more intense activation of thermoregulatory mechanisms during the warmest part of the study period compared to the group benefiting from 60 min ventilation cycles.

Exposure to solar radiation under ambient temperatures over 35 °C prevented ewes from maintaining their thermal balance. Provision of shade played a major role in helping the lactating ewe to minimize the adverse effects of high ambient temperatures on thermal balance and energy and mineral metabolism. Reduction of heat load during the warmest hours of the day through feed administration in late afternoon was beneficial to ewes in minimizing the impact of thermal stress on their immune function and udder health. Both solar radiation and time of feeding had only a minor impact on ewe production performance.

References

Abdalla E.B., Kotby E.A., Johnson H.D. 1993. Physiological responses to heat-induced hyperthermia of pregnant and lactating ewes. Small Ruminant Research, 11, 125-134.

Amaral-Phillips D.M., McGilliarg A.D., Lindberg G.L., Veenhuizen J.J., Yang J.W. 1993. Effects of decreased availability of glucose for dairy cows. Journal of Dairy Science, 76, 752-761.

Beede D.K., Collier R.J. 1986. Potential nutritional strategies for intensively managed cattle during thermal stress. Journal of Animal Science, 62, 543-554.

Costa M.J.R.P., Siva R., Souza R.C. 1992. Effect of air temperature and humidity on ingestive behaviour of sheep. International Journal of Biometereology, 36, 218-222.

Curtis S.E. 1983. Environmental management in animal agriculture. Iowa State Press, USA.

Hartung J. 1994. The effect of airborne particulate on livestock health and production. In: I. Ap Dewi, R.F.E. Axford, I.F.M. Marai, H. Omed, Pollution in livestock production systems. CAB International, UK, 55:69.

Klastrup O., Nakken G., Bramley J., Bushnell R. 1987. Environmental influences on bovine mastitis. IDF (International Dairy Federation Bullettin no. 217), Brussels, Belgium.

Kume S., Kurihara M., Takahashi S., Shibata M., All T. 1987. Effect of hot environmental temperature on major mineral balance in lactating cows. Japanese Journal of Zootechnical Science, 58, 764-770.

Rylander R. 1986. Lung diseases caused by organic dusts in the farm environment. American Journal of Industrial Medicine, 10, 221-227.

Schneider P.L., Beede D.K., Wilcox C.J. 1988. Nycterohemeral patterns of acid-base status, mineral concentrations and digestive function of lactating cows in natural or chamber heat stress environments. Journal of Animal Science, 66, 112-125.

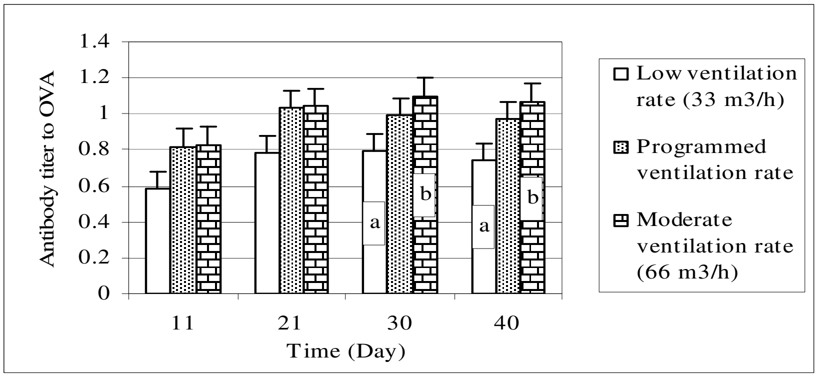

Figure 1. Least square means ± SEM of antibody response to chicken egg albumin injection in ewes subjected to a low (LVR), moderate (MVR) and programmed ventilation regimen (PROGR)

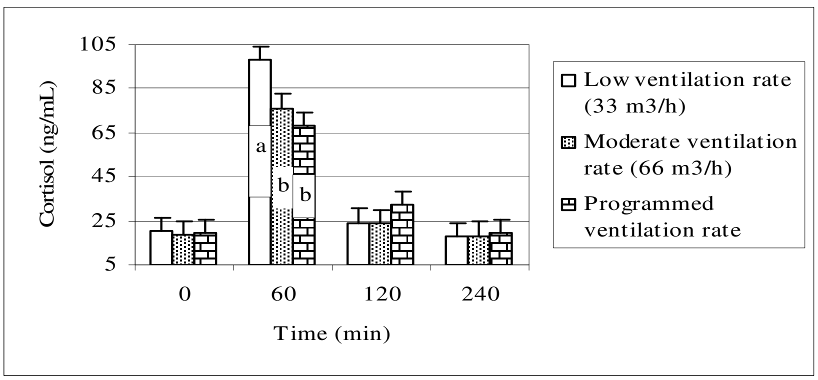

Figure 2. Least square means ± SEM of plasma cortisol levels after porcine ACTH injection in ewes subjected to a low (LVR), moderate (MVR) and programmed ventilation regimen (PROGR)

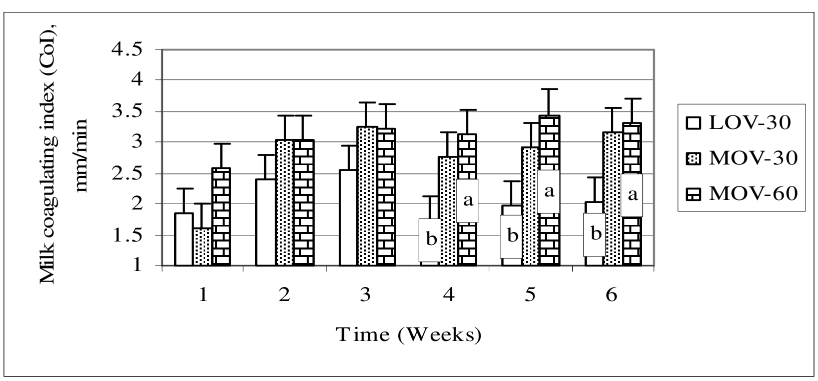

Figure 3. Least squares means ± SE of coagulating index (CoI) in ewe milk as affected by a low ventilation regimen (LOV-30), and moderate ventilation regimens providing short (MOV-30) and long ventilation cycles (MOV-60)

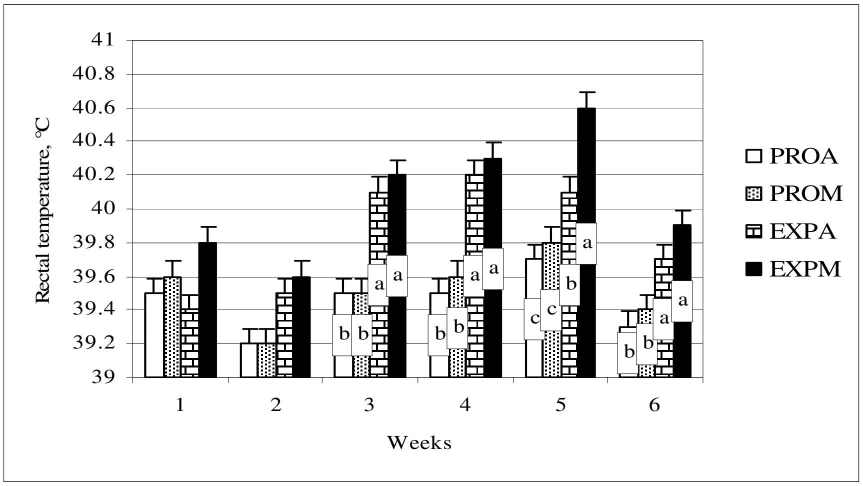

Figure 4. Rectal temperature of ewes when protected or exposed to solar radiation and fed in the morning (PROM, EXPM) or in the afternoon (PROA, EXPA)

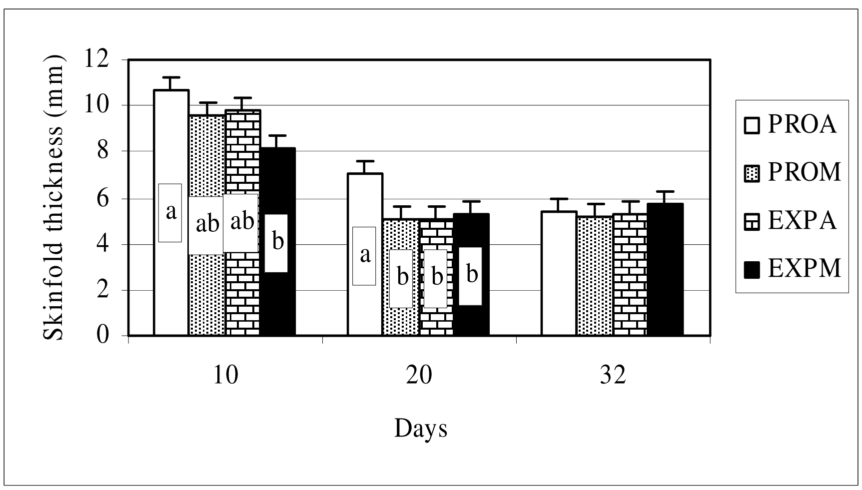

Figure 5. Immune response to PHA injection in ewes when protected or exposed to solar radiation and fed in the morning (PROM, EXPM) or in the afternoon (PROA, EXPA)