ABSTRACT: Causes of welfare reduction in dairy sheep flocks are presented and their impact on ovine milk and cheese quality is discussed. Attention is focused on climatic extremes, poor housing and milking hygiene, and nutritional imbalance: mechanisms are outlined through which stress-induced reduction of immune function can result in poor milk composition, deteriorated renneting ability of milk and altered proteolysis in cheese during ripening. In particular, the impact is brought out of exposure to high ambient temperature on the nutritional properties of ewe milk, in terms of increased short-chain and saturated fatty acids, and decreased unsaturated to saturated fatty acid ratio. As well, the relationship is highlighted between ewe welfare and udder health. Especially under poor hygiene conditions the risk of mastitis markedly increases due to reduction of the natural defense mechanisms of the teat and mammary gland and increased number and pathogenicity of the micro-organisms in contact with the entrance of the teat canal. Evidence is provided that rise in milk somatic cell count, in response to bacteria penetration into the udder, can lead to decreased milk yield and altered composition of milk and cheese, due to extensive epithelium secretory cell damage.

Keywords: Dairy sheep, Welfare, Milk quality, Cheese quality.

INTRODUCTION – The concept of animal welfare has ethical roots so it finds in itself its own reason for existence. Pet owners are fully aware of this, and farmers are starting to share such a thought. Of course, the substantial difference between pet owners and farmers lies in the fact the latter have an economic function so they legitimately asked themselves about cost and benefits of measures for sustaining animal welfare prior to adopt them. Generally rearing practices respectful of animal welfare are not more expensive than non-respectful ones in running conditions, whereas the turning phase from non-respectful to respectful practices is almost always accompanied by an increase, even if temporary, of costs to the farmer. Thus, it is advisable that measures aimed at improving farmed animal welfare are accompanied by specific grant programmes. However, to a lot of farmers the fact that their profit does not drop after the adoption of rearing practices respectful to animal welfare may not be a sufficient incentive; hence, evidence from scientific research that protection of animal welfare can turn to profit, in terms of reduced veterinary costs and of increased commercial value of animal products, can play a major role in sustaining the concept of animal welfare with farmers. The aim of this review is just to highlight the relationships between ewe welfare and ovine milk and cheese quality.

IMPACT OF HIGH AMBIENT TEMPERATURES ON MILK AND CHEESE QUALITY – In the Mediterranean basin main threats to dairy flock welfare come from climatic extremes, poor hygiene of housing and milking, and temporary nutritional imbalance. Protecting sheep from solar radiation, changing the time of feeding to late afternoon and providing sheep houses with adequate air change are the main strategies for helping flocks to face high ambient temperatures. Experiments conducted by Sevi et al. (2001a) showed that prolonged exposure to average daily temperatures of 30 °C or even to temperatures of 35 °C and THI of 80 for few hours a day is stressful to the lactating ewe, as documented by increased breath rate and rectal temperature, and reduced cell-mediated immune response. Worsening of milk coagulating properties and fat profile was also observed after ewe exposure to high ambient temperatur...
temperatures. In particular, hot weather resulted in higher proportions of short chain and saturated fatty acids (FA) in milk, primarily due to increased contents of caproic, capric, lauric, myristic and stearic acids, and decreased contents of oleic, linoleic and linolenic acids (Sevi et al., 2002b). As a consequence, the long to short chain and the unsaturated to saturated fatty acid ratios were significantly lower by 4 and 13 % in the milk yielded by ewes exposed to solar radiation under high ambient temperature compared to that of shaded animals. Changes in plasma NEFA concentrations and in body condition scores suggested that the increased energy demand for thermoregulation in unshaded ewes hampered the reconstitution of body reserves and probably the contribute of body fat to milk synthesis. Reduced energy availability for galactopoiesis may per se have a detrimental effect on the synthesis and assembly of milk long-chain lipids, because the lengthening of the fatty acid chain requires great amounts of energy to synthesize NADPH in the mammary tissue from glucose oxidation (Kaufmann and Hagemeister, 1987). Moreover, it is known that long-chain fatty acids (LCFA) in milk derive from body fat reserves and feeding via the low density lipoproteins and chilomicrons to a smaller extent (Eppard et al., 1985). However, if an environmental challenge, such as high ambient temperature, is of sufficient magnitude, homeostatic controls for survival can overwhelm homeorhetic mechanisms operating in support of milk synthesis. Also reduced rate of digesta passage under high ambient temperature (Christopherson and Kennedy, 1983), which can allow more time for microbial hydrogenation of dietary, may be claimed to explain reduced proportion of unsaturated fatty acids (UFA) in the milk of ewes exposed to high ambient temperature. In Sevi et al.’s experiments, the reduction of UFA in the milk from unshaded ewes depends on decreased content of oleic acid at a large extent. Extensive conversion of stearic to oleic acid occurs in mammary epithelium (Grummer, 1991), due to stearyl desaturase, which is concentrated in the endoplasmatic reticulum of the lactating cell (Kaufmann and Hagemeister, 1987). Exposure to solar radiation under high ambient temperature results in increased milk concentrations of neutrophil leukocytes, and of coliforms and staphylococci (Sevi et al., 2001a). There is evidence that neutrophil leukocyte recruitment in response to bacteria penetration into the udder can cause extensive epithelium secretory cell damage with the same mechanisms used to face invading bacteria (Burvenich et al., 2000). In addition, enzymes produced by the bacterial flora may act as activators of plasminogen (PG) (Fajardo-Lira and Nielsen, 1998) and of prostaglandins and cytokines. This leads to an increase in capillary permeability, resulting in a breakdown in the blood-milk barrier, which in turn results in transudation of lipolytic and proteolytic enzymes into the lacteal secretion (Kehrl et al., 2000). All these events may result in a decreased synthesis and altered profile of milk fat. Conversely, a solar radiation effect on milk fatty acid composition, through a change in the amount of lipid precursors produced in the rumen, should be excluded, because Muna and Abdelatif (1992) did not find significant differences in the concentration of volatile fatty acids in the rumen of shaded and non-shaded sheep. Due to changes in fatty acid composition, unshaded ewes display an increase in the lauric + myristic + palmitic acid content in milk, which are considered to have a hypercholesterolemic effect on human serum as well as a reduction in the stearic + oleic to palmitic acid ratio, which is regarded as a reliable index of the nutritional property of dietary fat in reducing serum cholesterol levels (Grummer, 1991). Also a worsening in milk coagulating behavior was observed after ewe exposure to solar radiation under high ambient temperature, in spite of casein and fat contents, and pH values similar to ewes protected from solar radiation. When studying the effects of lambing season (autumn vs winter) and of stage of lactation on ewe milk quality, Sevi et al. (2004) observed a dramatic increase in clotting time and rate of clot firming, and a marked reduction in clot firmness in the milk collected during the summer months was confirmed together with unchanged casein content and a slight increase in fat content (Sevi et al., 2004). Plasmin (PL) activity was found higher, and calcium and phosphorous contents lower in summer milk than in winter and spring milk. Thus, these authors hypothesized that the reduction of milk Ca and P contents could play a main role in the deterioration of renneting parameters generally observed in sheep summer milk together with an enhanced casein breakdown due to hydrolytic endogenous enzymes. Summer ventilation plays a main role in sustaining the welfare of farmed livestock, by enhancing thermal exchanges between the animal’s body surface and the environment and by removing aerial pollutants, which originate from animals and their excreta. Besides to high ambient temperature low ventilation rates can lead to increased relative humidity and higher air concentrations of ammonia and carbon dioxide that may be ascribed to failure in removing efficiently the moisture and gases, which originated from the respiratory activity of animals and the decomposition and fermentation of manure. Very high ventilation rates, however, can result in higher air dust concentrations, probably due to reduced humidity levels and to turbulent air currents maintaining dust particles suspended in the air for a longer time. With a pending high heat load situation, moderate ventilation rates (~70 m³/h/ewe) improves the well-being of the lactating ewe compared to low ventilation rates (~35 m³/h/ewe), as suggested by behavioural, endocrine and immune indicators (Sevi et al., 2002a). During the summer season, a poor ventilation rate may have deleterious effects on milk yield and on clotting properties of milk, too (Sevi et al., 2003b). When collected for Canestrato pugliese cheese making, the bulk milk from the ewes exposed to 35 m³/h had high-

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er microbial load and somatic cell count compared to the milk from the animals receiving a ventilation rate of 70 m³/h (Albenzio et al., 2005b). The lower ventilation regimen resulted in a weaker caseous matrix of the curd releasing higher concentration of fat and protein in the whey compared to the higher ventilation regimen. A lower casein content and higher non-casein nitrogen and water soluble proportions were also found in the milk of the less ventilated ewes together with a greater number of bands derived from CNs hydrolysis at 45 d of ripening, probably due to a less intact casein matrix. In contrast, the cheeses from the milk of the more ventilated ewes exhibited a higher PL activity levels at 45 days of ripening, suggesting the existence of a higher proteolytic potential, leading to a more intense proteolysis during further cheese ageing.

IMPACT OF POOR HOUSING AND MILKING HYGIENE ON MILK AND CHEESE QUALITY – Poor housing conditions may be stressful for animals (Hughes and Curtis, 1997). High concentrations of airborne wastemay impaired the immune function in farmed livestock (Rylander, 1986) and enhance the risk of udder infections in lactating ewes (Sevi et al., 1999b). The importance of air change during the winter season is often underestimated and this may result in a serious limitation to high efficiencies of production and good health of farmed animals. Indeed, during the winter season, when ewes have higher productive levels because they are in early or mid-lactation, the adverse effects of an inadequate ventilation regimen on the yield and quality of sheep milk are even more marked. Sevi et al. (2003c) and Albenzio et al. (2004b) demonstrated that exposure of ewes to low (23 m³/h/ewe) and very high ventilation rates (73 m³/h/ewe) resulted in increased noxious gases, dust and airborne microorganism concentrations compared to a moderate ventilation rate (47 m³/h/ewe). The low ventilation regimen led to a reduced yield and a deteriorated coagulating behaviour of milk compared to the two other ventilation rates. When the bulk milk was collected from the ewes, after 6 weeks of exposure to the three ventilation regimens, both the low (23 m³/h/ewe) and the very high (73 m³/h/ewe) ventilation rates resulted in higher levels of somatic cell and of mesophilic bacteria counts compared to the moderate ventilation rate (47 m³/h/ewe). In addition, the moderate ventilation rate resulted in the lowest PL activity in milk and in the highest levels of PL activity in cheese. This suggests that the better hygienic quality of the milk yielded by the ewes exposed to the moderate ventilation rate lead to a slower conversion of plasminogen (PG) to PL prior to manufacture and, consequently, to a higher release of PL during cheese ripening, which results in an accelerated proteolysis. A combined effect of ventilation rate and dietary protein level on nitrogen utilization, and the quality of sheep milk and cheese was demonstrated, too. In fact, Sevi et al. (2006), giving lactating ewes a low (13% CP of DM) and a moderate dietary protein level (16% CP of DM) under two ventilation rates in winter (23.5 m³/h/ewe –low- vs 47 m³/h/ewe –moderate), found that animals fed the 16% CP level and exposed to the low ventilation rate displayed the lowest efficiency of dietary N utilization, excreted the greatest amounts of urine, total water and fecal N, and had the highest bacterial load in their milk. Both protein level of the diet and ventilation rate influenced the chemical, enzymatic and biochemical characteristics of Canestrato pugliese cheese (Albenzio et al., 2007). Cheeses manufactured with the milk obtained from the ewes receiving 13% CP dietary level and exposed to moderate ventilation rate was characterized by higher protein and casein contents in the fresh cheese and exhibited a more intense proteolysis after 90 days of ripening. In cheeses from the milk of the ewes fed the 16% CP level and exposed to the low ventilation rate the lowest PL activity was recorded during ripening, probably due to the lowest casein content in fresh cheese curd, because it is known that PL is associated to casein micelle so the smaller is the amount of casein the lower is PL activity. A number of other factors can affect air, surface and litter hygiene in sheep houses with direct and indirect effects on ewe welfare, and on ovine milk and cheese quality. Evidence exists that high stocking densities and reduced air space lead to an increase in relative humidity and airborne micro-organism concentration in sheep houses, a marked rise of somatic cell and of micro-organism count in milk, and a higher incidence of sub-clinical mastitis. Such events are accompanied by 7 to 10% reduction of milk yield and 5 to 10% decrease in milk casein content when passing from 2 m² to 1.5 and 1 m² area/ewe (Sevi et al., 1999b, 2001d). As well, a 15% decrease in milk yield and a 5% reduction of casein content were observed after airspace reduction from 7 m³/ewe to 5.5 and 4 m³/ewe (Sevi et al., 2001b). Especially when sheep are housed at a high stocking density, careful litter management is particularly important to mitigate drawbacks on animal welfare and production performance (Sevi et al., 2003a). Spreading of appropriate chemical products on litter, which can reduce bacteria proliferation and degrading processes of the nitrogen contained in urine and in feces, is a suitable strategy to reduce airborne micro-organism levels and ammonia release from the manure (Sevi et al., 1998a, 2000a, 2001d). Poor housing hygiene leads risk of mastitis to a marked increase due to either a reduction of the natural defense mechanisms of the teat and mammary gland or to increased number and pathogenicity of the micro-organisms in contact with the entrance of the teat canal or both. Evidence that environmental and opportunistic pathogens have an incidence of more than 60% as etiological agents of sub-clinical mastitis in intensively managed dairy flocks (Albenzio et al., 2002) confirms that the greatest care should be taken in the control of ambient hygiene, and in minimizing the impact of environmental and
management stressors on sheep welfare. Moreover, evidence that hand milkers and teat cups are source of contamination in about 40% of sub-clinical mastitis cases highlights the importance of control of sanitation of milking procedures, and of milker hygiene to minimize the risk of ewe udder infection (Albenzio et al., 2003). Indeed, mastitis is probably the main cause of profit reduction for dairy sheep farmers, given that annual incidence of udder disease has been estimated at 10-35% in sheep and goat flocks (Bergonier and Berthelot, 2003). Contreras et al. (2007) report that sheep are more vulnerable than goats to mastitis and that vaccine strategies lead to a reduced prevalence of clinical mastitis but not of subclinical infections (Contreras et al., 2007). Irrespective of kind of pathogen, Albenzio et al. (2002) found that sub-clinical mastitis results in a 15 to 23% reduction of milk yield, 18 to 21% decrease in casein content, 3 to 11% decrease in fat content, 64 to 102% increase in rate of curd formation and 4 to 35% reduction of curd firmness. Rise in somatic cell count (SCC) is regarded as a reliable index of poor udder health and lowered nutritional and processing properties of milk. Sevi et al. (1999a) found that both renneting ability and the microbiological quality of ewe milk start to decline markedly from a SCC over 700,000/ml of milk so, given that almost all ewe milk is destined for cheese-making, they suggested to set the threshold of acceptability of sheep milk at 700,000 cells/ml. In bulk milk with more than 1,000,000 somatic cells/ml, Albenzio et al. (2004a) found that polymorphonuclear leukocytes (PMNL) were largely predominant and that macrophages markedly increased with the advancement of lactation. These events were responsible for enhanced plasmin activity in milk, which in turn led to a lower proteolytic potential of Canestrato pugliese cheese curds. Elevated SCC also resulted in higher moisture and lower fat contents of fresh cheese curds as well as in a lower recovery of fat and whey proteins. Albenzio et al. (2005a) demonstrated that both plasmin and non-plasmin proteolytic activity in sheep milk are strongly enhanced by elevated SCC and result in a higher degradation of α-casein than of β-casein. These authors also stated that, although plasmin activity is partly influenced by stage of lactation owing to mammary epithelium adjustment and related effects on the plasminogen-plasmin system, ewe udder health, rather than physiological factors, play the main role in addressing proteolytic activity in ovine milk.

EFFECTS OF UNDERNUTRITION ON THE YIELD AND QUALITY OF MILK – Sheep are typically grazing animals in marginal and less favorable areas so they can undergo nutritional stress rather frequently. Nutritional imbalance often occurs in late spring and summer, due to increased energy output for thermoregulation and reduced availability of good quality herbage. Pulina et al. (2006) found that short-term feed restriction strongly reduces milk yield and increases milk fat content in Sarda dairy ewes. Undernutrition significantly affects the milk fatty acid profile, as a consequence of body fat mobilisation. Underfed ewes show higher milk somatic cell count (SCC), indicating a metabolic stress of the animal and its mammary gland. Besides seasonal alteration of nutritional status, sheep can suffer from nutritional stress of physiological origin, too. This can occur during pregnancy and the transition period, especially in twin-bearing ewes and in primiparous animals, which at the same time have to synthesize milk, to complete their growth, and to acquire full immune competence. Proper feeding strategies are required in these cases. Sevi et al. (1999b) demonstrated that ewe undernutrition during the last 6 weeks of pregnancy leads to reduced yield of milk, and of protein and casein together with poor renneting ability, and altered amino acid composition of milk, probably due to extensive amino acid oxidation for energy supply. The adverse effects of undernutrition in late pregnancy on subsequent lactation are magnified by twin lambing and prolonged suckling (up to 8 weeks of age) of lambs. As concerns the effects of parity on the yield and quality of milk, Sevi et al. (2000b) found that primiparous ewes gave milk with significantly less protein, casein and fat and a lower renneting ability compared to older ewes, probably due to a smaller availability of body reserves for the synthesis of milk components or the reduced development of the udder glandular tissue or even the reduced efficiency of the homeorhetic dynamics involved in the partitioning of the nutrients for the processes of lactogenesis and galactopoiesis. These authors also observed a higher micro-organism concentration in the milk of primiparous ewes compared to older animals, in spite of very similar SCC, hypothesizing that the greater bacterial colonization of the udder in primiparous ewes could be attributed to a reduced efficiency in the natural defence mechanisms against the penetration and multiplication of bacteria in the udder. Irrespective of parity, Caroprese et al. (2006) demonstrated that sheep carrying out multiple gestations have a more marked reduction of immune function during parturition than single bearing sheep. These authors found that blood levels of immunoglobulin G and of IL-6 are the most sensitive markers of physiological and nutritional stress related to the transition period and the number of lambs born to be delivered. Hence, increase in prolificacy is one of the main goals of sheep farmers, in order to have an increase in lamb meat for the market and in milk destined for dairy products. However, multiple bearing sheep need a more careful control of housing and milking hygiene, due to their decreased pathogen resistance. Housing system can also affect the nutritional status of farmed animals. Farmer has to adjust feeding ration taking in account level of activity related to different housing systems in order to prevent transient conditions of nutritional stress in the ewe. When comparing behavior, milk yield and physiology of ewes maintained in external paddock dur-
ing daytime or confined indoor throughout the day, Casamassima et al. (2001) found that outdoor enclosure was beneficial to the behavioral needs of lactating ewes. In addition, ewes kept outdoor gave milk with a lower SCC compared to indoor animals. Nevertheless, increased muscular tissue metabolism, due to enhanced locomotion, and enhanced energy demand for thermoregulation, documented by higher creatinin and lower blood glucose concentrations, resulted in transient drop of milk yield and deterioration of milk quality in outdoor compared to indoor ewes. Finally it is not to be disregarded that frequent interaction between the animal and the stockman, with repeated animal manipulation, is another potential stress factor for housed sheep and goats. In lactating ewes, Sevi et al. (2001c) found that member exchange increased aggression and altered immune response. Cell mediated immunity was also affected by relocation. Mixing and moving also resulted in short-term but marked effects on production traits (up to 23% less milk yield, up to 19% less milk protein content and about 6% less milk fat content). A minor impact of regrouping and relocation was observed on ewe udder health. Thus, changes of environment and social conditions should be performed as less as possible in sheep flocks, always taking care to minimize their impact on animal welfare.

CONCLUSIONS – Poor welfare has a number of deleterious effects on the quality of ovine milk and cheese. Stress from climatic extremes and undernutrition can lead to severe energy deficit which in turn results in reduced protein and fat content, and in altered amino acid, fatty acid and mineral profile of milk. Such modifications are responsible for reduced nutritional property of milk, and lowered renneting ability and cheese yield. Poor housing and milking hygiene can endanger ewe udder health due to either a reduction of the natural defense mechanisms of the teat and mammary gland or to increased number and pathogenicity of the micro-organisms in contact with the entrance of the teat canal or both. Bacterial colonization of the udder is detrimental to milk quality per se and also provokes leukocyte recruitment in the mammary gland, which can cause extensive epithelium secretory cell damage. These events are responsible for decreased synthesis and altered composition of milk, lower recovery of fat and protein during cheese-making, and altered proteolysis during cheese ripening. Sheltering from high ambient temperatures, changing the time of feeding to late afternoon and providing adequate air change represent the most suitable strategies to minimize the impact of hot climates on ewe welfare, while careful control of sanitation of housing, milking procedures, udder and milker hygiene are the most proper tools for assuring ewe udder health and sustaining the nutritional and processing properties of ovine milk.

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