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SHORT COMMUNICATION

Expression profile of caseins, estrogen and prolactin receptors in mammary glands of dairy ewes

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Abstract

In this study, we analyzed the developmental expression of estrogen receptors (*ESR1* and *ESR2*), prolactin receptors (*PRLR*) and casein genes (*CSN1S1*, *CSN1S2*, *CSN2* and *CSN3*) in the ewe mammary glands from prepubertal stage to involution. Using Real-time PCR we showed that the activation of casein genes transcription was up regulated during lactation and significantly down regulated before lambing and at involution in comparison to the expression measured in the prepubertal group. The highest expression of *ESR1* and *ESR2* genes occurred in prepubertal group compared to adult group. The *PRLR* expression of the short and long forms was up regulated before lambing and down regulated during lactation and involution.

Thus, the mRNA expression data for *ESRs* and *PRLR* show clear regulatory changes suggesting involvement of these receptors in sheep mammary glands during development to involution. Casein genes transcription could be primed through *PRLR* signal, but other factors may be necessary for milk protein long-term expression during lactation.

Introduction

In dairy sheep, genetic selection has caused deep morphological changes in the udder and physiological changes in the whole body of the animal. The former is identified by the higher mammary cistern volume, the latter by neuro-hormonal changes. These changes allow the alveoli to have a longer life span and maintain a metabolic status that favours the switch of energy and nutrients to the mammary gland instead of body reserves (Pulina *et al.*, 2007). The pattern of the lactation curve is influenced

by the number of secretory cells in the mammary gland at each day in milking (DIM) and by the synthetic activity of each secretory cell. Growth and differentiation of the glandular epithelium during puberty and pregnancy are important determinants of the total area of secretory epithelium and consequently of milk yield (Pulina *et al.*, 2009).

These physiological changes are orchestrated by systemic and local factors, which control synthetic and secretory mechanisms by transcriptional control of key mammary genes (Stefanon *et al.*, 2002).

In dairy species, it is generally believed that there is normally little mammary growth during established lactation (Akers 2002); however, in human breast the onset of secretory activity is accompanied by glandular-alveolar growth and expansion of acini (Battersby and Anderson, 1988). Moreover, in many tissues it exists a dividing transit population of cells in which signs of proliferation, phenotypic differentiation and functional differentiation are displayed simultaneously (Potten and Loeffler, 1990). In a recent paper, we reported for the first time the turnover of mammary cells and the interaction of their signals during the complete lactation cycle in sheep (Colitti and Farinacci, 2009); we concluded that mammary glands of dairy ewes seem to operate in a much more dynamic state than other lactating animals and this is particularly important in the construction of mechanistic models of lactation. In general, these models are based on the assumption that milk production at each time of lactation depends on the number of active cells and on the secretory activity (Dimauro *et al.*, 2007). Therefore, mechanistic models of lactation could represent a useful tool to evaluate possible effect of selection for increasing lactation persistency in different breed and production scenarios. In a complementary paper (Pulina *et al.*, 2009), based on the same experimental units, we concluded that the milk production around lactation peak (30 L) is sustained by the higher epithelium volume and higher milk secretion rate per secretory tissue unit.

The estrogen receptor- α (*ESR1*) is a critical transcription factor that regulates epithelial cell proliferation and ductal morphogenesis during postnatal mammary gland development (Feng *et al.*, 2007). Between the two isoforms α and β (*ESR1* and *ESR2*, respectively), *ESR1* is considered the primary receptor for mammary gland development and function; it induces proliferation of the mammary tissue, but the mechanism is not clear, since the proliferating mammary cells do not contain this receptor (Clarke *et al.*, 1997). Moreover, *ESR2* modulates *ESR1* action in tissues where they

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are co-expressed (Hall and McDonnell, 1999).

The role of prolactin in milk synthesis is probably related to the fact that it inhibits mammary apoptosis by suppressing the actions of IGF binding protein (*IGFBP-5*), which antagonizes the effects of IGF-I on the survival of mammary epithelial cells (Tonner *et al.*, 2000). Proliferation and differentiation of secretory mammary epithelium are also dependent on the presence of the prolactin receptor (Ormandy *et al.*, 1997) and the downstream Jak2-Stat5 pathway (Liu *et al.*, 1998). The prolactin receptor (*PRLR*) belongs to the superfamily of cytokine receptors (Kelly *et al.*, 1991) and exists in different isoforms, generated by alternative splicing, that are identical in their extracellular ligand-binding domain, but differ in the length and sequence of their intracellular domain (Bole-Feysot *et al.*, 1998). cDNAs encoding a long and a short form of *PRLR* have been isolated from different species (Bignon *et al.*, 1997; Shirota *et al.*, 1990) and are differentially expressed in different tissues, suggesting that they can activate distinct signalling pathways (Schuler *et al.*, 1997). The long form of *PRLR* activates Jak2, a cytoplasmic protein tyrosine kinase, which in turn can serve as docking sites for the SH2 domains in *STAT5* (Groner, 2002). Activated *STAT5* binds to DNA sites in the nucleus known as GAS elements and modulates the activity of target genes, as the β -casein gene (Kazansky *et al.*, 1995; John *et al.*, 1999). However, the lack of correspondence of *STAT5a* gene expression and β -casein gene expression suggests that *STAT5* activation may facilitate the interaction of other factors binding within composite response elements identified recently in the milk protein gene promoters. Responsive

elements are responsible for the stable expression of milk protein genes in terminally differentiated mammary epithelial cells (Kazansky *et al.*, 1995). In lactating animals, *STAT5a* induces expression of milk protein genes, largely in response to prolactin (Nevalainen *et al.*, 2002) together with laminin-1, which is a major basement membrane component required for milk protein expression (Streuli *et al.*, 1995; Xu *et al.*, 2009).

Moreover, in a recent paper it has been demonstrated that in ruminants, the increased milking frequency enhances the expression of the long and short isoform of prolactin receptors and β casein on the mammary epithelial cells and reduces cell apoptosis by modulating hormone sensitivity (Bernier-Donner *et al.*, 2010).

Caseins comprise a group of four proteins (α s1, α s2, β , and κ) resulting from the expression of four structural genes (*CSN1S1*, *CSN1S2*, *CSN2* and *CSN3*, respectively) (Bevilacqua *et al.*, 2006). These proteins represent on average 82% of sheep milk Total Nitrogen (N x 6.38; Pulina and Nudda, 2004), but there is a large variability from one species to another (Miranda *et al.*, 2004).

Since a surprisingly very high proliferation index, measured by Ki-67 immunostaining, was observed during lactation in mammary glands of Sardinian sheep (Colitti and Farinacci 2009), the goal of this study was to investigate in the same mammary tissues the expression of *CSN1S1*, *CSN1S2*, *CSN2* and *CSN3*, markers of functional differentiation. The expression patterns of *ESR1* and *ESR2*, and *PRLR* long and short forms, which play an active role in morphogenesis, growths and functional differentiation, were also studied in mammary glands of sheep prior to lambing to involution.

Materials and methods

Animals

Tissue was collected from mammary glands of thirty Sardinian sheep that were slaughtered at different developmental stages: prepartal (30±5 days, group P), 10 days before lambing (group LateP), 30, 60, 150 DIM (groups 30L, 60L, 150L, respectively) and 8 days after the end of lactation (group 8IN). At each sampling periods, five animals were randomly selected from a flock of grazing sheep and a clinical examination was conducted in vivo to ascertain animal health and to exclude mastitis. Sardinian sheep are a breed primari-

ly used to produce milk; the typical breeding system implies one lambing per year, with the mating season starting in late spring for mature ewes and in early autumn for maiden ewes and with lactation starting in autumn and in late winter, respectively. Dry-off occurs simultaneously in mid summer for yearlings and mature ewes (lactation length 150 DIM and 240 DIM, approximately) when nutritional value of pastures collapses due to lack of rain in this season. In this study milk yield ranged from 1600 g/d to 900 g/d at 150 DIM. Ewes at 30 DIM were allowed to suckle their lamb; the other groups (60L, 150L) were mechanically milked twice daily and manually ten minutes before slaughtering, therefore just before tissue collection.

Samples of tissue were collected in TRIzol® (Invitrogen, Milano, Italy), frozen in liquid nitrogen and kept one week at -80°C till RNA extraction. The experiment was carried out in accordance with state and local laws and ethical regulations (Italian Regulation, 1992).

RNA extraction and primer design

Total RNA was extracted from about 30 mg of mammary tissues using TRIzol® Plus RNA Purification System (Invitrogen, Milano, Italy), following the manufacturer's instructions. The concentration of the extracted total RNA was

quantified using a spectrophotometer (NanoDrop 1000 Spectrophotometer, Thermo-Scientific, Wilmington, DE, USA) and the assessment of the purity of RNA samples ranged between 1.8-1.9. The RNA integrity was evaluated through the observation of 18S and 28S ribosomal bands after electrophoresis on 1% agarose gel, in the presence of ethidium bromide. In sample analysis, the β -actin (U39357) expression was used as an internal control, confirming thorough integrity of the RNA.

A Primer3 Input software (Rozen and Skaletsky, 2000) was used to design the primer sequences encoding for: *CSN1S1* (X03237), *CSN1S2A* (X03238), *CSN2* (X79703), *CSN3* (AY237637), *PRLR* long form (AF041257), *PRLR* short form (AF041977), *ESR1* (AY033393), *ESR2* (AF177936) and *18S rRNA* (AY753190). Primers and product lengths for each gene are listed in Table 1 according to the HUGO Gene Nomenclature Committee.

Reverse transcription

Reverse transcriptions were performed with 2 μ g of extracted total RNA by using Improm-II Reverse Transcriptase (Promega, Milano, Italy) as following described. Two micrograms of total RNA with 1 μ L oligo(dT)18 primers (0.5 μ g/ μ L MBI Fermentas, Italy) and nuclease

Table 1. Oligonucleotide primer sequences and reaction conditions for SybrGreen qRT-PCR.

Gene	Primer sets	Product length, bp	cDNA concentration, ng	Primers, nM
<i>CSN1S1</i>	F: 5'AGCACCAAGGACTCTCTCCA 3' R: 5'CACTTGACGAACTGCTTCCA 3'	186	0.1	300
<i>CSN1S2A</i>	F: 5'AAGAACCAGATGAAGAGGA 3' R: 5'ATCCCATGGGTTCAAACAA 3'	198	0.1	200
<i>CSN2</i>	F: 5'ACAGCCTCCCAAAAACATC 3' R: 5'AGGAAGGTGCAGCTTTTCAA 3'	206	0.1	300
<i>CSN3</i>	F: 5'ATTTATGGCCATTCACCAA 3' R: 5'GCAATCGATTCTGAGGAAGC 3'	156	0.1	200
<i>PRLR long</i>	F: 5'TTCCAGTGAAGGATACAAGC 3' R: 5'GTTCTTTGGAGGGGTGTGG 3'	310	10	200
<i>PRLR short</i>	F: 5'TTCCAGTGAAGGATACAAGC 3' R: 5'CTATTAACACAGACACAAGG 3'	207	10	600
<i>ESR1</i>	F: 5'CCACGATCAAGTCCACCTTT 3' R: 5'ACGGAACCGAGACGATGTAG 3'	193	10	200
<i>ESR2</i>	F: 5'TCTTTGCTCCAGACCTCGTT 3' R: 5'GACTGTTGCTGGAGGACAT 3'	292	50	300
<i>18S rRNA</i>	F: 5'AAACGGCTACCACATCCAAG 3' R: 5'TCCTGTATTGTTATTTTCGTAC 3'	90	0.1	100
<i>ACTB</i>	F: 5'TCCCTGGAGAAGAGCTACGA 3' R: 5'AGCACCGTGTGGGATAGAG 3'	102	5	200

CSN1S1, α -S1-casein; *CSN1S2A*, α -S2-casein; *CSN2*, β -casein; *CSN3*, κ -casein; *PRLR long*, prolactin receptor long form; *PRLR short*, prolactin receptor short form; *ESR1*, estrogen receptor α ; *ESR2*, estrogen receptor β ; *18S rRNA*, 18S subunit rRNA, *ACTB*, actin, β . F, forward primer; R, reverse primer.

free water to a final volume of 20 μ L, were incubated at 70°C for 5 min in a PTC-100 thermocycler (MJ Research Inc., Waltham, MA, USA). Then, a mix was prepared with 4 μ L of Improm-II Reverse Transcriptase buffer (5X Promega, Milano, Italy), 1.2 μ L $MgCl_2$ (50 mM), 1 μ L of Improm-II Reverse Transcriptase and 1 μ L of dNTP (10 mM) was added to the reaction and incubated at 37°C for 90 min and finally at 94°C for 5 min. The final concentration of cDNA was assumed as 100 ng/ μ L.

Standard curves analyses

For each gene, an aliquot of cDNA samples was pooled and standard curves with serial dilution of pool were used to optimize PCR conditions and to calculate the efficiency, fluorescence baseline and threshold. The expression of target genes was normalized using the 18S rRNA gene, which is known to be constitutively expressed (Robinson *et al.*, 2007) and was retro transcribed also with 1 μ L random hexamers (100 μ M, MBI Fermentas, Milano Italy).

Real time PCR quantitation

Realtime PCRs were performed in triplicate form using Platinum® SYBR® Green qPCR SuperMix-UDG (Invitrogen, Milano, Italy). For these reactions, a master mix with the following components was prepared to the indicated end concentration: 1 μ L of cDNA, 9.5 μ L water, 1 μ L of each primer and 12.5 μ L of 2X Platinum SYBR Green qPCR SuperMix-UDG for a total volume of 25 μ L. cDNA concentrations and primers molarities were different for each gene and determined with standard curves analyses performed before Real time PCR reactions. cDNA and primers concentrations are showed in Table 1.

PCR amplifications were conducted applying 45 cycles (1 sec at 95°C, 30 sec at the specific annealing temperature, 30 sec at 72°C) in a 96-well spectrofluorometric thermal cycler (DNA Engine Opticon 2; MJ Research, Inc., Waltham, MA USA). The melting curve analysis of amplification products was performed at the end of each PCR reaction to confirm that a single PCR product was detected.

The expression level of a given target gene in each experimental group was analyzed by the $2^{-\Delta\Delta Ct}$ method (Bustin, 2000; Pfaffl, 2001) where $2^{-\Delta\Delta Ct}$ represents the difference of a given target gene between each group before lambing and during lactation (groups from LateP to 8IN) vs. the group P. More precisely, individual $\Delta\Delta Ct$ was calculated for each sample of group (LateP to 8IN) as $\Delta\Delta Ct = \Delta Ct$ (sample group) – mean ΔCt (group P). The n -

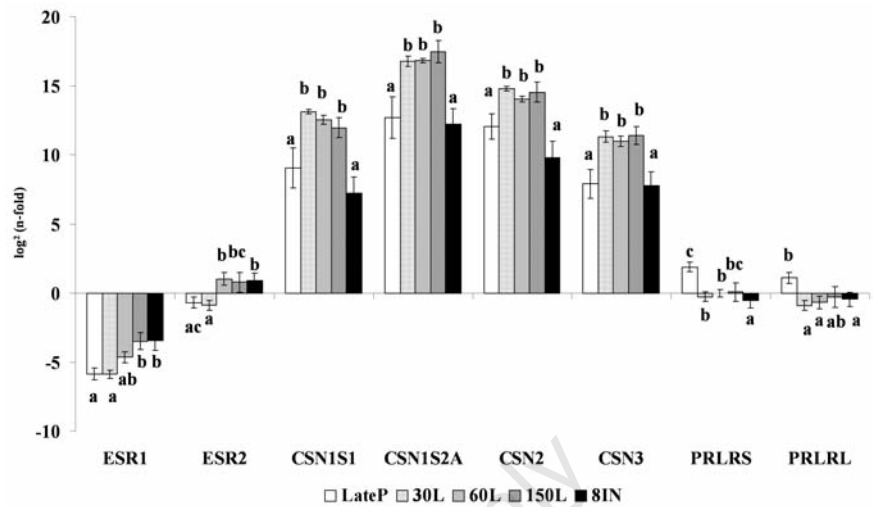


Figure 1. Expression analysis of target genes at 10 days before lambing, 30, 60, 150 days of lactation and 8 days from dry-off, related to the expression at prepubertal stage.

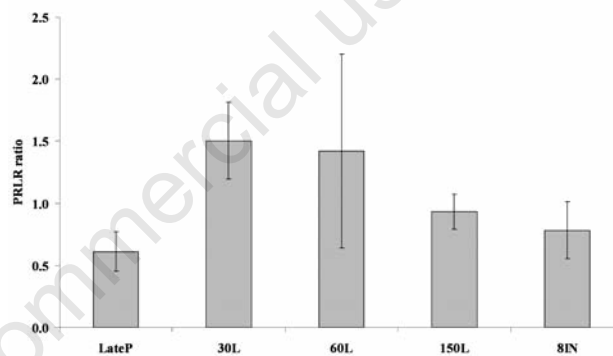


Figure 2. Ratio of the long to the short form of PRLR expression analysis at different developmental stages of ovine mammary glands.

fold expression of a given target gene was calculated as $\log_2(2^{-\Delta\Delta Ct})$ (Figure 1).

Statistical analysis

All the recorded variables were submitted to analysis of variance using the ANOVA model to assess significant differences between groups; Duncan's least significant difference test was used to compare the means (SPSS Inc., 1997).

Results

18S rRNA expression was quantified in all samples and resulted in constant expression levels. No significant differences between the groups could be shown in the investigated ovine mammary tissues. Expression of *ESR1*, *ESR2*, *PRLRs* and caseins mRNA were nor-

malised according to the relative 18S rRNA expression of each sample.

The n -fold values, reported in Figure 1 as $\log_2(n$ -fold), indicate the relative abundance of each target gene in comparison with the P group (prepubertal).

The relative expression of *CSN1S1*, *CSN1S2A*, *CSN2* and *CSN3* genes in the sheep mammary glands indicated the same significant pattern of difference ($P < 0.05$) among groups. These genes were down-regulated at LateP and 8IN and up-regulated during lactation (30L, 60L, 150L).

The relative transcription of *ESR1* significantly increased ($P < 0.05$) from LateP to 8IN; the same parameter for *ESR2* significantly increased at 60L and remained constant and up regulated (even if not significantly for 150L) until 8IN ($P < 0.05$). The *PRLR* expression of the short and long isoforms showed similar trend, being significantly up regulated

at LateP and down regulated during lactation and involution. Statistical analysis of the ratio between the long and the short form of *PRLR* did not significantly differ among groups, but showed a trend in which the mRNA encoding the long form of the ovine *PRLR* predominated on the short one, in every group of sheep (Figure 2).

Discussion

In a previous paper (Colitti and Farinacci, 2009), where cell turnover and gene activity in mammary gland of Sardinian sheep was evaluated, we suggested that sheep mammary glands seem to operate in a much more dynamic state than those of other domestic ruminants. In particular, to explain the high apoptosis to proliferation ratio we suggested that, as reported by Potten and Loeffler (1990), there was a dividing transit population of cells in which signs of proliferation, phenotypic differentiation and functional differentiation were displayed simultaneously. This was in agreement with the results reported by Suzuki *et al.* (2000) that also found cells, in the breast tissue of pregnant women, positive to marker of proliferation, Ki-67 and to markers of mammary functional differentiation, β -casein and κ -casein. We evaluated markers of functional differentiation like *CSN1S1*, *CSN1S2A*, *CSN2*, *CSN3* by Real time PCR analyses.

In this study, we showed that activation of casein genes transcription, relatively to the prepubertal group (P), is up regulated during lactation and significantly down regulated before lambing and at involution. This is concomitant to the enhancement, although not significantly, of the ratio between the long and short form of prolactin receptors (Figure 2). This is in agreement with the data found by Cassy *et al.* (1998) in which they suggested that the short form of the ovine *PRLR* may have a dominant negative action in the activation of milk protein gene transcription. In fact, the authors reported that the activation of caseins gene transcription was concomitant with the enhancement of the ratio of the long to the short form of the ovine *PRLR*, which may play a key role in the shift between growth and differentiation of the mammary gland.

Compared to P group, the long form of *PRLR* is up regulated before lambing and this is in agreement with the trend of *STAT5a* expression that was lower during lactation and higher after the end of lactation (Colitti and Farinacci, 2009). As already reported, *STAT5a* expression resulted negatively related to that

of lactalbumin, a major milk protein gene for ruminants, which significantly increased from lambing to lactation and it is also related to the expression of caseins. Therefore, in agreement with Kazansky *et al.* (1995) the activation of *STAT5a*, induced by *PRLR*, may prime milk gene expression, but other factors are necessary for milk protein long-term expression during lactation.

Our mRNA expression results demonstrated a high expression of *ESR1* and *ESR2* genes in prepubertal group. In fact, at the beginning of lactation period and during lactation (lactogenesis and galactopoiesis) the *n*-folds were significantly lower for *ERS1* gene and also for *ESR2* gene (Figure 1). These is in agreement with Schams *et al.* (2003), who found the presence of high *ERS1* and *ERS2* levels before the start of lobulo-alveolar development and *ESR1* significantly lower expression during pregnancy and lactogenesis. This is due to distinct regulatory mechanisms that involved the receptors, being the *ESR1* regulated at post-transcriptional level and *ESR2* at transcriptional level (Chang *et al.*, 2005). In fact, the receptors present opposite expressions in presence of estradiol (Schams *et al.*, 2003). This is in agreement with our results that showed a higher expression of *ESR2* during lactation. Moreover, *ESR2* is expressed, in mammary glands, not only in the luminal cells but also in myoepithelial and stromal cells, suggesting different roles for this gene within the glands (Speirs *et al.*, 2002). In fact, the colocalization of *ESR1* and *ESR2* expressions with that of proliferation marker (Ki-67) could be remarkable to clarify the nature of cells in which they are expressed and the pathways by which hormones modulate proliferation.

These observations suggest a possible and important role of these receptors for the initiation of alveolar development, maybe in cooperation with proliferative growth factors.

Conclusions

This study, designed to investigate in mammary tissues the expression of markers of functional differentiation as α s1, α s2, κ , β caseins, the expression patterns of α and β receptors for estrogen and prolactin receptors long and short forms, showed that: i) activation of casein genes transcription, relatively to the P group, is upregulated during lactation and significantly downregulated before lambing and at involution; ii) a high expression of α and β receptors for estrogen genes occurs in P group compared with adult group; iii) the

prolactin receptor expression of the short and long isoform are upregulated at LateP in comparison with P group, and down-regulated during lactation and involution.

References

- Akers, R.M., 2002. Mammary development, anatomy and physiology. In: Iowa State Press (eds.) Lactation and the mammary gland. Blackwell Publishing Co., Ames, IA, USA, pp 45-65.
- Battersby, S., Anderson, T.J., 1988. Proliferative and secretory activity in the pregnant and lactating human breast. *Virchows Arch. A.* 413:189-196.
- Bernier-Dodier, P., Delbecchi, L., Wagner, G.F., Talbot, B.G., Lacasse, P., 2010. Effect of milking frequency on lactation persistency and mammary gland remodeling in mid-lactation cows. *J. Dairy Sci.* 93:555-564.
- Bevilacqua, C., Helbling, J.C., Miranda, G., Martin, P., 2006. Translational efficiency of casein transcripts in the mammary tissue of lactating ruminants. *Reprod. Nutr. Dev.* 5:567-578.
- Bignon, C., Binard, N., Ormandy, C., Schuler, L.A., Kelly, P.A., Djiane, J., 1997. Long and short forms of the ovine prolactin receptor: cDNA cloning and genomic analysis reveal that the two forms arise by different alternative splicing mechanisms in ruminants and in rodents. *J. Mol. Endocrinol.* 19:109-120.
- Bole-Feysot, C., Goffin, V., Edery, M., Binart, N., Kelly, P.A., 1998. Prolactin (PRL) and its receptor: actions signal transduction pathways and phenotypes observed in PRL receptor knockout mice. *Endocr. Rev.* 19:225-268.
- Bustin, S.A., 2000. Absolute quantification of m-RNA using real-time reverse transcription polymerase chain reaction assays. *J. Mol. Endocrinol.* 25:169-193.
- Cassy, S., Charlier, M., Belair, L., Guillomot, M., Charron, G., Bloch, B., Djiane, J., 1998. Developmental expression and localization of the prolactin receptor (PRL-R) gene in ewe mammary gland during pregnancy and lactation: estimation of the ratio of the two forms of PRL-R messenger ribonucleic acid. *Biol. Reprod.* 58:1290-1296.
- Chang, G., Li, Y., Omoto, Y., Wang, Y., Berg, T., Nord, M., Vihko, P., Warner, M., Piao, Y.S., Gustafsson, J.A., 2005. Differential regulation of estrogen receptor (ER) α and ER β in primate mammary gland. *J. Clin. Endocr. Metab.* 90:435-444.

- Clarke, R.B., Howell, A., Potten, C.S., Anderson, E., 1997. Dissociation between steroid receptor expression and cell proliferation in the human breast. *Cancer Res.* 57: 4987-4991.
- Colitti, M., Farinacci, M., 2009. Cell turnover and gene activities in sheep mammary glands prior to lambing to involution. *Tissue Cell* 41:326-333.
- Dimauro, C., Cappio-Borlino, A., Macciotta, N.P.P., Pulina, G., 2007. Use of a computer-aided design to develop a stress simulation model for lactating dairy sheep. *Livest. Sci.*106:200-209.
- Feng, Y., Manka, D., Wagner, K-U., Khan, S.A., 2007. Estrogen receptor- α expression in the mammary epithelium is required for ductal and alveolar morphogenesis in mice. *P. Natl. Acad. Sci. USA* 104:14718-14723.
- Groner, B., 2002. Transcription factor regulation in mammary epithelial cells. *Domest. Anim. Endocrin.* 23:25-32.
- Hall, J. M., McDonnell D. P., 1999. The estrogen receptor beta-isoform (ERbeta) of the human estrogen receptor modulates ERalpha transcriptional activity and is a key regulator of the cellular response to estrogens and antiestrogens. *Endocrinology* 140:5566-5578.
- Italian Regulation, 1992. Application of the Council Directive (EEC) No. 86/609 regarding the protection of animals used for experimental and other scientific purposes. LD 116/1992. In: Official Journal No. 294, 15/12/1992, pp 5-24.
- John, S., Vinkemeier, U., Soldaini, E., Darnell, J.E., Leonard, W.J., 1999. The significance of tetramerization in promoter recruitment by Stat5. *Mol. Cell. Biol.* 19:1910-1918.
- Kazansky, A.V., Raught, B., Lindsey, S.M., Wang, Y.F., Rosen, J.M., 1995. Regulation of mammary gland factor/Stat5a during mammary gland development. *Mol. Endocrinol.* 9:1598-1609.
- Kelly, P.A., Djiane, J., Postel-Vinay, M.C., Edery, M., 1991. The prolactin/growth hormone receptor family. *Endocr. Rev.* 12:235-251.
- Liu, X., Gallego, M.I., Smith, G.H., Robinson, G.W., Hennighausen, L. 1998. Functional rescue of Stat5a-null mammary tissue through the activation of compensating signals including Stat5b. *Cell Growth Differ.* 9:795-803.
- Miranda, G., Mahé, M.F., Leroux, C., Martin, P., 2004. Proteomic tools to characterize the protein fraction of Equidae milk. *Proteomics* 4: 2496-2509.
- Nevalainen, M.T., Xie, J., Bubendorf, L., Wagner, K.U., Rui, H., 2002. Basal activation of transcription factor signal transducer and activator of transcription (Stat5) in nonpregnant mouse and human breast epithelium. *Mol. Endocrinol.* 16:1108-1124.
- Ormandy, C.J., Camus, A., Barra, J., Damotte, J.D., Lucas, B., Buteau, H., Edery, M., Brousse, N., Babinet, C., Binart, N., Kelly, P.A., 1997. Null mutation of the prolactin receptor gene produces multiple reproductive defects in the mouse. *Genes Dev.* 11:167-178.
- Pfaffl, M.W., 2001. A new mathematical model for relative quantification in real-time RT-PCR. *Nucleic Acids Res.* 29:e45.
- Potten, C.S., Loeffler, M., 1990. Stem cells: attributes, cycles, spirals, pitfalls and uncertainties: lesson for and from the crypt. *Development* 110:1001-1020.
- Pulina, G., Colitti, M., Farinacci, M., Mazzette, A., Canu, G., Castanares Castro, N., Nudda, A., 2009. The evolution of mammary glands at different stages in Sarda dairy ewes: preliminary results. *Ital. J. Anim. Sci.* 8 (suppl. 2):652-654.
- Pulina, G., Nudda, A., 2004. Milk production. In: G. Pulina (ed.) *Dairy sheep nutrition*. CAB International, Cambridge, MA, USA, pp 1-12.
- Pulina, G., Nudda, A., Macciotta, N.P.P., Battacone, G., Rassu, S.P.G., Cannas, A., 2007. Non-nutritional factors affecting lactation persistency in dairy ewes: a review. *Ital. J. Anim. Sci.* 6:115-141.
- Robinson, T.L., Sutherland, L.A., Sutherland, J., 2007. Validation of candidate bovine reference genes for use with real-time PCR. *Vet. Immunol. Immunopathol.* 115:160-165.
- Rozen, S., Skaletsky, H.J., 2000. Primer3 on the WWW for general users and for biologist programmers. In: S. Krawetz and S. Misener (eds.) *Bioinformatics Methods and Protocols: Methods in Molecular Biology*. Humana Press, Totowa, NJ, USA, pp 365-386.
- Schams, D., Kohlenberg, S., Amselgruber, W., Berisha, B., Pfaffl, M.W., Sinowatz F., 2003. Expression and localisation of oestrogen and progesterone receptors in the bovine mammary gland during development, function and involution. *J. Endocr.* 177: 305-317.
- Schuler, L.A., Nagel, R.J., Gao, J., Horseman, N.D., Kessler, M.A., 1997. Prolactin receptor heterogeneity in bovine fetal and maternal tissues. *Endocrinology* 138:3187-3194.
- Shirota, M., Banville, D., Ali, S., Jolicoeur, C., Boutin, J.M., Edery, M., Djiane, J., Kelly, P.A., 1990. Expression of two forms of prolactin receptor in rat ovary and liver. *Mol. Endocrinol.* 4:1136-1143.
- Speirs, V., Skliris, G.P., Burdall, S.E., Carder, P.J., 2002. Distinct expression patterns of ER α and ER β in normal human mammary gland. *J. Clin. Pathol.* 55:371-374.
- SPSS, 1997. *Advanced Statistics 7.5*. SPSS Inc., Chicago, IL, USA.
- Stefanon, B., Colitti, M., Gabai, G., Knight, C.H., Wilde, C.J., 2002. Mammary apoptosis and lactation persistency in dairy animals. *J. Dairy Res.* 69:37-52.
- Streuli, C.H., Schmidhauser, C., Bailey, N., Yurchenco, P., Skubitz, A.P.N., Roskelley, C., Bissell M.J., 1995. Laminin mediates tissue-specific gene expression in mammary epithelia. *J. Cell Biol.* 129:591-603.
- Suzuki, R., Atherton, A.J., O'Hare, M.J., Entwistle, A., Lakhani, S.R., Clarke, C., 2000. Proliferation and differentiation in the human breast during pregnancy. *Differentiation* 66:106-115.
- Tonner, E., Allan, G.J., Flint, D.J., 2000. Hormonal control of plasmin and tissue-type plasminogen activator activity in rat milk during involution of the mammary gland. *J. Endocrinol.* 167:265-273.
- Xu, R., Nelson, C.M., Muschler, J.L., Veiseh, M., Vonderhaar, B.K., Bissell, M.J. 2009. Sustained activation of STAT5 is essential for chromatin remodeling and maintenance of mammary-specific function. *J. Cell Biol.* 184:57-66.