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Review article

Mammary epithelial cells: Exploring the possibility of developing mammary organoids, artificial mammary glands, and mammary cell lines

Sumpun Thammacharoen[1], Sapon Semsirmboon[2], Nungnuch Saipin[3], Thiet Nguyen[4], Chanrit Kakhai[1], Narongsak Chaiyabutr[1,5,6] and Sutthasinee Poonyachoti[1,*]

[1] Department of Physiology, Faculty of Veterinary Science, Chulalongkorn University, HenriDunang street, Bangkok 10330, Thailand.
[2]Department of Physiology, Faculty of Medicine, Kasetsart University, Bangkok 10900, Thailand.
[3]Division of Agricultural Technology, Faculty of Science, Ramkhamhaeng University, Bangkok 10240, Thailand.
[4]Department of Agricultural Technology, College of Rural Development, Can Tho University, 3/2 street, Can Tho city 94000, Vietnam.
[5] The Academy of Science, The Royal Society of Thailand, Dusit, Bangkok 10300, Thailand.
[6]Queen Saovabha Memorial Institute, The Thai Red Cross Society, Bangkok 10330, Thailand.

Abstract

The mammary gland is a specific mammalian organ that synthesizes biological fluids required for young offspring. Milk is actively synthesized from this gland via mammary epithelial cells (MECs). In addition, breast cancer is the most commonly diagnosed cancer worldwide. The role of MEC as an in vitro model has been accepted to understand the mechanisms of milk synthesis and the biological mechanisms of breast cancer. This review aimed to determine the advantages of using MECs from two different sources: mammary tissue and fresh milk. MECs from mammary tissue contain stem cells that can be reconstituted to the mammary gland. The major MEC population from fresh milk is the epithelial progenitor. Because the *in vitro* MEC culture can synthesize major milk components; our first hypothesis is that the MEC culture can be enriched and used as a bioreactor to produce artificial milk components. We extended the protein-producing capacity of the MEC culture to pharmaceutical target proteins. This hypothesis based on the presence of intact posttranslation processes in MECs. Studies on breast cancer biology and the development of target cancer therapies require appropriate mammary cell lines. Therefore, this review provides information on the development of mammary cell lines using MECs from animals. We focused on the senescence and transformation of MECs from various mammalian species. These contemporary perspectives are essential for future research to enhance the well-being of the livestock, provide a choice for recombinant proteins, and refine our understanding of breast cancer.

Keywords: Artificial organs, Breast cancer, Cell culture, Ruminant, Welfare.

[*]**Corresponding author**: Sutthasinee Poonyachoti, Department of Physiology, Faculty of Veterinary Science, Chulalongkorn University, HenriDunang street, Bangkok 10330, Thailand. E-mail: Sutthasinee.P@chula.ac.th.

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INTRODUCTION

The mammary gland, a unique organ found only in mammals, produces significant quantities of biological fluid. Milk contains all the nutrients required for a newborn baby. It emerged as an important part of the human diet during the prehistoric pastoral period, approximately 5,000 BC (Ramsoe et al., 2021; Gillis et al., 2024). Currently, the global milk production has reached around 900 million tons per year (FAO, 2023). Breast cancer is the most prevalent cancer worldwide, and the burden is predicted to double by 2040 (Coles et al., 2021). Regarding the origin of breast cancer, the progenitors and tumor subtypes are distinct and apparent during the stage of ductal carcinoma in situ (Wilson et al., 2022). Thus, mammary glands play a crucial role in both physiological and biomedical aspects, with epithelial cells from the glands being fundamental in almost all mechanisms.

Milk synthesis and let down can be accomplished mainly by the mammary epithelial cell (MEC) and myoepithelial cell (MC). With the formation of the fat pad scaffold during the postnatal period, both MECs and MCs undergo morphological and physiological changes under the programming and endocrine controls initiated during mammogenesis, lactogenesis, galactopoiesis, and involution. The mammary gland undergoes repeated morphological and functional changes according to the gestation stage. The mammary parenchyma mainly consists of mammary alveoli and a tubular system that supports its functions (milk synthesis and let down). It is widely acknowledged that the genetic advancements in milk production for dairy cows are facilitated through rigorous genetic selection programs (Menchon et al., 2024), and the highly productive dairy cows are distributed globally. High-potential dairy animals produce less milk in hot and humid tropical conditions. The yield from summer lactation in dairy cows was reported to be 16% lower than that from winter lactation (Thammacharoen et al., 2020). These seasonal effects on lactation were also observed in dairy goats (Saipin et al., 2020a). We have shown that high ambient temperature (HTa) influences milk synthesis from the mammary gland via indirect and direct pathways. The direct effect of HTa on milk synthesis is thought to be mediated partly by the activation of heat shock protein 70 (Hsp70) and the mammalian target of the rapamycin (mTOR) pathway (Thammacharoen et al., 2022). Based on these findings, understanding the cellular physiology of the MEC is essential for comprehending the direct effect of HTa on milk synthesis. Our previous study showed that MECs derived from fresh goat milk can successfully express lactose synthase and lactose under *in vitro* culture conditions (Saipin et al., 2020b). Other studies have reported similar findings, demonstrating the ability to form a mammary organoid using mammary stem cells derived from mammary tissue (Shackleton et al., 2006; Machado et al., 2013; Jamieson et al., 2017). Different sources of MECs determine the fate of *in vitro* growth, leading to significant differences in the behavioral and physiological properties of the MEC culture among these sources. This simple hypothesis holds true and underscores the critical need for fundamental knowledge of cellular heterogeneity, which may influence the outcome of MEC culture (Corro et al., 2020).

In this review, we have attempted to provide details of currently used MEC culture systems. Specifically, the contributions of two sources of MECs have been reviewed, and specific questions have been addressed to determine the advantages of the two culture techniques. Contemporary perspectives have been proposed to emphasize the future directions (Figure 1) for using primary MEC cultures and to address the physiological functions of mammary glands, the pathological mechanisms involved in breast cancer, and the possibility of using the MEC culture system as a powerful tool in biological mammalian cell culture.

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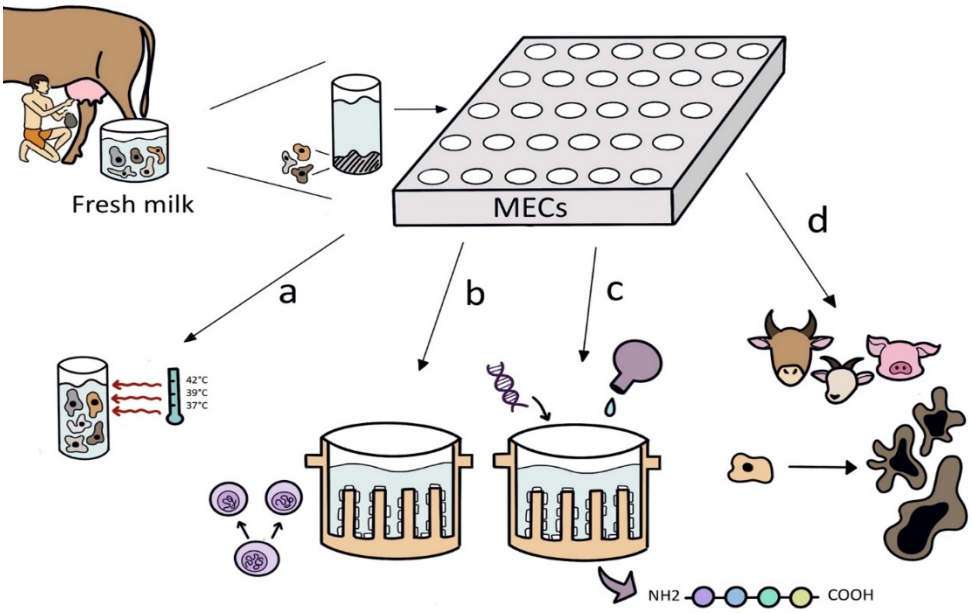

Figure 1 Propose contributions of the mammary epithelial cell (MECs) from dairy animal to (a) the mammary gland and lactation physiology, (b) agricultural & (c) pharmaceutical productions and (d) biology of cancer. This figure is original data, not previously published.

MAMMARY EPITHELIAL CELL CULTURES FROM TWO DIFFERENT SOURCES

The mammary gland, a unique secretory organ, comprises a secretory alveoli and a tubular ductal system. The gland undergoes cyclical changes throughout life based on the pregnancy status. The parenchyma epithelial cells, including the MECs and MCs, are targets for major cellular transformation and differentiation. During the postnatal mammogenesis and peripubertal period, the terminal end bud (TEB) of the primary duct acts as the growing tip containing both the cap cell (outer layer of TEB) and body cell (body mass of TEB). Differentiation of the TEB, proliferation of the terminal differentiated cell, and apoptosis of the inner luminal body cell are the fundamental mechanisms involved in ductal elongation and ramification. During the pregnancy stage, the secretory alveoli are generated from the terminal ends of the secondary side branches via another differentiation process (lactogenesis I). At this stage, the MECs undergo a transformation step involving organelle polarization and the expression of milk-specific enzymes. These physiological processes indicate that the mammary gland consists of a cell population with stem-cell-like abilities. While mammary cell lines have been extensively used in biomedical research (Neve et al., 2006), limited information is available regarding primary MEC cultures. To address this, we describe the phenotypic characteristics of MECs derived from both mammary tissue biopsies and fresh milk

MEC culture from mammary tissue

Primary MEC cultures used in most experiments were derived from mammary tissue. Based on the physiological transformation of the mammary gland described above, MECs from mammary tissue exhibit diverse phenotypic characteristics. Furthermore, there is no clear evidence for the presence of tissue stem cells, particularly mammary epithelial stem cells (MESCs; Shackleton et al., 2006; Machado et al., 2013; Jamieson et al., 2017), or whether the stem-cell-like activity results from the stem-cell niche within the mammary tissue (Lin, 2002;

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Mokbel, 2024). One study showed that single mammary stem cells could reconstitute a complete mammary gland *in vivo*. Hematopoietic ($CD45^-$ and $TER119^-$) and endothelial ($CD31^-$) or Lin^- populations with high expression levels of the stem-cell markers for skin (β1-integrin, CD29) and neurons (heat stable antigen, CD24), $Lin^-CD29^{hi}CD24^+$, were the putative MESCs derived from mouse mammary tissue (Shackleton et al., 2006). Likewise, another study reported the purification of MESCs ($CD24^+CD49f^+$) from colonies derived from mammary tissue that contained self-renewal and differentiation properties (Sting et al., 2006). Based on the $Lin^-CD29^{hi}CD24^+$ population, the mammary organoid has been generated *in vitro* with specific enhancing culture conditions (Jamieson et al., 2017). These findings indicate the vital role of the stem-cell niche in the structural and functional properties of the mammary gland and suggest the recapitulation of the essential niche from mammary tissue.

Notably, mammary tissue contains a heterogeneous population of cell types. Only a small subpopulation of MECs (approximately 0.07–0.2% of dissociated cells) exhibits multipotent and self-renewing properties sufficient to regenerate a complete mammary gland (Shackleton et al., 2006; Machado et al., 2013; Jamieson et al., 2017). In rodents, each gland contains about 2 million viable MECs, among which roughly 1,400 subpopulations may be transplantable (Sting et al., 2006). This rarity poses a major limitation for isolating such cells from biopsy samples. MECs obtained from fresh milk, which display pluripotent characteristics, offer an alternative source for culture.

MEC culture from fresh milk

Previously, we have demonstrated MEC colonies in our short-term cultures of goat raw milk. The single colony exhibited an epithelial-like cobblestone appearance with alveoli-like structures (Figure 2). The colony-forming MECs from our culture conditions expressed epithelial markers, such as cytokeratin 8 (CK8) and 18 (CK18), consisted of droplet-like inclusions, and expressed the β-casein (CNS2) gene (Saipin et al., 2018); subsequently, we demonstrated that the MECs expressed lactogenic enzymes. High-temperature culture conditions (37°C vs. 39°C) increased the expression of Hsp70; however, it did not dramatically influence the beta-galactosyltransferase (β-GALT) and alpha-lactalbumin (α-LA) levels (Saipin et al., 2020b). The morphometric colony from MECs derived from this source was a confluent monolayer with various cell shapes. Interestingly, most cultured cells were CK18-positive (Figure 2) and CK14-negative; this was different from cultured cells derived from the mammary tissues of dairy cows, which were positive for both CK18 and CK14 (Diego et al., 2014). The colony-forming MECs derived from fresh milk under our culture conditions formed a single epithelial layer rather than an alveolar-like structure (Shackleton et al., 2006; Saipin et al., 2018), which may be attributed to two reasons: first, it may be due to apparent differences between alveolar (or luminal) MECs from fresh raw milk and MESCs from mammary tissue. When the mammary cell population is enriched with mammary progenitor cells, there is a higher chance that the colony will present with an alveolar-like structure. Second, differences in culture conditions and growth factors are a crucial driving force for the formation of the colony. Specifically, the organoid structure can be generated when the culture condition contains enhancing factors, such as Wnt3, R-spondin 2, FGF2, and heparin (Jamieson et al., 2017). These findings indicate that MECs from mammary tissue exhibit stem-cell-like properties. However, the identity of cells from MECs derived from fresh milk remains unclear. Thus, it would be interesting to investigate whether MECs derived from fresh milk exhibit progenitor or transit properties; if they did, the presence of this population in milk during the lactation period would prove even more intriguing.

The adhesion of MECs with the extracellular matrix (ECM) is essential for normal lactation and milk synthesis in the mammary gland. Signals from the ECM have been demonstrated as necessary for normal physiological function and cell death in many types of epitheliums. Loss of physical attachment between MECs

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and the ECM in the mammary gland occurs during the involution period (Pullan et al., 1996). This apoptosis-induced loss of the MEC/ECM attachment is caused by anoikis (Gilmore., 2005; Rutherford et al., 2021). In rodents, the normal involution processes can be divided into two phases: the reversible phase of involution starts within 12–48 hours when the rat undergoes natural or force weaning, following which the loss of MEC/ECM interaction induces tissue remodeling by matrix metalloproteinases leading to anoikis and the collapse of the alveoli (Sutherland et al., 2007). Regenerative involution involves a different mechanism in ruminants, with a limited degree of anoikis and MEC removal (Motyl et al., 2007). Although MEC removal during mammary gland involution has been well studied, there is scarce information about the detachment of MECs from the ECM during the lactation period. However, many experiments have demonstrated that MECs are typically detached in raw milk during lactation (Boutinaud et al., 2015; Lollivier et al., 2015; Saipin et al., 2018). These milk-isolated MECs might be derived from two possible sources: the epithelium of the mammary alveolus or the tubular system (or luminal part). Interestingly, these MECs can be cultivated and exhibit a proliferative property. At this point, it is important to establish whether MEC detachment during lactation is associated with anoikis. The viability of milk-purified MECs has been reported to be over 60% using trypan blue staining (Boutinaud et al., 2015). Nonetheless, whether MEC detachment during lactation represents the normal loss of MEC/ECM interaction and whether these cells can survive and proliferate under the appropriate *in vitro* culture conditions remain unclear.

The MEC culture from fresh milk contains lactogenic enzymes that can be transformed by lactogenic hormones. After hormone activation, MECs contain droplets and produce lactose (Saipin et al., 2018; Saipin et al., 2020b), indicating that fresh milk-isolated MECs might be progenitor cells that can be transformed into alveolar epithelial cells (Figure 3). During the prepartum period, the standard lactogenesis mechanism involves essential preparation steps such as secretory compartment differentiation and specific lactogenic enzyme expression. Under this natural condition, polarization of the nucleus and the Golgi apparatus constitute the major part of organelle differentiation. The lactogenic enzymes for lactose, casein, and lipid synthesis are expressed during the peripartum period. These lactogenesis processes are under the hormone milieu and exhibit a chronological pattern (Neville et al., 2002). However, how do MECs from *in vitro* conditions synthesize lactose? Do they undergo compartment differentiation similar to that during the lactogenesis processes? Are there other milk compositions synthesized by these MECs, such as casein micelle and fat globule? These fundamental questions are important and must be investigated to verify the fresh milk-isolated MEC culture system and to use them as a culture system in the future.

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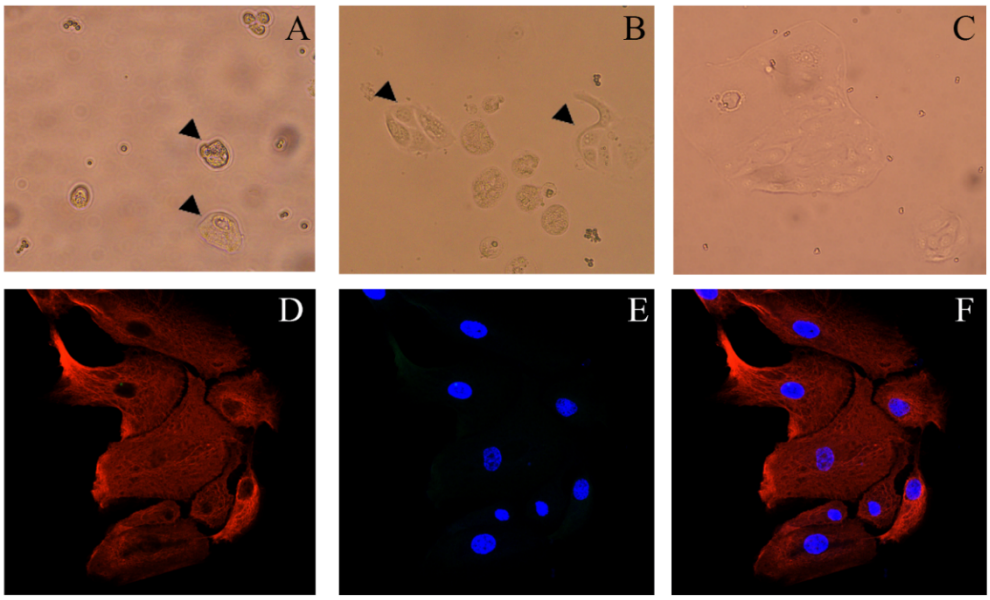

Figure 2 Cell morphology and characteristics of mammary epithelial cells (MECs) derived from fresh goat milk. (upper panel) Phase contrast monitoring during MEC propagation from day 0 to day 2. The single MEC morphology (arrow heads) could be detected a few hours after culture start (day 0, A), cobblestone-like morphology (arrow heads) could be seen 24 hours later (day 1, B) and the large colonies were developed after 48 hours (day 2, C), (lower panel) The immunocytochemistry staining of MEC with cytoskeleton strained with anti-cytokaracin 18 (cyt18, D), nucleus staining with DAPI (E), and overlay 1-µm confocal micrograph of cyt18/DAPI (F). This figure is original data, not previously published.

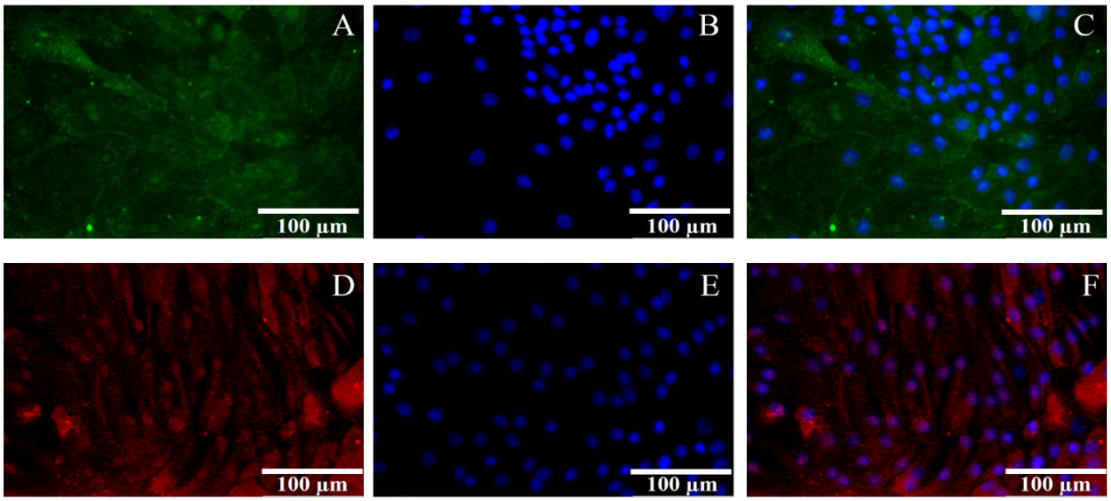

Figure 3 Mammary epithelial cells (MECs) derived from fresh goat milk can be transformed into mammary secretory cells. (upper panel) These MECs contain β-casein molecules (green, A) and DAPI (blue, B) after 9 days of hormone induction. The merged image (C) between β-casein and DAPI immunohistochemistry. (lower panel) With a similar hormone induction, the immunostaining signal for xanthine oxidoreductase (red, C), the crucial protein for lipid secretion, is also expressed. Immunostaining signal of DAPI (blue, D) for the same area and merged image with xanthine oxidoreductase signal (E). This figure is original data, not previously published.

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MAMMARY EPITHELIAL CELL CULTURE AS THE BIOREACTOR

Cellular agriculture has the potential to promote environmental sustainability, improve animal welfare, and enhance human health and well-being. Cultivated meat has been actively researched over the past two decades; however, many challenges have impeded its path into the market (Reiss et al., 2021; Olenic et al., 2025). Because the functional nature of MEC is primarily synthetic, the bioreactor containing MECs can be conceptualized into 2 main production pathways. Dairy products are the first target that may support the agricultural welfare and mitigate the issues associated with conventional dairy farming. The second involves the production of biomedical substances, including specific target proteins.

MECs can synthesize milk

Along with genetic enhancements in dairy cows, there is growing interest in MEC-cultured milk (Kwon et al., 2024). The term 'artificial mammary gland' used in this review broadly refers to a bioreactor containing MECs that can produce cultured or artificial milk. The MECs isolated from a mammary biopsy or fresh milk can synthesize milk or major components of milk (Shackleton et al., 2006; Machado et al., 2013; Jamieson et al., 2017; Saipin et al., 2018; Saipin et al., 2020b). This fundamental knowledge is just a tiny light at the end of the tunnel. The MEC culture has been used to synthesize major milk components, such as whey, caseins, and milk fat. Currently, commercially available animal-free mozzarella and β-lactoglobulin are produced using undisclosed microorganisms and fermentation-based techniques (Waltz, 2022). Although mammalian cells should be the ideal bioreactor for dairy products, producing individual milk components via MEC culture is more complicated than fermentation-based techniques due to the specific biochemical synthesis pathways within mammalian cells. Moreover, the production of whole milk is even more complicated due to the presence of micronutrients in whole milk.

Resident mammary progenitor cells serve as the primary source for MEC culture. Although $Lin^{-}CD29^{hi}CD24^{+}$ MEC has been demonstrated as the candidate mammary progenitor cell (Shackleton et al., 2006), where these cells reside in the mammary tissue and how they can be quiescent, activated, and differentiated temporally during lactogenesis remain poorly understood. Moreover, the protocol to manipulate various signaling pathways involving the differentiation from the quiescent stage to the alveolar stage remains unclear. This limitation presents an opportunity to isolate MECs from fresh milk. Our previous reports suggested that the MEC culture from fresh milk can potentially differentiate into alveolar cells. Although MECs obtained from fresh milk contain basic stem cells, their primary lineage shows a positive staining for epithelial markers (Saipin et al., 2018; Saipin et al., 2020b), providing the opportunity to examine the appropriate protocol to transform them into functional alveolar cells. In addition, it is possible to combine the idea of pluripotent stem-cell induction with these MECs (Bressan et al., 2020; Weeratunga et al., 2023) and test whether the induced pluripotent mammary stem cells (iPSCmams) behave similarly to the mammary progenitor cells ($Lin^{-}CD29^{hi}CD24^{+}$ MECs) isolated from mammary tissues. The iPSCmam hypothesis would be valuable due to its repeatability and noninvasive nature.

Natural milk contains lactose, caseins, and lipids as the major milk components in addition to several minor components, such as electrolytes (mainly calcium, phosphorus, and iodine), whey proteins (α-lactalbumin, β-lactoglobulin, and lactoferrin), and small molecules (growth factors). At present, it is not feasible to establish a culture system that can produce all the milk components in the precise concentrations found in natural milk. This hypothesis holds for the lipid synthesis pathway that needs two types of cells from the mammary gland. Adipose tissue from the mammary gland is an important source of glycerol for the mammary

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alveolar epithelium via glyceroneogenesis (Jiménez et al., 1987), and loss of the enzyme involved in glyceroneogenesis (phosphoenolpyruvate carboxykinase; PEPCK) leads to a reduction in lipid synthesis in MECs (Hsieh et al., 2011). The pattern of glucose uptake is the most important limiting step in the lactose synthesis pathway. We have demonstrated that 75% of the glucose uptake by the mammary gland was converted to lactose in lactating goats (Chaiyabutr et al., 1980). Glucose transporter I (GLUT1) is the primary transporter at the basolateral membrane in bovine mammary alveolar epithelium (Thammacharoen et al., 2002; Zhao, 2014). Interestingly, the basolateral GLUT1 can maintain the steep gradient between plasma glucose and the intracellular compartment of the MEC (3–5 mM and 0.1–0.5 mM in ruminants, respectively; Zhao, 2014). To our knowledge, information about glucose uptake and the expression of GLUT1 in the MEC culture is limited. Therefore, it is crucial to investigate whether cellular glucose uptake is the limiting factor for lactose synthesis in the MEC culture. These findings indicate the presence of several technical challenges for producing MEC-based culture milk; moreover, the technoeconomic challenge is a major task for those aiming to achieve this goal. Thus, the future goal is to establish a mammary organoid that contains both MECs and adipocytes within the three dimensions of the culture system.

MEC culture for mammalian protein production

In addition to the expression of β-galactosyltransferase in the lactose synthesis pathway, we have demonstrated the presence of β-casein in MECs (Saipin et al., 2018; Saipin et al., 2020b). Casein micelles have been demonstrated in the secretory vesicles of cultured mouse MECs; the sizes of the micelles secreted into the culture medium were comparable (approximately 80 nm) to those of the natural casein micelle (Aggeler et al., 1991). Although MEC culture can secrete casein micelles, the ability of individual MECs to synthesize casein micelles at concentrations similar to those in natural milk remains to be investigated. Specifically, under culture conditions, the concentration of α-casein was approximately 0.52 g/L, much lower than that in natural milk (~13 g/L; Kwon et al., 2024). If the capacity of the individual MEC from the culture condition were similar to that from mammary tissue, the total number of active MECs from the culture condition would have been the limiting factor for casein yield.

Given our understanding that the MEC culture can synthesize casein micelles, we can generate strategies that increase the proliferation and production of MECs (Bachhav et al., 2023), which would prove useful for synthesizing major milk components (or cultured milk). In addition, the MEC culture can be employed as a mammalian bioreactor for recombinant therapeutic proteins commanding high revenue. In 1987, human tissue plasminogen activator (tPA) was the first FDA-approved recombinant protein synthesized from immortalized Chinese hamster ovary (CHO) cells. Since then, several candidate recombinant proteins based on mammalian cells have been in the pipelines. Currently, the standard protocol, involving cellular bioengineering, medium development, and selection method, can increase production protein yield up to 4.7 g/L, with individual cells capable of producing up to 90 pg/cell/day (Wurm, 2004). The suppression of asymmetrical mammary cell division by xanthosine has increased the proliferation capacity in bovine MECs (Choudhary and Capuco, 2012). The suppression of asymmetric cell kinetics is based on suppressing p53-induced asymmetric cell division by promoting guanine ribonucleotide formation (Lee et al., 2003). In contrast to manipulating p53-induced cell division, ionized radiation has been shown to promote the outgrowth of human MECs by expressing p16-dependent cell senescence (Mukhopadhyay et al., 2010). Progress in our understanding of the cell division control mechanisms would culminate in bottlenecks in recombinant protein production. Our hypothesis to use MEC culture as an alternative mammalian cell focuses on the diverse range of cellular biochemical pathways, such as the

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posttranslation processes (Bachhav et al. 2023), which is not often seen in some protein products from common cell line lineages, such as the CHO cell.

MAMMARY ORGANOIDS AS A MODEL FOR BREAST CANCER

Breast cancer has surpassed lung cancer (11.4%) to reign as the most common cancer with 2.3 (11.7%) million new cases (Coles et al., 2021). Studies on the biology of mammary cell lines are essential to understanding breast cancer and developing new treatments. Currently, several mammary cell lines derived from the tumor (Table 1) are available for various investigations (Sharma et al., 2024). However, the ability of a single cell line to accurately mimic phenotypes of breast cancer has been challenged (Keller et al., 2010). Breast cancer can be subdivided into four types (Luminal A, Luminal B, human epidermal growth factor receptor 2 [HER2], and basal-like) using immunohistochemistry staining with estrogen and progesterone receptors (ER and PR, respectively) and human epidermal growth factor receptor 2 (HER2). Luminal A cancers contain ER- and/or PR-positive and HER2-negative cells, whereas luminal B cancers contain ER- and/or PR-positive and HER2-positive cells. HER2-type breast cancers consist of ER- and/or PR-negative and HER2-positive cells, while basal-like breast cancer consists of cells that are ER- and/or PR-negative, HER2-positive, p53-positive, and epidermal growth factor receptor-positive.

Luminal cells have been reported to express the epithelial cell adhesion molecule (EpCAM) with or without α6 integrin (CD49). CD24 is a cell surface marker that involves hormone responses. Based on these three markers, human breast tissue can be subdivided into those containing luminal 1 cells ($EpCAM^{hi}/CD49f^{-}/CD24^{+}$) and luminal 2 cells ($EpCAM^{+low}/CD49f^{+}/CD24^{+}$), basal cells ($EpCAM^{+low}/CD49f^{+}/CD24^{-}$), or mesenchymal cells ($EpCAM^{-}/CD49f^{+}/CD24^{-}$). These three markers highlighted the restricted lineage profiles of breast cancer cell lines and indicated that individual cell lines fail to reach the heterogeneity of breast cancer cells (Keller et al., 2010). This information also supports the idea of establishing other cellular models for studying the biology of breast cancer.

With the advancement of bioengineering methods, it is now possible to create an appropriate cell line to study breast cancer biology. Human breast tissue is the primary source of MECs (Bergstraesser and Weitzman, 1993). MCF10A is the first normal human breast cell line derived from benign breast tissue and demonstrates an immortal property (Qu et al., 2015). In addition, mammary organoids developed using three-dimensional (3D) culture techniques based on primary human MECs and human breast cell lines have led to a better understanding of breast cancer biology (Rosenbluth et al., 2020; Qu et al., 2021; Souto et al., 2022). The fundamental knowledge of cancer biology, including cellular senescence and neoplastic transformation (O'Sullivan et al., 2024), invasiveness (Shea et al. 2020), and tumor formation during xenograft (Qu et al., 2021; Souto et al., 2022), can be understood using the mammary organoid. An alternative source of MECs for establishing mammary cell lines can be generated from other mammals (dairy cow, goat, or pig). Normal bovine MECs can be transformed into immortal cell lines following microinjection with SV40 large T-antigen (Arévalo et al., 2016; Hu et al., 2016). Most MECs collected from mammary tissue contain both luminal and basal lineages, similar to human MECs. The mammary biopsy is an invasive technique. Obtaining MECs from fresh milk will eliminate this invasive technique, enhance animal welfare, and allow repeatability (Saipin et al., 2018; Saipin et al., 2020b).

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Table 1 Selected human mammary cell lines and the characteristics.

Cell line	Origin**	Cellular markers***	Tumorigenicity	References
BT474	IDC, LU	$ER^+/PR^+/HER2^+/T53^+$	+	[1-2]
MCF7	IDC, LU	$ER^+/PR^+/HER2^-/T53^-$	$+/-^{WT}$	[2-4]
MCF10A	F, BA	$ER^-/PR^-/HER2^-/T53^-$	$+/-^{WT}$	[5, 6]
MDAMB231	AC/iDC, BA	$ER^-/PR^-/HER2^-/T53^+$	$+^{M}$	[2, 7-8]
MDAMB468	AC, BA	$ER^-/PR^-/HER2^-/T53^+$	+	[7-8]
SKBR3	AC/iDC, LU	$ER^-/PR^-/HER2^+/T53^+$	+	[9-10]
T47D	iDC, LU	$ER^+/PR^+/HER2^-/T53^+$	$+^{M}$	[1, 11]

*Selection criteria: mammary cell lines were selected and modified from Neve et al. (2006). The list is mammary cell lines that are top quartile from the number of research papers searched within 10 years (2014-2024 and more than 50 articles) & without review articles from PubMed database.
** Abbreviations of tumor type and epithelial phenotype from each immortal cell: AC, adenocarcinoma; iDC, invasive ductal carcinoma; F, fibrocystic mammary tissue; BA, basal, LU, luminal type; WT, wild type; M, mutant;
*** Cellular marker information is modified from Lacroix et al. (2004) and Neve et al. (2006).
List of references: 1) Lasfargues et al. (1978); 2) Vikram et al. (2020); 3) Soule et al. (1973); 4) Gong et al. (2013); 5) Qu et al. (2015); 6) Soule et al. (1990); 7) Cailleau et al. (1978); 8) Corner et al. (2024); 9) Thomson et al. (1981); 10) Shi et al. (2016); 11) Keydar et al. (1979).

CONCLUSION

The *in vitro* mammary cell culture is important in mammary gland and lactation physiology. Additionally, it can improve our understanding of the mechanisms involved in breast cancer development and help in the bioinnovation of target proteins. Mammary tissue and fresh milk are the two different sources of MECs that can be used for culture. With the recent advances in bioengineering cells, generating appropriate strategies to improve culture density, longevity, and productivity seems plausible. The mammary organoid or artificial mammary gland can serve as a bioreactor for synthesizing artificial milk or its key components. Due to intact posttranslation processes in the mammalian cells, this bioreactor can be adapted to synthesize the target pharmaceutical proteins. Primary MECs and cell lines induced by MECs from various animals are currently being actively researched using 3D culture to study the breast cancer biology and treatment options comprehensively. To achieve all of the above advantages of MEC culture, MEC subpopulation identification and classification represent crucial information. The collection of MECs from various mammalian species is another important goal. This review emphasizes the significant potential for creating novel systems and models designed to meet specific objectives.

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AUTHOR CONTRIBUTIONS

ST Conceptualization, writing – original draft preparation, Funding acquisition. SS: Data curation, NS: Data curation, TN: Data curation, CK: Data curation, NC: Supervision, Validation. SP: Conceptualization, writing - review & editing, Validation.

CONFLICT OF INTEREST

The authors declare no conflicts of interest, financial or otherwise.

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REFERENCES

Aggeler, J., Ward, J., Blackie, L.M., Barcellos-Hoff, M.H, Streuli, C.H., Bissell, M.J., 1991. Cytodifferentiation of mouse mammary epithelial cells cultured on a reconstituted basement membrane reveals striking similarities to development in vivo. J. Cell. Sci. 99, 407-417.

Arévalo Turrubiarte, M., Perruchot, M.H., Finot, L., Mayeur, F., Dessauge, F., 2016. Phenotypic and functional characterization of two bovine mammary epithelial cell lines in 2D and 3D models. Am. J. Physiol. Cell. Physiol. 310(5), C348-C356.

Bachhav, B., de Rossi, J., Llanos, C.D., Segatori, L., 2023. Cell factory engineering: Challenges and opportunities for synthetic biology applications. Biotechnol. Bioeng. 120(9), 2441-2459.

Bergstraesser, L.M., Weitzman, S.A., 1993. Culture of normal and malignant primary human mammary epithelial cells in a physiological manner simulates in vivo growth patterns and allows discrimination of cell type. Cancer. Res. 53(11), 2644-2654.

Boutinaud, M., Herve, L., Lollivier, V., 2015. Mammary epithelial cells isolated from milk are a valuable, non-invasive source of mammary transcripts. Front. Genet. 6, 323.

Bressan, F.F., Bassanezze, V., de Figueiredo Pessôa, L.V., Sacramento, C.B., Malta, T.M., Kashima, S., Fantinato Neto, P., Strefezzi, R.F., Pieri, N.C.G., Krieger, J.E., Covas, D.T., Meirelles, F.V., 2020. Generation of induced pluripotent stem cells from large domestic animals. Stem. Cell. Res. Ther. 11(1), 247.

Cailleau, R., Olivé, M., Cruciger, Q.V., 1978. Long-term human breast carcinoma cell lines of metastatic origin: preliminary characterization. In Vitro. 14(11), 911-915.

Chaiyabutr, N., Faulkner, A., Peaker, M., 1980. The utilization of glucose for the synthesis of milk components in the fed and starved lactating goat in vivo. Biochem. J. 186(1), 301-308.

Choudhary, R.K., Capuco, A.V., 2012. In vitro expansion of the mammary stem/progenitor cell population by xanthosine treatment. BMC. Cell. Biol. 13, 14.

Coles, C.E., Earl, H., Anderson, B.O., Barrios, C.H., Bienz, M., Bliss, J.M., Cameron, D.A., Cardoso, F., Cui, W., Francis, P.A., Jagsi, R., Knaul, F.M., McIntosh, S.A., Phillips, K.A., Radbruch, L., Thompson, M.K., André, F., Abraham, J.E., Bhattacharya, I.S., Franzoi, M.A., Drewett, L., Fulton, A., Kazmi, F., Inbah Rajah, D., Mutebi, M., Ng, D., Ng, S., Olopade, O.I., Rosa, W.E., Rubasingham, J., Spence, D., Stobart, H., Vargas Enciso, V., Vaz-Luis, I., Villarreal-Garza, C., 2024. The lancet breast cancer commission. Lancet. 403(10439), 1895-1950.

Conner, S.J., Guarin, J.R., Le, T.T., Fatherree, J.P., Kelley, C., Payne, S.L., Parker, S.R., Bloomer, H., Zhang, C., Salhany, K., McGinn, R.A., Henrich, E., Yui, A., Srinivasan, D., Borges, H., Oudin, M.J., 2024. Cell morphology best predicts tumorigenicity and metastasis in vivo across multiple TNBC cell lines of different metastatic potential. Breast. Cancer. Res. 26(1), 43.

Corrò, C., Novellasdemunt, L., Li, V.S.W., 2020. A brief history of organoids. Am. J. Physiol. Cell. Physiol. 319(1), C151-C165.

Diego, C., Martignani, E., Miretti, S., Macchi, E., Accornero, P., Baratta, M., 2014. Bovine mammary epithelial cells retain stem-like phenotype in long-term cultures. Res. Vet. Sci. 97(2), 367-375.

Food and Agriculture Organization of the United Nations, 2023. Dairy Market Review – Overview of global dairy market and policy developments in 2022. FAO, Rome.

VETERINARY INTEGRATIVE SCIENCES

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Gillis, R.E., Kendall, I.P., Roffet-Salque, M., Zanon, M., Anders, A., Arbogast, R.M., Bogucki, P., Brychova, V., Casanova. E., Classen E., Csengeri, P., Czerniak, L., Domboróczki, L., Fiorillo, D., Gronenborn, D., Hachem, L., Jakucs, J., Ilett, M., Lyublyanovics, K., Lenneis, E., Marciniak, A., Marton, T., Oross, K., Pavúk, J., Pechtl, J., Pyzel, J., Stadler, P., Stäuble, H., Vostrovská, I., van Wijk, I., Vigne, J.D., Balasse, M., Evershed, R.P., 2024. Diverse prehistoric cattle husbandry strategies in the forests of Central Europe. Nat. Ecol. Evol. 9(1), 87-98.

Gilmore, A.P., 2005. Anoikis. Cell Death Differ. 12, 1473-1477.

Gong, C., Bauvy, C., Tonelli, G., Yue, W., Deloménie, C., Nicolas, V., Zhu, Y., Domergue, V., Marin-Esteban, V., Tharinger, H., Delbos, L., Gary-Gouy, H., Morel, A.P., Ghavami, S., Song, E., Codogno, P., Mehrpour, M., 2013. Beclin 1 and autophagy are required for the tumorigenicity of breast cancer stem-like/progenitor cells. Oncogene. 32(18), 2261-2272.

Hsieh, C.W., Huang, C., Bederman, I., Yang, J., Beidelschies, M., Hatzoglou, M., Puchowicz, M., Croniger, C.M., 2011. Function of phosphoenolpyruvate carboxykinase in mammary gland epithelial cells. J. Lipid. Res. 52(7), 1352-1362.

Hu, H., Zheng, N., Gao, H., Dai, W., Zhang, Y., Li, S., Wang, J., 2016. Immortalized bovine mammary epithelial cells express stem cell markers and differentiate in vitro. Cell. Biol. Int. 40(8), 861-872.

Jamieson, P.R., Dekkers, J.F., Rios, A.C., Fu, N.Y., Lindeman, G.J., Visvader, J.E., 2017. Derivation of a robust mouse mammary organoid system for studying tissue dynamics. Development. 144(6), 1065-1071.

Jiménez, J., Page-Peñuelas, A., Ros, M., García-Ruíz, J.P., Moreno, F.J., 1987. Glycerogenic pathway in the rat mammary gland. Int. J. Biochem. 19(2), 201-204.

Keller, P.J., Lin, A.F., Arendt, L.M., Klebba, I., Jones, A.D., Rudnick, J.A., DiMeo, T.A., Gilmore, H., Jefferson, D.M., Graham, R.A., Naber, S.P., Schnitt, S., Kuperwasser, C., 2010. Mapping the cellular and molecular heterogeneity of normal and malignant breast tissues and cultured cell lines. Breast. Cancer. Res. 12(5), R87.

Keydar, I., Chen, L., Karby, S., Weiss, F.R., Delarea, J., Radu, M., Chaitcik, S., Brenner, H.J., 1979. Establishment and characterization of a cell line of human breast carcinoma origin. Eur. J. Cancer (1965). 15(5), 659-670.

Kwon, H.C., Jung, H.S., Kothuri, V., Han, S.G., 2024. Current status and challenges for cell-cultured milk technology: a systematic review. J. Anim. Sci. Biotechnol. 15(1), 81.

Lacroix, M., Leclercq, G., 2004. Relevance of breast cancer cell lines as models for breast tumours: an update. Breast. Cancer. Res. Treat. 83(3), 249-289.

Lasfargues, E.Y., Coutinho, W.G., Redfield, E.S., 1978. Isolation of two human tumor epithelial cell lines from solid breast carcinomas. J. Natl. Cancer. Inst. 61(4), 967-978.

Lee, H.S., Crane, G.G., Merok, J.R., Tunstead, J.R., Hatch, N.L., Panchalingam, K., Powers, M.J., Griffith, L.G., Sherley, J.L., 2003. Clonal expansion of adult rat hepatic stem cell lines by suppression of asymmetric cell kinetics (SACK). Biotechnol. Bioeng. 83(7), 760-771.

Lin, H., 2002. The stem-cell niche theory: lessons from flies. Nat. Rev. Genet. 3(12), 931-940.

Lollivier, V., Lacasse, P., Angulo Arizala, J., Lamberton, P., Wiart, S., Portanguen, J., Bruckmaier, R., Boutinaud, M., 2015. In vivo inhibition followed by exogenous supplementation demonstrates galactopoietic effects of prolactin on mammary tissue and milk production in dairy cows. J. Dairy. Sci. 98(12), 8775-8787.

Machado, H.L., Kittrell, F.S., Edwards, D., White, A.N., Atkinson, R.L., Rosen, J.M., Medina, D., Lewis, M.T., 2013. Separation by cell size enriches for mammary stem cell repopulation activity. Stem. Cells. Transl. Med. 2(3), 199-203.

VETERINARY INTEGRATIVE SCIENCES

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Menchon, P., Manning, J.K., Swain, D.L., Cosby, A., 2024. Exploration of extension research to promote genetic improvement in cattle production: systematic review. Animals (Basel). 14(2), 231.

Mokbel, K., 2024. Unveiling the complex ecosystem of breast cancer: crucial insights for patients and doctors. Anticancer. Res. 44(8), 3317-3319.

Motyl, T., Gajewska, M., Zarzynska, J., Sobolewska, A., Gajkowska, B., 2007. Regulation of autophagy in bovine mammary epithelial cells. Autophagy. 3(5), 484-486.

Mukhopadhyay, R., Costes, S.V., Bazarov, A.V., Hines, W.C., Barcellos-Hoff, M.H., Yaswen, P., 2010. Promotion of variant human mammary epithelial cell outgrowth by ionizing radiation: an agent-based model supported by in vitro studies. Breast. Cancer. Res. 12(1), R11.

Neve, R.M., Chin, K., Fridlyand, J., Yeh, J., Baehner, F.L., Fevr, T., Clark, L., Bayani, N., Coppe, J.P., Tong, F., Speed, T., Spellman, P.T., DeVries, S., Lapuk, A., Wang, N.J., Kuo, W.L., Stilwell, J.L., Pinkel, D., Albertson, D.G., Waldman, F.M., McCormick, F., Dickson, R.B., Johnson, M.D., Lippman, M., Ethier, S., Gazdar. A., Gray, J.W., 2006. A collection of breast cancer cell lines for the study of functionally distinct cancer subtypes. Cancer. Cell. 10(6), 515-527.

Neville, M.C., McFadden, T.B., Forsyth, I., 2002. Hormonal regulation of mammary differentiation and milk secretion. J. Mammary. Gland. Biol. Neoplasia. 7(1), 49-66.

Olenic, M., Deelkens, C., Heyman, E., De Vlieghere, E., Zheng, X., van Hengel, J., De Schauwer, C., Devriendt, B., De Smet, S., Thorrez, L., 2025. Review: Livestock cell types with myogenic differentiation potential: Considerations for the development of cultured meat. Animal. 19, 101242.

O'Sullivan, E.A., Wallis, R., Mossa, F., Bishop, C.L., 2024. The paradox of senescent-marker positive cancer cells: challenges and opportunities. NPJ. Aging. 10(1), 41.

Pullan, S., Wilson, J., Metcalfe, A., Edwards, G.M., Goberdhan, N., Tilly, J., Hickman, J.A., Dive, C., Streuli, C.H., 1996. Requirement of basement membrane for the suppression of programmed cell death in mammary epithelium. J. Cell. Sci. 109, 631-642.

Qu, J., Kalyani, F.S., Liu, L., Cheng, T., Chen, L., 2021. Tumor organoids: synergistic applications, current challenges, and future prospects in cancer therapy. Cancer. Commun (Lond). 41(12), 1331-1353.

Qu, Y., Han, B., Yu, Y., Yao, W., Bose, S., Karlan, B.Y., Giuliano, A.E., Cui, X., 2015. Evaluation of MCF10A as a reliable model for normal human mammary epithelial cells. PLoS. One. 10(7), e0131285.

Ramsøe, A., Crispin, M., Mackie, M., McGrath, K., Fischer, R., Demarchi, B., Collins, M.J., Hendy, J., Speller, C., 2021. Assessing the degradation of ancient milk proteins through site-specific deamidation patterns. Sci. Rep. 11(1), 7795.

Reiss, J., Robertson, S., Suzuki, M., 2021. Cell sources for cultivated meat: applications and considerations throughout the production workflow. Int. J. Mol. Sci. 22(14), 7513.

Rosenbluth, J.M., Schackmann, R.C.J., Gray, G.K., Selfors, L.M., Li, C.M., Boedicker, M., Kuike,n H.J., Richardson, A., Brock, J., Garber, J., Dillon, D., Sachs, N., Clevers, H., Brugge, J.S., 2020. Organoid cultures from normal and cancer-prone human breast tissues preserve complex epithelial lineages. Nat. Commun. 11(1), 1711.

Rutherford, T.R., Elder, A.M., Lyons, T.R., 2021. Anoikis resistance in mammary epithelial cells is mediated by semaphorin 7a. Cell. Death. Dis. 12(10), 872.

Saipin, N., Noophun, J., Chumyim, P., Rungsiwiwut, R., 2018. Goat milk: Non-invasive source for mammary epithelial cell isolation and in vitro culture. Anat. Histol. Embryol. 47(3), 187-194.

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Saipin, N., Semsirmboon, S., Rungsiwiwut, R., Thammacharoen, S., 2020a. High ambient temperature directly decreases milk synthesis in the mammary gland in Saanen goats. J. Therm. Biol. 94, 102783.

Saipin, N., Thuwanut, P., Thammacharoen, S., Rungsiwiwut, R., 2020b. Effect of incubation temperature on lactogenic function of goat milk-derived mammary epithelial cells. In Vitro. Cell. Dev. Biol. Anim. 56(10), 842-846.

Shackleton, M., Vaillant, F., Simpson, K.J., Stingl, J., Smyth, G.K., Asselin-Labat, M.L., Wu, L., Lindeman, G.J., Visvader, J.E., 2006. Generation of a functional mammary gland from a single stem cell. Nature. 439(7072), 84-88.

Sharma, M.P., Shukla, S., Misra, G., 2024. Recent advances in breast cancer cell line research. Int. J. Cancer. 154, 1683-1693.

Shea, E.K.H., Koh, V.C.Y., Tan, P.H., 2020. Invasive breast cancer: Current perspectives and emerging views. Pathol. Int. 70(5), 242-252.

Shi, J.H., Cui, N.P., Wang, S., Zhao, M.Z., Wang, B., Wang, Y.N., Chen, B.P., 2016. Overexpression of YB1 C-terminal domain inhibits proliferation, angiogenesis and tumorigenicity in a SK-BR-3 breast cancer xenograft mouse model. FEBS. Open. Bio. 6(1), 33-42.

Soule, H.D., Maloney, T.M., Wolman, S.R., Peterson, W.D. Jr., Brenz, R., McGrath, C.M., Russo, J., Pauley, R.J., Jones, R.F., Brooks, S.C., 1990. Isolation and characterization of a spontaneously immortalized human breast epithelial cell line, MCF-10. Cancer. Res. 50(18), 6075-6086.

Soule, H.D., Vazguez, J., Long, A., Albert, S., Brennan, M., 1973. A human cell line from a pleural effusion derived from a breast carcinoma. J. Natl. Cancer. Inst. 51(5), 1409-1416.

Souto, E.P., Dobrolecki, L.E., Villanueva, H., Sikora, A.G., Lewis, M.T., 2022. In Vivo Modeling of Human Breast Cancer Using Cell Line and Patient-Derived Xenografts. J. Mammary. Gland. Biol. Neoplasia. 27(2), 211-230.

Stingl, J., Eirew, P., Ricketson, I., Shackleton, M., Vaillant, F., Choi, D., Li, H.I., Eaves, C.J., 2006. Purification and unique properties of mammary epithelial stem cells. Nature. 439(7079), 993-997.

Sutherland, K.D., Lindeman, G.J., Visvader, J.E., 2007. The molecular culprits underlying precocious mammary gland involution. J. Mammary. Gland. Biol. Neoplasia. 12(1), 15-23.

Thammacharoen, S., Chanpongsang, S., Chaiyabutr, N., Teedee, S., Pornprapai. A., Insam-ang, A., Srisa-ard, C., Channacoop, N., 2020. An analysis of herd-based lactation curve reveals the seasonal effect from dairy cows fed under high ambient temperature. Thai. J. Vet. Med. 50(2), 169-178.

Thammacharoen, S., Komolvanich, S., Suwankamjaya, T., Saowakhataphum, M., Chaiyo, N., Chaiyabutr, N., 2002. Glucose transporter I in the mammary tissue during late lactation in crossbred Holstein and Sahiwal cattle. Int. J. Anim. Sci. 17, 39-42.

Thammacharoen, S., Saipin, N., Nguyen, T., Chaiyabutr, N., 2022. Effects of high ambient temperature on milk protein synthesis in dairy cows and goats: insights from the molecular mechanism studies. Available online: https://www.intechopen.com/online-first/81528.

Thompson, B.J., Stern, A., Smith, S., 1981. Purification and properties of fatty acid synthetase from a human breast cell line. Biochim. Biophys. Acta. 662(1), 125-130.

Vikram, R., Chou, W.C., Hung, S.C., Shen, C.Y., 2020. Tumorigenic and metastatic role of CD44-/low/CD24-/low cells in luminal breast cancer. Cancers (Basel). 12(5), 1239.

Waltz, E., 2022. Cow-less milk: the rising tide of animal-free dairy attracts big players. Nat. Biotechnol. 40(11), 1534-1536.

Weeratunga, P., Harman, R.M., Van de Walle, G.R., 2023. Induced pluripotent stem cells from domesticated ruminants and their potential for enhancing livestock production. Front. Vet. Sci. 10, 1129287.

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Wilson, G.M., Dinh, P., Pathmanathan, N., Graham, J.D., 2022. Ductal carcinoma in situ: molecular changes accompanying disease progression. J. Mammary. Gland. Biol. Neoplasia. 27(1), 101-131.
Wurm, F.M., 2004. Production of recombinant protein therapeutics in cultivated mammalian cells. Nat. Biotechnol. 22(11), 1393-1398.
Zhao, F.Q., 2014. Biology of glucose transport in the mammary gland. J. Mammary. Gland. Biol. Neoplasia. 19(1), 3-17.

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