Animal Science Papers and Reports vol. 36 (2018) no. 3, 263-273
Institute of Genetics and Animal Breeding, Jastrzębiec, Poland

Occurrence and aetiology of Staphylococcal mastitis – a review*

Aleksandra Kalińska[1], Agata Wójcik[1], Jan Slósarz[1], Brygida Kruzińska[2], Monika Michalczuk[2], Sławomir Jaworski[3], Mateusz Wierzbicki[3], Marcin Gołębiewski[1]**

[1] Cattle Breeding Division, Warsaw University of Life Sciences, Ciszewskiego 8, 02-787 Warsaw, Poland

[2] Poultry Breeding Division, Warsaw University of Life Sciences, Ciszewskiego 8, 02-787 Warsaw, Poland

[3] Division of Nanobiotechnology, Warsaw University of Life Sciences, Ciszewskiego 8, 02-787 Warsaw, Poland

(Accepted July 30, 2018)

Nowadays udder inflammation, referred to as *mastitis*, is one of the biggest issues for milk producers. This disease causes significant economic losses and has a negative impact on cows' yields, their welfare, as well as milk composition and technological properties. *Mastitis* may be caused by several pathogens belonging to bacterial species (e.g. *Streptococcus uberis*, *Streptococcus dysgalactiae*, *Escherichia coli*, *Enterococcus* spp. and *Pseudomona*s spp.), fungi (e.g. *Candida* spp. or *Cryptococcus* spp.) or algae (e.g. *Prototheca*). However, staphylococci (e.g. *Staphylococcus aureus*, *Staphylococcus epidermidis*) are some of the most common mastitis bacterial pathogens. Available information concerning the most frequent species involved in staphylococcal *mastitis* is reviewed in this paper.

KEYWORDS: aetiology / bacteria / cows / *mastitis* / staphylococci

*This paper was funded by the National Centre for Research and Development (LIDER/6/0070/L–7/15/NCBR/2016).
**Corresponding author: aleksandra_kalinska@sggw.pl

Mastitis in dairy herds

Mastitis is a multifactorial disease that requires proper herd management to eliminate or at least minimise its incidence in herds. Resistance of selected bacteria (*Staphylococcus aureus*, *Mannheimia haemolytica*, *Pasteurella multocida*, *Streptococcus dysgalactiae*, *Streptococcus uberis* and *Escherichia coli*) to antimicrobial agents varies among European countries, possibly due to differences in applied treatment methods [Hendriksen *et al.* 2008]. Nevertheless, it is absolutely clear that excessive antibiotic treatment in the past has resulted in greater resistance of mastitis pathogens [Oliver and Murinda 2012, Kalińska *et al.* 2017]; therefore, mastitis treatment solutions should be based on local knowledge of the resistant strains observed in each country [Hendriksen *et al.* 2008].

According to several authors the frequency of clinical mastitis in different countries is 12-30% [Riekerink *et al.* 2008, Mrode *et al.* 2012, Koeck *et al.* 2014, Santman-Berends *et al.* 2015, Kalińska and Slósarz 2016]. *Mastitis* increases production costs and has a negative impact on milk composition and its technological properties [Halasa *et al.* 2007, Biggs 2009, Kalińska *et al.,* 2017]. Moreover, the genetic correlation between clinical *mastitis* and cows' yields is unfavourable [Heringstad *et al.* 2000, Koivula *et al.* 2007, Negussie *et al.* 2008, Oltenacu and Broom 2010]. It is therefore the most economically significant disease affecting the dairy industry [Miglior *et al.* 2017]. Previous studies revealed that cows suffering from clinical *mastitis* had lower yields during the rest of the lactation period in comparison to healthy cows [Wilson *et al.* 2004, Hagnestam *et al.* 2007] and if *mastitis* occurred before the production peak its influence on cows' yields was more severe [Bartlett *et al.* 1991, Rajala-Schultz *et al.* 1999, Wilson *et al.* 2004]. Halasa *et al.* [2009] estimated the yearly costs of *mastitis* in a herd of 100 dairy cows to be EUR 4896. The prevalence of subclinical *mastitis* at 45% of a herd generates costs of USD 180 to 320 per case [Wilson *et al.* 1997], with approximately 70% of the costs associated with reduced milk production.

The first sign of inflammation in the mammary gland may be an elevated somatic cell count (SCC). Raw milk should contain <200,000 somatic cells per 1 cm^3. The somatic cells present in milk are white blood cells (e.g. macrophages, neutrophils) that penetrate mammary gland tissue from the blood in order to fight the inflammation process [Miller and Paape 1985, Akers and Nickerson 2011]. Clinical *mastitis* that occurs in the first 100 days of the first lactation increases the risk of culling by 34% [Hertl *et al.* 2017].

Even subclinical *mastiti*s influences the costs of milk production and has a negative impact on cows' yields. This relationship may be explained as a lack of visible symptoms during the subclinical stage of *mastitis* [Hagnestam *et al.* 2007]. Several authors have shown that decreased production may be observed at least a week before a *mastitis* diagnosis (Lucey *et al.* 1986, Rajala-Schultz *et al.* 1999, Gröhn *et al.* 2004, Wilson *et al.* 2004, Hagnestam *et al.* 2007]. Therefore, particularly clinical *mastitis* is connected with high production losses [Houben *et al.* 1993, Gröhn *et al.* 2004].

Many authors have presented positive relationships between parity and the risk of udder inflammation [Hagnestam-Nielsen *et al.* 2009, Taponen *et al.* 2017]. This

phenomenon is still not well enough understood by scientists; however, researchers usually explain it as the impairment of leukocyte function in older cows [Mehrzad *et al.* 2002, Rainard and Riollet 2006] or alterations in teat conformation that occurs in older cows. Increasing lactation numbers may also have an impact on udder conformation, teat end callosity and susceptibility to inflammation [Rogers 1993, Breen *et al.* 2009]. The pre-milking diameter of the teat apex is also described as a clinical *mastitis* risk factor and the risk is greater in cows with a lactation number ≥3 [Guarín and Ruegg 2016].

Mastitis may be caused by various pathogens, e.g. bacteria, fungi and algae, which may be classified as either contagious pathogens (e.g. *S. aureus*, *Streptococcus agalactiae*) or environmental pathogens (e.g. *E. coli*, *Klebsiella* spp.). Therefore, *mastitis* aetiology varies depending on the source and route of infection. The aim of this paper is to review the occurrence of *mastitis* caused by staphylococci and to present the *Staphylococcus* species associated with *mastitis*.

Pathogenesis of staphylococcal *mastitis* and changes in mammary gland tissue

Mastitis is an inflammation process in the mammary glands and usually occurs in response to an intramammary bacterial infection. However, the infection may also be caused by fungi or algae, mechanical injuries or thermal trauma. The occurrence of *mastitis* depends on the interaction between many factors (host, agent and environmental conditions).

Infection occurs after pathogens overcome anatomical defences (streak canal and teat canal). If they evade the cellular and humoral defence mechanisms of the mammary gland in a cow's organism, a disease can develop [Sordillo and Streicher 2002]. Inflammation leads to damage in the mammary epithelium, it increases SCC, while the alveoli lose their structural integrity. These changes also become visible as changes in milk quality and as symptoms of clinical *mastitis* in the udder (e.g. swelling, redness, pain during milking) [Zhao and Lacasse 2008]. Intramammary infections damage the cells in mammary gland tissue, because (1) a range of cellular and extracellular products are released by the pathogens; (2) lysosomal enzymes and oxidative products are released from phagocytes during the phagocytosis of invading organisms; and (3) proteases from blood and cytokines are released during the immune response [Zhao and Lacasse 2008].

Bacteria found in the cows' environment are responsible for 90% of *mastitis* cases [Lassa *et al.* 2013, Taponen *et al.* 2017]. Poor conditions (e.g. increased stock density of animals, high humidity in barns or dirty bedding) have a negative effect on animal welfare, but also elevate pathogen pressure on cows. Therefore, keeping the highest possible farm hygiene standard is the best method for *mastitis* prevention, which results, among other things, in lower SCCs. *Mastitis* pathogens use different mechanisms to adhere to bovine mammary gland cells, which results from their different cell specificity

targets [Lammers *et al.* 2001]. Malinowski *et al.* [2006] suggested that milk samples with lower SCCs (<200,000) were around 60% culture negative.

Staphylococcus aureus and coagulase-negative staphylococci (CNS) may be the main aetiological agents of bovine *mastitis* [Myllys *et al.* 1998, Malinowski *et al.* 2003, Gröhn *et al.* 2004, Malinowski *et al.* 2006]. However, *mastitis* cases associated with CNS are characterised by lower SCCs compared to infections caused by *S. aureus* [Janosi and Baltay 2004, Malinowski *et al.* 2006].

The probability of *S. aureus* intramammary infections is lower in organic farm systems than in conventional herds [Levison *et al.* 2016, Taponen *et al.* 2017]. This relationship has not been fully explained by scientists, but it may be associated with more intensive culling of cows infected by *S. aureus* due to the farmers' reluctance to use antibiotic treatment. As it was reported by Taponen *et al.* [2017], *mastitis* was the reason for culling in 24% cases in conventional herds and in 31% cases in organic herds. Moreover, Levison *et al.* [2016] also pointed out that in organic herds the prevalence of clinical mastitis was generally lower.

CNS have not been associated with milking systems, but these bacteria are common on teat skin and in teat canals [De Visscher *et al.* 2014]. The results from studies conducted by Taponen *et al.* [2017] were similar to previous data [Sampimon *et al.* 2009, Piepers *et al.* 2011] and suggested that an increased prevalence of *mastitis* caused by CNS could be associated with several cow and herd-level risk factors rather than any specific milking or housing system. Infections caused by CNS in multiparous cows occur rather during later lactation, in contrast to their incidence before or shortly after calving in primiparous cows [Gröhn *et al.* 2004, Taponen *et al.* 2007, Pyörälä and Taponen 2009]. However, the recovery rates after treatment are usually high in CNS *mastitis* cases [Pyörälä and Taponen 2009].

A different perspective may be presented for *S. aureus*, since *mastitis* caused by this pathogen has been more common in tiestall milking than in parlour milking systems. However, no significant difference was found between parlour milking and automatic milking systems [Taponen *et al.* 2017]. Similar observations were presented by Riekerink *et al.* [2008] and Ericsson Unnerstad *et al.* [2009], stating that *mastitis* caused by *S. aureus* was associated with tiestalls.

The histopathological reactions (or lesions) of lactating tissue in the case of *S. aureus* mastitis were extensively studied in the previous century [Chandler and Reid 1973, Heald 1979, Nickerson and Heald 1981, Sordillo and Nickerson 1988, Trinidad *et al.* 1990b]. They are characterised, among other things, by massive polymorphonuclear neutrophil infiltration, secretory tissue necrosis, involution of alveolar epithelium and the replacement of secretory tissue with non-secretory tissue. Results of a study on heifers carried out by Trinidad *et al.* [1990b] proved particularly that *S. aureus* infections causes necrosis of the secretory tissue and that the damaged secretory tissue is replaced with non-secretory tissue.

Results obtained by Bannerman *et al.* [2004ab] revealed that different *in vivo* responses to specific pathogens may be elicited by the ability of bacteria to establish

infection, but also by the ability of the host to respond to pathogens. The initiation of the inflammatory process is caused by the production and release of the tumour necrosis factor, fibroblasts and interleukins. These complex interactions result in an accumulation of polymorphonuclear neutrophils, which are the main somatic cells in milk during *mastitis* [Paape *et al.* 2002, Barański *et al.* 2005] and are predominant in acute udder infections caused by *S. aureus* [Leitner *et al.* 2000].

What is more, *S. aureus* produces toxins that destroy cell membranes, damage secretory tissue and induce necrosis in mammary glands [Chandler and Reid 1973, Heald 1979, Nickerson and Heald 1981, Sordillo and Nickerson 1988, Trinidad *et al.* 1990b]. First, the bacteria damage tissues in the teat and gland cisterns within one quarter of the udder and later invades the duct system, where the infection can be established in the milk-secreting cells. In the late 1990's Bayles *et al.* [1998] provided evidence that *S. aureus* can induce apoptosis in epithelial cells.

Staphylococci associated with *mastitis*

The most common pathogens isolated from the milk samples of cows that have both stages of *mastitis* are streptococci, staphylococci and *E. coli* [Riekerink *et al.* 2008, Breen *et al.* 2009]. Grave cases of mastitis were usually connected with infections caused by *Truepella* (formerly *Arcanobacterium) pyogenes*, *S. agalactiae*, coliforms, CAMP-negative streptococci, yeasts and *Prototheca* spp. [Wilson *et al.* 1997, Leitner *et al.* 2000, Lammers *et al.* 2001, Gröhn *et al.* 2004, Malinowski *et al.* 2006].

Pathogens associated with bovine *mastit*is may be described as contagious (*S. aureus*, *S. agalactiae* and *Mycoplasma bovis*) or as environmental pathogens (*S. dysgalactiae*, *S. uberis*, *Corynebacterium bovis*, CNS) [Reyher *et al.* 2012]. Various species of staphylococci and streptococci are the most frequent *mastitis* bacteria [Malinowski *et al.* 2006, Reyher *et al.* 2012, Lassa *et al.* 2013, Wernicki *et al.* 2014].

Staphylococcus aureus is one of the most common bacteria isolated from cows suffering from *mastitis* [Reksen *et al.* 2006, Malinowski *et al.* 2006, Riekerink *et al.* 2008, Wernicki *et al.* 2014]. This contagious udder pathogen is well-known as a cause of chronic *mastitis* [Barkema *et al.* 2006]. Some authors reported that infections caused by *S. aureus* are mostly subclinical [Janosi and Baltay 2004, Malinowski *et al.* 2006].

CNS also have a negative influence on cows' overall health [Taponen and Pyörälä 2009, Oliveira *et al.* 2013]. This group of bacteria can be the cause of both subclinical *masti*tis [Janosi and Baltay 2004, Malinowski *et al*. 2006, Pyörälä and Taponen 2009] and clinical *mastitis* [Malinowski *et al.* 2006, Koivula *et al.* 2007, Riekerink *et al.* 2008, Levison *et al.* 2016]. Some authors suggest that the incidence of *mastitis* caused by CNS increases with increasing parity [Taponen *et al.* 2017], although reports where CNS are more common in first-lactation cows are also available [Sampimon *et al.* 2009, Tenhagen *et al.* 2009, Pyörälä and Taponen 2009]. CNS include such species as e.g. *S. chromogenes*, *S. epidermidis*, *S. haemolyticus*, *S. simulans*, *S. equorum*, and *S. xylosus* [Piessens *et al.* 2011]. *Staphylococcus epidermidis* has been more frequently

isolated from human skin than from cows' skin and this may suggest humans as a likely source of infection [Thorberg *et al.* 2006].

CNS are important pathogens in cattle of all ages. *Staphylococccus simulans* and *S. chromogenes* have been the most frequently isolated CNS species in bovine *mastitis* [Trinidad *et al.* 1990a, Pyörälä and Taponen 2009]. *Staphylococcus chromogenes* has been the major reason for infections in pre-calving heifers and primiparous cows [Trinidad *et al.* 1990a, Rajala-Schultz *et al.* 2006, Taponen *et al.* 2006, Pyörälä and Taponen 2009], whereas *S. simulans* has been more frequent in older cows [Taponen *et al.* 2006, Pyörälä and Taponen 2009]. In turn, *S. hyicus* and *S. epidermidis* were also reported as being common CNS species in cattle [Myllys 1995, Thorberg *et al.* 2006].

In several studies authors have claimed that udder quarters infected with minor pathogens (*C. bovis* or CNS) were more resistant to subsequent natural infections by major pathogens (streptococci and *S. aureus*) [Rainard and Poutrel 1988, Schukken *et al.* 1989, Lam *et al.* 1997]. Some authors believe that the presence of CNS (e.g. *S. chromogenes*) inhibits the growth of other pathogens due to the production of inhibitory substances [De Vliegher *et al.* 2004]. A similar situation was reported by dos Santos Nascimento *et al.* [2005] and the authors suggested that it could be connected with an elevated SCC or with bacteriocins (antibacterial peptides) produced by CNS. Nevertheless, references that show that pre-calving intramammary CNS infections in heifers increased the risk for post-calving infections with CNS, *S. aureus*, or *S. uberis*, are also available [Parker *et al.* 2007, Compton *et al.* 2007].

According to an analysis presented by Malinowski *et al.* [2006] the level of the SCC was connected with specific pathogens, with *Staphylococcus aureus* and CNS being mainly isolated from samples with SCCs from 200,000 to 2,000,000. Therefore, planning *mastitis* management should maintain or improve the udder health status of a herd. This aspect is important not only for dairy farmers, but for the whole dairy industry due to an increasing consumer interest in the quality of dairy products [Hogeveen *et al.* 2011]. Scientists, veterinarians and experts connected with cattle breeding and the dairy industry should encourage milk producers to develop mastitis prevention systems. Udder inflammation will remain an important problem, but a reduction in mastitis occurrence can bring benefits (mainly economic) to producers and other parts of the dairy industry as well as consumers. Another positive influence in minimising its prevalence is related with more advantageous technological properties of the milk as well as improved animal health status and welfare.

Conclusions

Mastitis remains one of the greatest concerns for milk producers and continues to cause significant economic losses, while also having a negative impact on cows' yields, their welfare and milk quality. Mastitis may be caused by several pathogens belonging to bacteria (e.g. *S. uberis*, *S. dysgalactiae*, *E. coli*, *Enterococcus* spp., and *Pseudomona*s spp.), fungi (e.g. *Candida* spp. or *Cryptococcus* spp.) or algae (e.g.

Prototheca spp.). However, gram-positive bacteria from the *Staphylococcus* genus are some of the most common *mastitis* pathogens, such as one of the most frequent major *mastitis* pathogens, *S. aureus*, but also the common minor pathogens belonging to CNS (e.g. *S. epidermidis*, *S. simulans* or *S. chromogenes*). Coagulase-negative staphylococci may also be the cause of clinical mastitis and their occurrence in herds can vary depending on different factors. According to many observations and reports an appropriate level of herd management is crucial for *mastitis* prevention.

REFERENCES

1. AKERS R.M., NICKERSON S.C., 2011 – Mastitis and its impact on structure and function in the ruminant mammary gland. ***Journal of Mammary Gland Biology and Neoplasi*a** 16, 275-289.
2. BANNERMAN D.D., PAAPE M.J., LEE J.W., ZHAO X., HOPE J.C., RAINARD P., 2004a – *Escherichia coli* and *Staphylococcus aureus* elicit differential innate immune responses following intramammary infection. ***Clinical and Diagnostic Laboratory Immunology*** 11, 463-472.
3. BANNERMAN D.D., PAAPE M.J., GOFF J.P., KIMURA K., LIPPOLIS J.D., HOPE J.C., 2004 – Innate immune response to intramammary infection with *Serratia marcescens* and *Streptococcus uberis*. ***Veterinary Research*** 35, 681-700.
4. BARANSKI W., RAS M., JANOWSKI T., ZDUNCZYK S., OPSOMER G., DEWULF J., DE KRUIF A. 2005 – Bacteria isolated from bovine mammary glands before drying off and their antibiotic sensitivity. **P**roceedings of the 6th Middle European buiatrics congress, Cracow, Poland 1, 405-411.
5. BARKEMA H.W., SCHUKKEN Y.H., ZADOKS R.N., 2006 – Invited review: The role of cow, pathogen, and treatment regimen in the therapeutic success of bovine *Staphylococcus aureus* mastitis. ***Journal of Diary Scienc***e 89, 1877-1895.
6. BARTLETT P.C., VAN WIJK J., WILSON D.J., GREEN C.D., MILLER G.Y., MAJEWSKI G.A., HEIDER L.E., 1991 – Temporal patterns of lost milk production following clinical mastitis in a large Michigan Holstein herd. ***Journal of Diary Science*** 74, 1561-1572.
7. BAYLES K.W., WESSON C.A., LIOU L.E., FOX L.K., BOHACH G.A., TRUMBLE W.R., 1998 – Intracellular *Staphylococcus aureus* escapes the endosome and induces apoptosis in epithelial cells. ***Infection and Immunity*** 66, 336-342.
8. BIGGS A., 2009 – Mastitis in cattle. Crowood Press.
9. BREEN J.E., GREEN M.J., BRADLEY A.J., 2009 – Quarter and cow risk factors associated with the occurrence of clinical mastitis in dairy cows in the United Kingdom. ***Journal of Diary Science*** 92, 2551-2561.
10. CHANDLER R.L., REID I.M., 1973 – Ultrastructure and associated observations in clinical cases of mastitis in cattle. **Journal of Comparative Pathology** 83, 233–241.
11. COMPTON C.W.R., HEUER C., PARKER K., MCDOUGALL S., 2007 – Risk factors for peripartum mastitis in pasture–grazed dairy heifers. ***Journal of Diary Science*** 90, 4171-4180.
12. ERICSSON UNNERSTAD H., LINDBERG A., PERSSON WALLER K., EKMAN T., ARTURSSON K., NILSSON-ÖST M., BENGTSSON B., 2009 – Microbial aetiology of acute clinical mastitis and agent–specific risk factors. ***Veterinary Microbiology*** 137, 90-97.
13. GRÖHN Y.T., WILSON D.J., GONZÁLEZ R.N., HERTL J.A., SCHULTE H., BENNETT G., SCHUKKEN Y.H., 2004 – Effect of pathogen–specific clinical mastitis on milk yield in dairy cows. ***Journal of Diary Science*** 87,3358-3374.
14. GUARÍN J.F., RUEGG P.L., 2016 – Pre- and postmilking anatomical characteristics of teats and their associations with risk of clinical mastitis in dairy cows. ***Journal of Diary Science*** 99, 8323-8329.

15. HAGNESTAM C., EMANUELSON U., BERGLUND B., 2007 – Yield losses associated with clinical mastitis occurring in different weeks of lactation. ***Journal of Diary Science*** 90, 2260-2270.
16. HAGNESTAM–NIELSEN C., EMANUELSON U., BERGLUND B., STRANDBERG E., 2009 – Relationship between somatic cell count and milk yield in different stages of lactation. ***Journal of Diary Science*** 92, 3124-3133.
17. HALASA T., HUIJPS K., ØSTERÅS O., HOGEVEEN H., 2007 – Economic effects of bovine mastitis and mastitis management: A review. ***Veterinary Quarterly*** 29, 18-31.
18. HALASA T, NIELEN M, HUIRNE RBM, HOGEVEEN H., 2009 – Stochastic bio–economic model of bovine intramammary infection. ***Livestock Scienc*****e** 124, 295-305.
19. HEALD C.W., 1979. Morphometric study of experimentally induced *Staphylococcus aureus* mastitis in the cow. ***American Journal of Veterinary Research*** 40, 1294-1298.
20. HENDRIKSEN R.S., MEVIUS D.J., SCHROETER A., TEALE C., MEUNIER D., BUTAYE P., FRANCO A., UTINANE A., AMADO A., MORENO M., GREKO C., STÄRK K., BERGHOLD C., MYLLYNIEMI A.L., WASYL D., SUNDE M., AARESTRUP F.M., 2008 – Prevalence of antimicrobial resistance among bacterial pathogens isolated from cattle in different European countries: 2002-2004. ***Acta Veterinaria Scandinavica*** 50, 28.
21. HERINGSTAD B., KLEMETSDAL G., RUANE J., 2000 – Selection for mastitis resistance in dairy cattle: a review with focus on the situation in the Nordic countries. ***Livestock Production Science*** 64, 95-106.
22. HERTL J.A., SCHUKKEN Y.H., TAUER L.W., WELCOME F.L., GRÖHN Y.T., 2017 – Does clinical mastitis in the first 100 days of lactation 1 predict increased mastitis occurrence and shorter herd life in dairy cows? ***Journal of Diary Science*** 101, 2309-2323.
23. HOGEVEEN H., HUIJPS K., LAM T.J.G.M., 2011 – Economic aspects of mastitis: new developments. ***New Zealand Veterinary Journal*** 59,16-23.
24. HOUBEN E.H., DIJKHUIZEN A.A., VAN ARENDONK J.A., HUIRNE R.B., 1993 – Short– and long–term production losses and repeatability of clinical mastitis in dairy cattle. ***Journal of Diary Science*** 76, 2561-2578.
25. JANOSI S.Z., BALTAY Z.S., 2004. Correlations among the somatic cell count of individual bulk milk, result of the California Mastitis Test and bacteriological status of the udder in dairy cows. ***Acta Veterinaria Hungarica*** 52, 173-183.
26. KALIŃSKA A., SLÓSARZ J., 2016 – Influence of cow temperament and milking speed on herd life, lifetime milk yield and reasons of cow culling. ***Annals of Warsaw University of Life Sciences – SGGW, Animal Science*** 55, 177-186.
27. KALIŃSKA A., GOŁĘBIEWSKI M., WÓJCIK A., 2017 – Mastitis pathogens in dairy cattle – a review. ***World Scientific News*** 89, 22-31.
28. KOECK A., LOKER S., MIGLIOR F., KELTON D.F., JAMROZIK J., SCHENKEL F.S., 2014 – Genetic relationships of clinical mastitis, cystic ovaries, and lameness with milk yield and somatic cell score in first–lactation Canadian Holsteins. ***Journal of Diary Science*** 97, 5806-5813.
29. KOIVULA M., PITKÄLÄ A., PYÖRÄLÄ S., MÄNTYSAARI E.A., 2007 – Distribution of bacteria and seasonal and regional effects in a new database for mastitis pathogens in Finland. ***Acta Agriculturae Scand Section A*** 57, 89-96.
30. LAM T.J., SCHUKKEN Y.H., GROMMERS F.J., TIELEN M.J., BRAND A., 1997 – Effect of natural infection with minor pathogens on susceptibility to natural infection with major pathogens in the bovine mammary gland. ***American Journal of Veterinary Research*** 58,17-22.
31. LAMMERS A., VAN VORSTENBOSCH C.J., ERKENS J.H., SMITH H.E., 2001 – The major bovine mastitis pathogens have different cell tropisms in cultures of bovine mammary gland cells. ***Veterinary Microbiology*** 80, 255-265.
32. LASSA H., KUBIAK J., MAŁKIŃSKA-HORODYSKA M., 2013 – Bakterie najczęściej izolowane

z klinicznych postaci mastitis u krów oraz ich wrażliwość na antybiotyki. ***Życie Weterynaryjne*** 88, 651-653 (angielski tytuł). In Polish with English summary???

33. LEITNER G., SHOSHANI E., KRIFUCKS O., CHAFFER M., SARAN A., 2000 – Milk leucocyte population patterns in bovine udder infection of different aetiology. ***Journal of Veterinary Medicine Series B*** 47, 581 589.
34. LEVISON L.J., MILLER-CUSHON E.K., TUCKER A.L., BERGERON R., LESLIE K.E., BARKEMA H.W., DEVRIES T.J., 2016 – Incidence rate of pathogen-specific clinical mastitis on conventional and organic Canadian dairy farms. ***Journal of Dairy Science*** 99, 1341-1350.
35. LUCEY S., ROWLANDS G.J., RUSSELL A.M., 1986. Short-term associations between disease and milk yield of dairy cows. **Journal of Dairy Research** 53, 7-15.
36. MALINOWSKI E., KŁOSSOWSKA A., KACZMAROWSKI M., KOTOWSKI K., NADOLNY M., KUZMA K., 2003 – Health status of mammary glands and etiological agents of mastitis in herds with a high somatic cell count. ***Medycyna Weterynaryjna*** 59, 128-132.
37. MALINOWSKI E., LASSA H., KŁOSSOWSKA A., MARKIEWICZ H., KACZMAROWSKI M., SMULSKI S., 2006 – Relationship between mastitis agents and somatic cell count in foremilk samples. ***Bulletin of the Veterinary Institute in Pulawy*** 50, 349-352.
38. MEHRZAD J., DUCHATEAU L., PYÖRÄLÄ S., BURVENICH C., 2002 – Blood and milk neutrophil chemiluminescence and viability in primiparous and pluriparous dairy cows during late pregnancy, around parturition and early lactation. ***Journal of Dairy Science*** 85, 3268-3276.
39. MIGLIOR F., FLEMING A., MALCHIODI F., BRITO L.F., MARTIN P., BAES C.F., 2017 – A 100-Year Review: Identification and genetic selection of economically important traits in dairy cattle. ***Journal of Dairy Science*** 100, 10251–10271
40. MILLER R.H., PAAPE M.J., 1985 – Relationship between milk somatic cell count and milk yield. In Annual meeting – National Mastitis Council, Inc (USA), 60.
41. MRODE R., PRITCHARD T., COFFEY M., WALL E., 2012 – Joint estimation of genetic parameters for test-day somatic cell count and mastitis in the United Kingdom. ***Journal of Diary Science*** 95, 4618-4628.
42. MYLLYS V., ASPLUND K., BROFELDT E., HIRVELÄ-KOSKI V., HONKANEN-BUZALSKI T., JUNTTILA J., KULKAS L., MYLLYKANGAS O., NISKANEN M., SALONIEMI H., SANDHOLM M., SARANPÄÄ T., 1998 – Bovine mastitis in Finland in 1988 and 1995 – changes in prevalence and antimicrobial resistance. ***Acta Veterinaria Scandanvica*** 39, 119-126.
43. MYLLYS V., 1995 – Staphylococci in heifer mastitis before and after parturition. **Journal of Dairy Research** 62, 51–60.
44. NEGUSSIE E., STRANDÉN I., MÄNTYSAARI E.A., 2008 – Genetic association of clinical mastitis with test-day somatic cell score and milk yield during first lactation of Finnish Ayrshire cows. ***Journal of Diary Science*** 91, 1189-1197.
45. NICKERSON S.C., HEALD C.W., 1981 – Histopathologic response of the bovine mammary gland to experimentally induced Staphylococcus aureus infection. ***American Journal of Veterinary Research*** 42, 1351-1355.
46. OLIVER S.P., MURINDA S.E., 2012 – Antimicrobial resistance of mastitis pathogens. ***Veterinary Clinics of North America: Food Animal Practice*** 28,165-185.
47. OLIVEIRA L., HULLAND C., RUEGG P.L., 2013 – Characterization of clinical mastitis occurring in cows on 50 large dairy herds in Wisconsin. ***Journal of Diary Science*** 96, 7538-7549.
48. OLTENACU P.A., BROOM D.M., 2010 – The impact of genetic selection for increased milk yield on the welfare of dairy cows. ***Animal Welfare*** 19, 39-49.
49. PAAPE M., MEHRZAD J., ZHAO X., DETILLEUX J., BURVENICH C., 2002 – Defense of the bovine mammary gland by polymorphonuclear neutrophil leukocytes. ***Journal of Mammary Gland Biology and Neoplasia*** 7, 109-121.

50. PARKER K.I., COMPTON C., ANNISS F.M., WEIR A., HEUER C., MCDOUGALL S., 2007 – Subclinical and clinical mastitis in heifers following the use of a teat sealant precalving. ***Journal of Diary Science*** 90, 207-218.
51. PIEPERS S., PEETERS K., OPSOMER G., BARKEMA H. W., FRANKENA K., DE VLIEGHER S., 2011 – Pathogen group specific risk factors at herd, heifer and quarter levels for intramammary infections in early lactating dairy heifers. ***Preventive Veterinary Medicine*** 99, 91-101.
52. PIESSENS V., VAN COILLIE E., VERBIST B., SUPRÉ K., BRAEM G., VAN NUFFEL A., DE VUYST L., HEYNDRICKX M., DE VLIEGHER S., 2011 – Distribution of coagulase-negative *Staphylococcus* species from milk and environment of dairy cows differs between herds. ***Journal of Diary Science*** 94, 2933-2944.
53. PYÖRÄLÄ S., TAPONEN S., 2009 – Coagulase–negative staphylococci — Emerging mastitis pathogens. *Veterianry Microbiology* 134, 3-8.
54. RAINARD P., POUTREL B., 1988 – Effect of naturally occurring intramammary infections by minor pathogens on new infections by major pathogens in cattle. *American Journal of Veterinary* **Research** 49, 327-329.
55. RAINARD P., RIOLLET C., 2006 – Innate immunity of the bovine mammary gland. *Veterinary Research* 37, 369-400.
56. RAJALA-SCHULTZ P.J., GROHN Y.T., MCCULLOCH C.E., GUARD C.L. 1999 – Effects of clinical mastitis on milk yield in dairy cows. ***Journal of Diary Science*** 82, 1213-1220.
57. RAJALA-SCHULTZ P.J., SMITH K.L., HOGAN J.S., LOVE B.C., 2004 – Antimicrobial susceptibility of mastitis pathogens from first lactation and older cows. ***Veterinary Microbiology*** 102, 33-42.
58. REKSEN O., SØLVEROD L., BRANSCUM A.J., ØSTERÅS O., 2006 – Relationships between milk culture results and treatment for clinical mastitis or culling in Norwegian dairy cattle. ***Journal of Diary Science*** 89, 2928–-937.
59. REYHER K.K., HAINE D., DOHOO I.R., REVIE C.W., 2012 – Examining the effect of intramammary infections with minor mastitis pathogens on the acquisition of new intramammary infections with major mastitis pathogens — A systematic review and meta–analysis. ***Journal of Diary Science*** 95, 6483-6502.
60. RIEKERINK R.O., BARKEMA H.W., KELTON D.F., SCHOLL D.T., 2008 – Incidence rate of clinical mastitis on Canadian dairy farms. ***Journal of Diary Science*** 91, 1366-1377.
61. ROGERS G.W., 1993 – Index selection using milk yield, somatic cell score, udder depth, teat placement, and foot angle. **Journal of Diary Science** 76, 664-670.
62. SAMPIMON O.C., BARKEMA H.W., BERENDS I.M., SOL J., LAM T.J., 2009 – Prevalence and herd–level risk factors for intramammary infection with coagulase-negative staphylococci in Dutch dairy herds. ***Veterinary Microbiology*** 134, 37-44.
63. Santman–Berends I.M.G.A., Lam T.J.G.M., Keurentjes J., Van Schaik G., 2015 – An estimation of the clinical mastitis incidence per 100 cows per year based on routinely collected herd data. ***Journal of Diary Science*** 98, 6965-6977.
64. SANTOS NASCIMENTO DOS J., FAGUNDES P.C., DE PAIVA BRITO M.A., DOS SANTOS K.R.N., DE FREIRE BASTOS M.D.C., 2005 – Production of bacteriocins by coagulase-negative staphylococci involved in bovine mastitis. ***Veterinary Microbiology*** 106, 61-71.
65. SCHUKKEN Y.H., VAN DE GEER D., GROMMERS F.J., SMIT J.A., BRAND A., 1989 – Intramammary infections and risk factors for clinical mastitis in herds with low somatic cell counts in bulk milk. ***Veterinary Record*** 125, 393-396.
66. SORDILLO L.M., NICKERSON S.C., 1988 – Morphologic changes in the bovine mammary gland during involution and lactogenesis. ***American Journal of Veterinary Research*** 49, 1112-1120.

67. SORDILLO L.M., STREICHER K.L., 2002 – Mammary gland immunity and mastitis susceptibility. ***Journal of Mammary Gland Biology and Neoplasia*** 7, 135-146.
68. TAPONEN S., SIMOJOKI H., HAVERI M., LARSEN H.D., PYÖRÄLÄ S., 2006 – Clinical characteristics and persistence of bovine mastitis caused by different species of coagulase-negative staphylococci identified with API or AFLP. ***Veterinary Microbiology*** 115, 199-207.
69. TAPONEN S., KOORT J., BJÖRKROTH J., SALONIEMI H., PYÖRÄLÄ S., 2007 – Bovine intramammary infections caused by coagulase-negative staphylococci may persist throughout lactation according to amplified fragment length polymorphism-based analysis. ***Journal of Diary Science*** 90, 3301-3307.
70. TAPONEN S., PYÖRÄLÄ S., 2009 – Coagulase–negative staphylococci as cause of bovine mastitis — Not so different from *Staphylococcus aureus*? ***Veterinary Microbiology*** 134, 29-36.
71. TAPONEN S., LISKI E., HEIKKILÄ A.M., PYÖRÄLÄ S., 2017 – Factors associated with intramammary infection in dairy cows caused by coagulase-negative staphylococci, *Staphylococcus aureus*, *Streptococcus uberis*, *Streptococcus dysgalactiae*, *Corynebacterium bovis*, or *Escherichia coli*. ***Journal of Diary Science*** 100, 493-503.
72. TENHAGEN B.A., HANSEN I., REINECKE A., HEUWIESER W., 2009 – Prevalence of pathogens in milk samples of dairy cows with clinical mastitis and in heifers at first parturition. ***Journal of Dairy Research*** 76, 179-187.
73. THORBERG B.M., KÜHN I., AARESTRUP F.M., BRÄNDSTRÖM B., JONSSON P., DANIELSSON-THAM M.L., 2006 – Pheno- and genotyping of *Staphylococcus epidermidis* isolated from bovine milk and human skin. ***Veterinary Microbiology*** 115, 163-172.
74. TRINIDAD P., NICKERSON S.C., ALLEY T.K., 1990a – Prevalence of Intramammary Infection and Teat Canal Colonization in Unbred and Primigravid Dairy Heifers. ***Journal of Diary Science*** 73, 107-114.
75. TRINIDAD P., NICKERSON S.C., ADKINSON R.W., 1990b – Histopathology of Staphylococcal Mastitis in Unbred Dairy Heifers. ***Journal of Diary Science*** 73, 639-647.
76. WERNICKI A, PUCHALSKI A, URBAN–CHMIEL R., DEC M., STĘGIERSKA D., DUDZIC A., WÓJCIK A., 2014 – Antimicrobial properties of gold, silver, copper and platinum nanoparticles against selected microorganisms isolated from cases of mastitis in cattle. ***Medycyna Weterynaryjna*** 70, 564-567.
77. WILSON D.J., GONZALEZ R.N., DAS H.H., 1997 – Bovine mastitis pathogens in New York and Pennsylvania: prevalence and effects on somatic cell count and milk production. ***Journal of Diary Science*** 80, 2592-2598.
78. WILSON D.J., GONZALEZ R.N., HERTL J., SCHULTE H.F., BENNETT G.J., SCHUKKEN Y.H., GRÖHN Y.T., 2004 – Effect of clinical mastitis on the lactation curve: a mixed model estimation using daily milk weights. ***Journal of Diary Science*** 87, 2073-2084.
79. VISSCHER DE A., SUPRÉ K., HAESEBROUCK F., ZADOKS R.N., PIESSENS V., COILLIE E.V., PIEPERS S., DE VLIEGHER S., 2014 – Further evidence for the existence of environmental and host–associated species of coagulase–negative staphylococci in dairy cattle. ***Veterinary Microbiology*** 172, 466-474.
80. VLIEGHER DE S., OPSOMER G., VANROLLEGHEM A., DEVRIESE L.A., SAMPIMON O.C., SOL J., BARKEMA H.W., HAESEBROUCK F., DE KRUIFA A., 2004 – In vitro growth inhibition of major mastitis pathogens by *Staphylococcus chromogenes* originating from teat apices of dairy heifers. ***Veterinary Microbiology*** 101, 215-221.
81. ZHAO X., LACASSE P., 2008 – Mammary tissue damage during bovine mastitis: causes and control. ***Journal of Animal Science*** 86, 57-65.