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Somatic cells – causes and consequences of their varying presence in cow milk

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This study analyses key aspects of somatic cells in cow milk. It outlines their types, physiological levels, and diagnostic value for udder health, particularly in detecting subclinical mastitis. Methods for determining somatic cell counts are presented, with bacterial infections identified as the main cause of elevated levels. The role of lactose concentration as a practical indicator is highlighted, alongside environmental and genetic factors influencing somatic cell variation in breeding practice. The consequences of high counts – such as reduced milk yield, lower processing quality, and diminished reproductive performance – are summarized. Finally, the study discusses hygiene prophylaxis measures and the role of somatic cell monitoring in dairy cattle improvement programs worldwide.

KEYWORDS: somatic cells / milk / cows / variation / consequences

Somatic cells are cells originating from the cow's body. Their name is derived from the classification of living organisms' cells introduced by 19th-century biologist and geneticist August Weismann (1834-1914) – Maehle [2011]. The word "soma" refers to all cells in living organisms, both plant and animal, except for reproductive cells. In general, the name indicates a connection with plant or animal cells, e.g., somatic cells in milk.

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Somatic cells in milk are leukocytes, or white blood cells, which include macrophages, lymphocytes, and polymorphonuclear neutrophils [Harmon 2001]. Macrophages are the dominant type of somatic cells, constituting 66-88% of the total number of somatic cells in the milk of healthy cows [Alhussien *et al.* 2018, Harmon 2001]. Macrophages are the main phagocytic cells. Phagocytosis is the fundamental mechanism for removing microorganisms from the body and is particularly important in defence against extracellular bacteria, including those present in milk [Rosales and Uribe-Querol 2017]. Lymphocytes are a part of the acquired immune response. According to Harmon [2001], they make up 10-27%, while Alhussien *et al.* [2018] report 15% of the total somatic cell count (Photo 1). They are activated when the effectiveness of the first line of defence (i.e., phagocytic cells) is insufficient. Neutrophils are the key cells in acute inflammation. According to Harmon [2001], they make up 0-11%, while Alhussien *et al.* [2018] report 19% of somatic cells. They contain alkaline phosphatase, acid phosphatase, and antimicrobial peptides that participate in killing bacteria. The main function of neutrophils is to detect and eliminate pathogenic microorganisms throughout the body. Milk from healthy udders also contains a certain number of exfoliated epithelial cells from the glandular tissue of the udder (accounting for up to 0-7%), which contribute to the somatic cell count, especially during apoptosis.

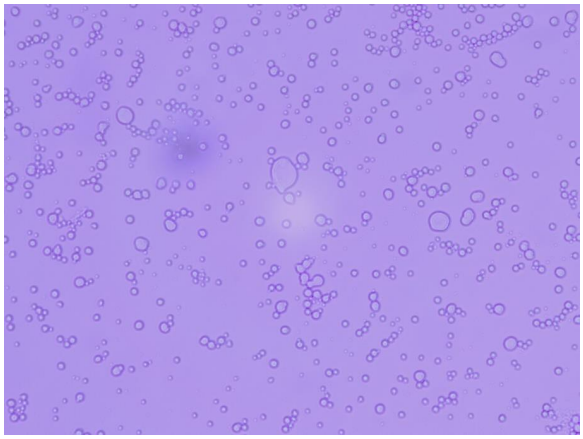

Photo 1. Somatic cell in cow milk from udders with subclinical *mastitis* (photo by Piotr Guliński).

The structure of somatic cells undergoes dramatic changes in the milk of cows affected by inflammatory conditions [Sarikaya *et al.* 2005, Sarikaya *et al.* 2006]. According to Alhussien *et al.* [2018], the percentages of macrophages, neutrophils, and lymphocytes in the milk of cows affected by this condition were 17%, 75%, and 8%, respectively.

Since the development of technologies enabling large-scale evaluation of somatic cell count (SCC), information about its level in cow milk has become a key biomarker for assessing the health status of the mammary glands and the cytological quality of

milk. An increase in SCC indicates an ongoing inflammatory process in the mammary gland.

The presence of somatic cells in milk is a fundamental component of the body's immune response to microorganisms in the mammary gland. An SCC in milk from a healthy udder is considered physiologically normal if it ranges between 18,000 and 200,000 cells per mL [Lavon *et al.* 2012]. According to Dohoo and Leslie [1991] and Dohoo *et al.* [2011], the optimal cut-off point between a healthy and an infected udder is 200,000 somatic cells per mL.

In Poland and the European Union, raw milk collected from cows should not contain more than 100,000 microorganisms and more than 400,000 somatic cells per mL [Schadt 2023]. An SCC of <400,000 cells/mL in raw cow milk is set as a quality criterion in Council Directive 92/46/EEC, which establishes health regulations for the production and marketing of raw milk, pasteurized milk, and dairy products, as well as in Regulation (EC) No. 853/2004 of the European Parliament and of the Council, which sets hygiene rules for food of animal origin. Similar standards to those in Europe are applied in Australia, Canada, Switzerland, and New Zealand. In the United States, the applicable standard allows a somatic cell count in raw milk at collection centres of no more than 750,000 cells/mL, while in Brazil the limit is 1 million cells per mL [Moore *et al.* 2013, Schadt 2023].

An increasing somatic cell count (SCC) indicates the presence of disease in the mammary gland, commonly referred to in the literature as *mastitis* [Guliński 2017]. On modern dairy farms, the inevitable contact between the microbiological environment and cow milk creates ideal conditions for microbial growth. For this reason, *mastitis* is often described as a "professional disease," affecting, in some herds, a very high percentage of cows. The progression and proliferation of microorganisms in the mammary gland lead to inflammation of the secretory tissue and milk ducts of the udder. The term *mastitis*, derived from the Greek word *mastos* (meaning udder) and the Latin suffix *-itis* (meaning inflammation), has therefore been adopted to describe this condition of the mammary gland. Unfortunately, today's high-producing cows are increasingly vulnerable to the bacteria that cause *mastitis*. This vulnerability is partly due to the continuously rising milk yields per cow and the increasing size of herds, which result in greater stress and reduced immune resistance to new infections.

Assessment of somatic cell count in milk: methods, role, and significance in the dairy sector

In technologically advanced agricultural sectors of developed countries, subclinical *mastitis* in dairy herds can be diagnosed based on somatic cell count (SCC) through various methods: analysis of SCC test results regularly conducted by milk quality monitoring organizations, such as the Polish Federation of Cattle Breeders and Dairy Farmers (PFCBDF) in Poland; the use of somatic cell counters; or devices measuring electrical conductivity or cows' locomotor activity. One of the simplest and oldest

methods for detecting *mastitis* is the California *Mastitis* Test (CMT). Each of these methods has its own advantages and limitations; therefore, the choice depends on the purpose of the analysis, available resources, and the needs of breeding practice.

Automated direct counting of somatic cells

The automated direct counting method of somatic cells is employed in devices such as the Fossomatic. It is the primary method used worldwide to assess somatic cell count (SCC) in the dairy industry. This technique involves the automatic electronic counting of photo-optical pulses generated by fluorescent DNA complexes (somatic cells) combined with a suitable dye, such as ethidium bromide. Well-known and widely used devices from the FOSS company are characterized by several functional features, the most important of which include: a measuring capacity of 200 to 600 samples per hour, a closed-system reagent addition mechanism, high adjustable accuracy, and safe waste handling. The disadvantages of this method include the high cost of equipment purchase and maintenance, the need to send samples to a laboratory – resulting in a lack of immediate feedback – and the requirement for qualified personnel and technical support. Therefore, it is an ideal method for monitoring SCC on a population scale and for milk recording purposes, but it is not very practical for individual on-farm diagnostics.

In smaller devices, such as the DeLaval DCC somatic cell counter, the operating principle is based on counting the nuclei of somatic cells stained with a specific reagent – Propidium Iodide. The resulting fluorescence is detected using digital imaging, which is then processed by dedicated software to determine the somatic cell count. The cassettes used in somatic cell count assessments can be analysed in under a minute. The measurement error of these counters ranges from approximately 7% (at SCC levels of ~1 million cells/mL) to 12% (at SCC levels of ~100,000 cells/mL). However, this device has some disadvantages, such as: relatively high unit cost of tests, slightly lower precision compared to Fossomatic, the device requires regular calibration and attention to cleanliness, and is not suitable for analysing a large number of samples. In summary, DeLaval Cell Counter (DCC) is a very good tool for individual, quick diagnostics of cows suspected of mastitis – an effective compromise between precision and mobility.

In 1956, Danish inventor Nils Foss established FOSS Electric A/S in the USA, a company now operating under the name FOSS Analytical A/S. Its products, based on infrared spectrophotometry, revolutionized the assessment of milk's chemical composition (e.g., MilkoScan). They also evaluate somatic cell count (Fossomatic) and bacterial count (BactoScan) in milk. The introduction of these devices in the 1970s and 1980s enabled large-scale analysis of various milk quality parameters, as well as other food raw materials. These parameters include protein, fat, lactose, casein, urea, density, freezing point, fructose, sucrose, glucose, galactose, total sugar content, citric acid, lactic acid, saturated and unsaturated fatty acids, free fatty acids, salt, and moisture.

Assessment of somatic cell count in milk – a new detection method

Damm *et al.* [2017] described new methods for diagnosing and assessing somatic cell count (SCC) in cow milk by introducing the concept of differential somatic cell count (DSCC). This method enables evaluation not only of the total number of somatic cells, but also of the specific types of cells present. Using flow cytometry techniques, the numbers of polymorphonuclear neutrophils (PMNs) and lymphocytes are quantified directly. The proportion of macrophages is then calculated by subtracting the DSCC (sum of PMNs and lymphocytes) from the total SCC. Damm *et al.* [2017] assessed the relevance of SCC levels in relation to their differential composition. The results showed that the average proportions of PMNs, macrophages, and lymphocytes were 58.68, 33.45, and 5.09%, respectively. In milk samples with SCC levels below 400,000 cells/mL, DSCC values ranged from 34 to 79%. In samples with SCC above 400,000 cells/mL, higher DSCC values were observed, ranging from 53 to 89%. Similarly, Halasa and Kirkeby [2020] demonstrated a significant correlation between increasing SCC levels and the changing proportions of lymphocytes, macrophages, and PMNs. As SCC increased across predefined ranges (<50,000; 50,000-100,000; 100,000-200,000; 200,000-400,000; and >400,000 cells/mL), the percentage of lymphocytes declined by 26, 14, 12, 11, and 9%, respectively, while macrophage proportions decreased by 43, 35, 29, 25, and 24%. Conversely, the proportion of polymorphonuclear leukocytes increased in parallel with SCC levels by 31, 51, 59, 64, and 67%, respectively (Fig. 1).

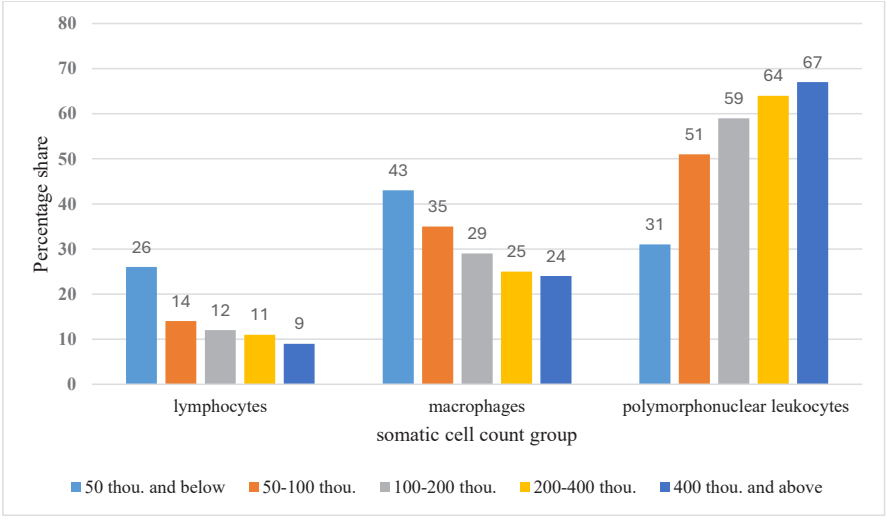

Fig. 1. Percentage changes in the share of individual types of somatic cells with an increase in their actual number in cows' milk [Halasa and Kirkeby 2020].

Olde Riekerink *et al.* [2007] demonstrated that fluctuations in the actual somatic cell count (SCC) in milk across different milkings were primarily associated with variations in the number of macrophages.

Since cows exhibit routine and repetitive behaviour, their activity can be monitored to identify differences in behaviour, such as feeding time, standing/lying down, chewing time, movement, and location within the barn [Tucker *et al.* 2021]. Physiological monitoring includes measuring body temperature (ear, milk, rumen using ceramic capsules, udder, vagina). Additionally, information regarding milk composition (SCC, fat concentration, lactose, protein) and electrical conductivity can be used to assess the presence of inflammatory conditions.

Electrical conductivity measurements (i.e., measurements of electrical resistance)

The concentration of sodium and chloride ions in milk increases in cows with *mastitis* [Harmon, 2001]. Electrical conductivity detectors measure changes in milk's electrical resistance because the development of subclinical *mastitis* (asymptomatic phase) is accompanied by an increase in the salt content in milk, which in turn causes changes in its conductivity [Janzekovic *et al.* 2009]. These are inexpensive and easy-to-use devices. The results depend on factors such as the timing of sample

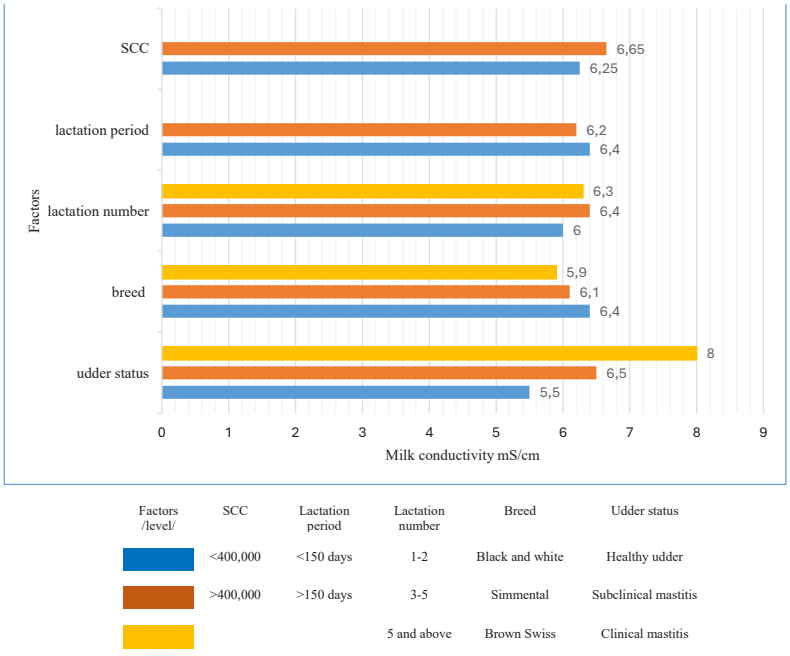

Fig. 2. Milk conductivity within selected factors [Janzekovic *et al.* 2009].

collection, breed, lactation number, lactation period, milk viscosity, temperature, and the calibration accuracy of the sensors (Fig. 2).

Accelerometers

Accelerometers, devices used to measure acceleration, are widely utilized in cattle husbandry and breeding. High-frequency data recordings enable the identification of animal behaviours even when the animals are out of sight. Additionally, these recordings facilitate the estimation of an animal's energy expenditure in its natural environment and the determination of limb movement frequency. It is important to highlight that accelerometers also play a crucial role in studying marine animal behaviour, where direct visual observation in natural habitats is often impossible. These devices can be connected to signal amplifiers to enhance data collection. In dairy cattle, accelerometers have been employed for many years to measure lying time and locomotor activity. Lying behaviour is considered a key welfare indicator. *Mastitis* significantly affects this behaviour, causing a reduction in lying time by approximately 73 minutes per day in affected cows (Fig. 3) – Cyples *et al.* [2012].

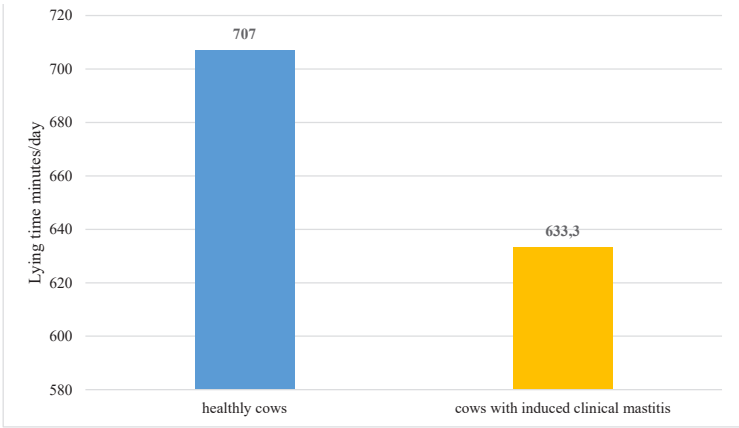

Fig. 3. The average lying time of the healthy cows and cows with induced clinical *mastitis* [Cyples *et al.* 2012].

The Israeli company SCR is a world leader in producing sensors that monitor cattle behaviour [Pereira *et al.* 2020]. Their latest devices, the SCR Heatime® HR System, are standalone monitoring systems designed to track a comprehensive range of estrus-related behaviours and overall cow health. These systems consist of neck-worn tags equipped with motion sensors and rumination recorders, with one central device capable of managing up to 400 cow tags simultaneously. The multisensor devices enable simultaneous measurement of body temperature, activity, rumination time, and feeding time.

California Mastitis Test

The California *Mastitis* Test (CMT) is a simple method used to diagnose somatic cell count (SCC) elevations and inflammatory conditions in cows' udders. The test is based on the reaction between sodium hydroxide and the cell walls and nucleic acids of leukocytes, which results in the formation of a gel. The CMT was developed by Whiteside in 1939 [Whiteside 1939] and is widely employed for the rapid, commercial detection of subclinical *mastitis*. In Poland, a similar test known as TOK (territorial cellular reaction) is commonly used. This test relies on the interaction of somatic cells with compounds contained in the Mastirapid diagnostic fluid.

The disadvantages of this method are: subjective interpretation of the result – dependent on the experience of the person performing the test, lack of an exact numerical result – only an approximate assessment, lower sensitivity at low SCC (<200,000 cells/ml) – the test may give a negative result in subclinical infections and the possibility of cross-reactions – e.g. with high protein content or the presence of disinfectants. Therefore, it is a good approximate method for quick selection and treatment decisions, but it does not replace accurate laboratory methods.

Causes of somatic cell presence in milk

Microorganisms are key factors responsible for the increase in somatic cell count (SCC) and, consequently, the occurrence of *mastitis* in cows. This group primarily includes bacteria and mycoplasmas – bacteria that lack a cell wall and represent the smallest type of bacteria. Fungi and algae can also be sources of *mastitis.* Under production conditions, mechanical or chemical injuries to the cow's udder may increase the risk of infection by allowing pathogenic microorganisms to enter. It is important to note that approximately 80% of *mastitis* cases in cows are of bacterial origin [Ruegg 2017].

Available literature data indicate that *mastitis* can be caused by more than 140 different species of microorganisms [Pascu *et al.* 2022]. These bacteria can be found both in the barn environment and on the animals themselves. Milk samples taken from cows with clinical *mastitis* on Polish dairy farms revealed that environmental bacteria were the most common causes of udder infections [Czernomysy-Furowicz *et al.* 2008]. According to these authors, the most frequent bacterial species responsible for udder infections in Poland were *Streptococcus agalactiae* (Bovine *Mastitis* Streptococcus), *Escherichia coli*, and *Staphylococcus hyicus* (coagulase-positive *Staphylococcus*). These species accounted for 16.26, 8.13, and 6.50% of the *mastitis* cases, respectively (Fig. 4).

Escherichia coli is one of the most common causes of udder inflammation in cows, both in Poland and worldwide [Goulart and Mellata 2022]. These environmental microorganisms are gram-negative rods that ferment lactose, using it as an energy source, and can survive in nearly anaerobic conditions. *Escherichia coli* does not

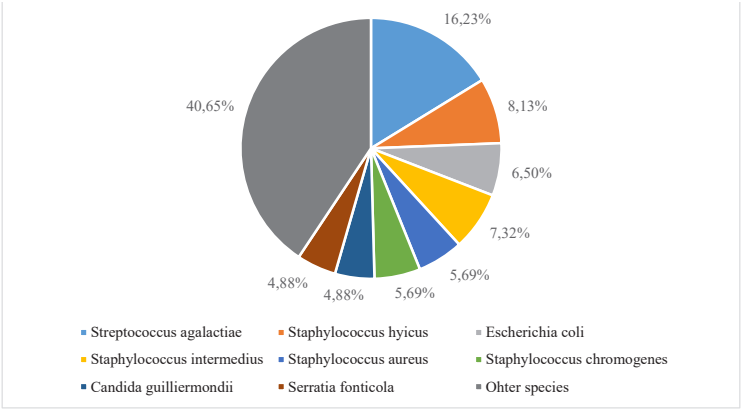

Fig. 4. Percentage of particular bacteria species causing *mastitis* in cows according to Czernomysy-Furowicz *et al*. [2008].

colonize the udder tissue but remains within the lumen of the teat canal and cistern. The severity of clinical symptoms is related to the amount of lipopolysaccharide released during bacterial growth and cell lysis. A notable characteristic of *E. coli* is its extremely rapid reproduction rate, with populations doubling approximately every 20 minutes. Typical *E. coli*-induced *mastitis* has a sudden onset, featuring loss of milk secretion in the affected quarter, swelling, tenderness, and an increase in body temperature. Infections caused by *E. coli* are often spontaneously eliminated, with a rapid decline in bacterial numbers in the milk occurring within 8 to 24 hours after infection [Markiewicz 2013].

Among the many bacterial species that cause udder inflammation in cows, *Staphylococcus aureus* is considered one of the most dangerous pathogens responsible for *mastitis* in dairy cattle [Campos *et al.* 2022, Cheng and Hang 2020, Kerro Dego and Vidlund 2024]. The cellular structure of *S. aureus* enables it to resist the host's immune response. These bacteria can cause acute clinical infections, chronic infections, and subclinical infections – the latter being the most prevalent form. *Staphylococcus aureus* produces various enzymes and toxins, such as catalase and coagulase, and is resistant to phagocytosis. It can lead to abscess formation and fibrosis in udder tissues. Furthermore, due to its ability to mutate, *S. aureus* often exhibits antibiotic resistance, making it difficult to eliminate in practice.

For many years, research has been conducted on vaccines against infections caused by *Staphylococcus aureus*, but none of the vaccines studied so far has been able to fully prevent these infections. Currently, there are two available vaccines on the market for *Staphylococcus aureus*-induced *mastitis*: Lysigin® (Boehringer Ingelheim Vetmedica Inc.) available in the United States, and Startvac® (HIPRA) available in Europe and Canada [Ismail 2017].

Barkema *et al.* [2006] emphasized that the informed selection of cows with a reasonable probability of recovering from *mastitis* caused by *Staphylococcus aureus* is a key element in controlling the disease. Assessing this probability should involve: (1) early detection; (2) rapid response to test results; (3) access to cow-level data including age, lactation stage, pregnancy status, production level, *mastitis* history, and somatic cell count; (4) characterization of *Staphylococcus aureus* isolates with respect to penicillin susceptibility; and (5) a decision-making protocol for selecting the appropriate treatment and its duration. According to the authors, cows with a low probability of recovery should be culled from the herd, while those with a higher likelihood of recovery should receive treatment. This approach highlights the importance of proactive and targeted management in controlling *mastitis* caused by *S. aureus*, focusing on early detection, timely intervention, and data-driven decision-making regarding treatment and culling.

Lactose levels as a practical tool for assessing somatic cell count in cow milk

Lactose is the most stable component of cow milk. It is a disaccharide composed of one glucose molecule and one galactose molecule. Along with fat, lactose is one of the key components of cow milk responsible for energy supply, providing approximately 40% of the total energy content. The relatively small variation in lactose concentration in cow milk is due to the strong correlation between lactose synthesis and the water content in milk. The process of lactose synthesis drives water absorption during milk formation in the alveolar cells of the udder. Because of this close relationship, lactose content remains one of the least variable, or most stable, constituents of cow milk [Davies *et al.* 1983, Jenness 1985]. In the Podlaskie region of Poland, the average lactose concentration in cow milk was reported as 4.72%, with a coefficient of variation (CV) of 5.3% [Guliński *et al.* 2018]. Across different stages of lactation, lactose content ranged from an average of 4.82% (CV = 4.3%) in the first month of lactation to 4.6% (CV = 6.1%) in the 14th to 15th month of lactation. In a study by Salamończyk and Guliński [2023] the average lactose level in the milk of 4,822 Polish Holstein-Friesian cows was 4.74%, with a CV of 5%.

In dairy production, changes in lactose levels typically result from a decline in milk hygiene quality and an increase in somatic cell count (SCC) [Alessio *et al.* 2021, Costa *et al.* 2019]. Lactose is easily metabolized by microorganisms, making milk highly susceptible to fermentation. Many bacterial species ferment lactose into lactic acid and are thus classified as lactic acid bacteria. Approximately 450 strains of lactic acid bacteria have been identified, belonging to several genera. The most common genera include *Lactobacillus* (189 strains), *Streptococcus* (101 strains), and *Enterococcus* (49 strains) [Gajewska and Błaszczyk 2012, Mozzi 2018]. Controlled fermentation by lactic acid bacteria is widely used in the production of dairy products such as yogurt and cheese.

Several studies have demonstrated a significant negative correlation between lactose concentration and somatic cell count (SCC) in cow milk [Jurczak 2005, Kwaśnicki *et al.* 2004, Pawelska-Góral *et al.* 2005]. Salamończyk and Guliński [2023] showed that an increase in SCC was accompanied by a decrease in lactose concentration. In their study, the lowest SCC (<200,000 cells/mL) corresponded to the highest lactose concentration (4.81%), while the highest SCC (>400,000 cells/mL) was associated with a mean lactose content of 4.62%. This represented a decrease of nearly 0.2% compared to cows with the healthiest udder status.

This correlation suggests that lactose can serve as a reliable and practical indicator for assessing udder health and somatic cell levels in milk. Because lactose is a stable and easily measurable component, it provides a valuable tool for monitoring milk quality and for the early detection of subclinical *mastitis*, which is often accompanied by an increase in SCC.

Available studies also indicate that, alongside somatic cell count (SCC), cow age is one of the main factors influencing lactose levels in milk across cattle populations worldwide [Costa *et al.* 2019, Haile-Mariam and Pryce 2017]. Research on Australian and Italian Holstein cows has confirmed a decline in milk lactose concentration with increasing cow age. Domestic studies similarly support the finding that lactose content significantly decreases as cows age [Bogucki and Sawa 2002, Brzozowski and Zdziarski 2006, Piwczyński *et al.* 2001, Salamończyk and Guliński 2023]. This trend is likely related to the observed increase in somatic cell numbers in milk from older cows. Litwińczuk *et al.* [2006] reported that the highest lactose concentration (4.89%) was found in milk from cows in their first lactation, with a steady decrease thereafter, reaching the lowest level (4.69%) by the fifth lactation. Similarly, Guliński *et al.* [2018] observed a significant decrease in lactose levels in older Polish Holstein-Friesian cows. In their study, the average lactose content in milk from first-lactation cows was 4.84%, whereas in cows in their tenth lactation and beyond, lactose content decreased by an average of 0.28%, reaching 4.56% in this age group (Fig. 5).

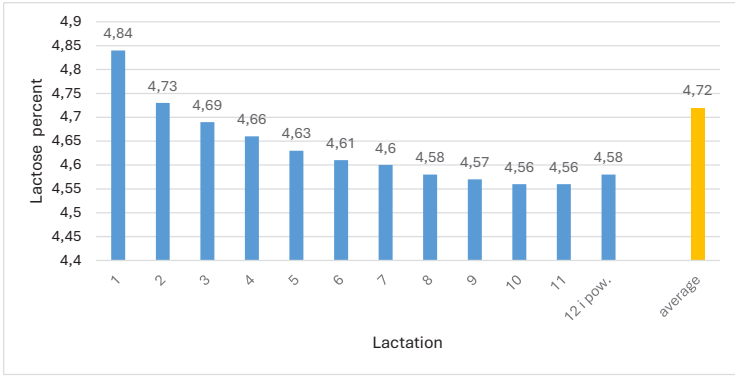

Fig. 5. Changes in the level of lactose in milk obtained in subsequent lactations in the population of Polish Holstein-Friesian cows [Guliński *et al.* 2018].

Routes of bacterial entry into the teats and udder

The primary route for bacteria to enter the mammary gland of cows is through the teat canals [Alhussien *et al.* 2018, Cheng *et al.* 2020]. These canals open during udder cleaning and massage and remain open for approximately half an hour after milking is completed [Litwińczuk *et al.* 2015]. During this period, cows may defecate or lie down on manure, increasing the risk of microorganisms entering the udder. Several factors promote bacterial entry into the udder. As mentioned, the teat canal remains open post-milking – particularly in cases involving abnormal udder, teat, or sphincter muscle structures, which often have a strong hereditary component [Strapák *et al.* 2017]. Additionally, a slight subatmospheric pressure occurs in the mammary gland after milking, causing contaminated air and residues of infected milk to be drawn into the udder [Blau *et a*l. 2019]. Repeated cycles of this process, combined with bacterial multiplication, can compromise the animal's immune defences, ultimately leading to the development of *mastitis.*

Variation in SCC in milk – the influence of environmental and genetic factors

Due to varying epidemiological conditions across different dairy cattle populations, the actual somatic cell count (SCC) in milk shows high variability [Sølverød *et al.* 2005, Salamończyk and Guliński 2023]. In a study by Salamończyk and Guliński [2023], the coefficient of variation (CV) for SCC in milk samples from 10 dairy herds in Poland (4,822 observations) was 223%. Applying the standard logarithmic transformation commonly used in scientific research "normalizes" the distribution of SCC values and reduces variability within populations [Ali and Shook, 1980]. However, this transformation does not alter the fundamental conclusion drawn by most studies that SCC is a highly variable trait. According to Guliński [2017], the typical composition of a dairy herd based on SCC is as follows: healthy cows (<400,000 cells/mL) account for 64%, cows with subclinical *mastitis* (400,000 to 1 million cells/mL) make up 34.5%, and cows with clinical *mastitis* (>1 million cells/mL) comprise 1.5% of the total herd population.

Available research indicates that in Poland, an elevated somatic cell count (SCC >400,000 cells/mL), indicative of subclinical inflammation, affects at least 30-40% of cows at least once per lactation. Subclinical *mastitis* accounts for approximately 95% of all *mastitis* cases in cows and represents a significant problem [International Dairy Federation 2013]. It occurs 15 to 40 times more frequently than clinical *mastitis* and usually precedes the clinical form. Subclinical *mastitis* often persists for extended periods, leading to decreased milk production and lowered milk quality. Additionally, cows with subclinical *mastitis* serve as carriers of pathogenic microorganisms, which can spread to healthy animals. In a study by Hertl *et al.* [2010], approximately 30% of multiparous cows and 16.6% of primiparous cows from seven herds in New York

(USA) experienced at least one case of clinical *mastitis*. In Sweden and Denmark, the incidence of clinical *mastitis* in Holstein, Jersey, and Red Cattle breeds ranged from 3.5 to 13.2%, 5.6 to 13.6%, and 3.1 to 10.9%, respectively [Vargas Jurado *et al.* 2024]. Zavadilova *et al.* [2023] estimated the incidence of clinical *mastitis* at 19.91% across 132,614 completed lactations of Czech Holsteins between 2017 and 2021. *Mastitis* is one of the leading causes of culling in dairy herds. Chronic or incurable *mastitis* accounted for the following proportions of culling cases: 22.6% in Estonia [Rilanto *et al.* 2020], 10.6% after the first lactation and 20.4% after the second lactation in the Netherlands [Kulkarni *et al*. 2023], 15.5% in Poland [Adamczyk *et al.* 2017], and 13.5% in Spain [Armegoli and Fraile 2018]. Barkema *et al.* [2006] reported that the frequency of clinical *mastitis* cases was the highest during the first trimester of lactation.

The assessment of somatic cell count (SCC) in cow milk has been the focus of numerous scientific studies over the past several decades. According to Guliński [2011], knowledge about SCC in the domestic dairy sector is primarily utilized by two main entities: dairy processing plants, which determine milk quality classes and related pricing, and breeding programs, which evaluate cows' milk production performance. Guliński [2017] identified the most common factors contributing to an increase in somatic cell count in cow milk as follows: cow age (older animals tend to have higher SCC, while younger cows generally exhibit lower SCC); lactation stage (cows producing smaller quantities of milk in later lactation stages tend to have lower SCC); stress (exposure to various stressful situations results in higher SCC); and production season (SCC is usually lower in milk produced under clean, dry, and comfortable conditions, whereas wet or humid weather tends to increase SCC) – Figure 6.

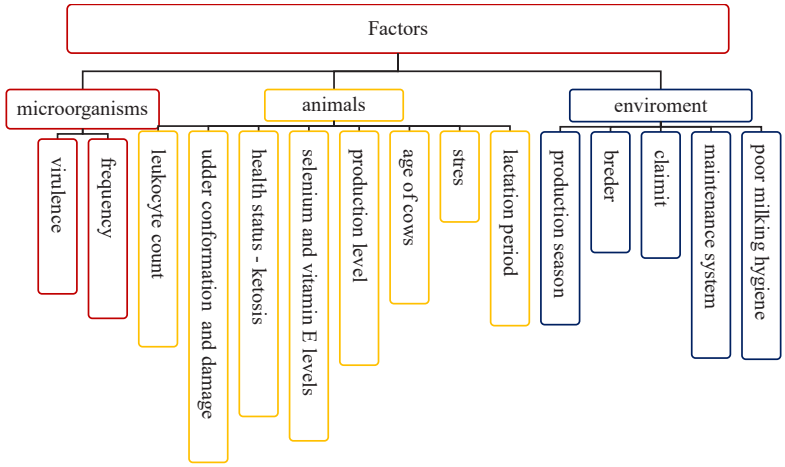

Fig. 6. Causes of *mastitis* in cows [Guliński 2017].

In the specialized literature, in addition to the factors previously mentioned, the main sources of variability in somatic cell count (SCC) in cow milk also include cattle breeding technologies, mechanical injuries, and indirect causes [Alhussien and Dang 2018, Guliński 2017]. Regarding environmental factors influencing SCC, Guliński [2011] showed that, under national conditions, the lowest SCC levels were observed in milk from cows kept in free-stall housing systems, milked in milking parlours, and maintained in herds with high production levels.

In the study by Stocco *et al.* [2023], cow age and lactation stage were identified as the primary sources of variability in somatic cell count (SCC). The authors analysed milk samples from two breeds, Holstein-Friesian and Simmental, maintained on farms in northern Italy. This large-scale study, encompassing 22,124 milk samples, demonstrated that among the factors analysed, age and lactation stage exhibited the highest and statistically significant F-test values. Specifically, the F-test values for age and lactation stage were 583.8 and 648.3, respectively, both highly significant statistically.

As the primary sources of variability in somatic cell count (SCC), Olechnowicz and Jaśkowski [2012] identified, in order of significance: cow age, lactation stage, production season, herd size, metabolic or physiological stress, variability in daily milk yield, low or high body condition score (BCS), and technical measurement errors. The significant influence of cow age on SCC was also emphasized by Tančin *et al.* [2007]. Their study showed that SCC increased with the number of completed lactations. The highest SCC, expressed as the natural logarithm of the raw count (LOGSCC), was found in milk from cows in their fourth and subsequent lactations (LOGSCC = 5.52/mL), whereas milk from first-lactation cows had a LOGSCC of 5.22/mL.

Some studies indicate that the production season is a significant factor influencing somatic cell count (SCC) in cow milk. Czyżak-Runowska *et al.* [2020], analysing bulk milk samples, found higher average SCC during the autumn-winter period (427,000 cells/mL) compared to the spring-summer period (251,000 cells/mL). However, Tančin [2013] reported contrasting results. In his study, SCC values in milk produced during summer were higher than those in milk produced during winter. Specifically, he found that in June and July, as many as 18% of analysed milk samples had an SCC exceeding 1 million cells/mL.

Jónás *et al.* [2016] analysed 4,891 milk samples collected from Hungarian Holstein cows. Their study indicated a significant negative impact of the summer production season, cow age, and lactation stage on somatic cell count (SCC) in milk. The highest SCC values, expressed in points (LKSP), were observed in milk produced during the summer (5.31), from the oldest cows in their fifth lactation (5.71), and during the last 100 days of lactation (5.38). In contrast, Malinowski [2001] reported that the production season did not significantly affect SCC in milk.

Barłowska *et al*. [2012] evaluated the impact of various milking systems on somatic cell count (SCC) in milk. The authors analysed four milking systems: manual milking and three types of mechanical milking systems – bucket milking, pipeline

milking, and milking parlours – and their effect on the cytological quality of bulk milk. The results showed the following SCC values per 1 mL of milk for each system: 108.6, 194.1, 248.5, and 251.9 thousand cells, respectively. In summary, the authors concluded that modern milking systems, such as milking parlours, tend to produce milk with slightly lower cytological quality.

Lambertz *et al.* [2014] emphasized the significant impact of microclimatic conditions in barns on somatic cell count (SCC) in cow milk. Their study demonstrated that heat stress leads to a reduction in milk yield, fat and protein content, and an increase in SCC. Under the dry climate conditions of Iran, Sadeghi-Sefidmazgi and Rayatdoost-Baghal [2014] identified several statistically significant factors influencing SCC in milk, including milk yield level during lactation, herd size, cow housing system, type of bedding in stalls, udder disinfection methods, and the use of gloves during milking. The highest SCC values, expressed in points (LKSP), were found in milk from cows producing over 10,000 kg per lactation (LKSP = 3.15), cows kept in herds with fewer than 100 animals (LKSP = 3.85), cows housed in stalls with straw bedding (LKSP = 4.62), and herds where gloves were not used during milking (LKSP = 3.95).

Salamończyk and Guliński [2013] evaluated somatic cell count (SCC) in milk from cows that extended their standard lactation period and examined the influence of selected factors on milk cytological quality during both the standard lactation and lactation extension. The average SCC in milk from cows extending their lactation was as follows: 408,000 cells/mL during the standard 305-day lactation, 539,000 cells/mL during the lactation extension period, and 426,000 cells/mL throughout the entire lactation period, which averaged 390 days. The SCC during the lactation extension period (from day 306 until the end of lactation) was significantly higher compared to milk obtained during the standard 305-day lactation. The lowest SCC during the extension period was found in milk from primiparous cows, with an average of 338,000 cells/mL.

Milk from individual teats can exhibit variable somatic cell counts (SCC) [Alhussien *et al.* 2018]. The number of somatic cells also fluctuates between milkings and during the milking process itself [Ayadi *et al.* 2004, Guliński and Kroszka 2024, Mijić *et al.* 2003, Nørstebø *et al.* 2019, Quist *et al.* 2008]. The first streams of milk flowing from the teat sinus may contain a high number of leukocytes, which reflects the teat's active defence mechanism against bacterial entry. Guliński and Kroszka [2024] evaluated SCC in milk from the alveolar and sinus portions of the udder in a selected population of Polish Holstein-Friesian cows. We found that the average SCC during 1 minute of milking, based on 105 observations from 15 cows, was 219,000 cells/mL, whereas during 8 minutes of milking, it was 229,000 cells/mL. A detailed analysis showed that, comparing SCC after 1 minute to that after 8 minutes of milking, SCC was higher in seven cows, lower in seven cows, and unchanged in one cow. Table 1 presents the influence of selected genetic and environmental factors on SCC indices, according to various authors.

Table 1. The influence of selected environmental and genetic factors on SCC in cow milk according to different authors

Factor	Level of the factor	Somatic cell count indices	Author(s)
Age of cows	Parity: 1 2 3 4 5	log10(SCC): 1)5.12, 2)5.10, 3)5.29, 4)5.42, 5)5.71.	Jónás *et al.* [2016]
	Parity: 1 2 3 4 and above	log10(SCC): 1)5.22, 2)5.24, 3)5.30, 4)5.52.	Tančin [2013]
	Parity: 1)1 2)2 3)3-4 4)5-11	log10(SCC): SCC(thou.) 1)4.87, 328, 2)5.11, 403, 3)5.49, 603, 4)5.84. 756.	Salamończyk and Guliński [2023]
	Parity 1 2 3 4 5 and above	SCC (points): 1)2.43, 2)2.51, 3)3.36, 4)3.87, 5)4.68.	Oravcová *et al.* [2024]
	Parity 1 2 3 and above	LNSCC: 1)11.61, 2)11.70, 3)12.82.	Bogucki *et al.* [2011]
	Parity: 1 2 3	log10(SCC): 1)4.93, 2)4.93, 3)5.03.	Kul *et al.* [2019]
Production season	Month of lactation: 1)December 2)June	log10(SCC): 1)5.10 – the lowest, 2)5.58 – the highest.	Tančin [2013]
	Production season: 1)Autumn – winter 2)Spring – summer	SCC (thou.) 1)427, 2)251.	Czyżak-Runowska *et al.* [2020]
	Production season: 1)Spring, 2)Summer, 3)Autumn, 4)Winter.	SCC (points): 1)3.32, 2)3.37, 3)3.36, 4)3.53.	Oravcová *et al.* [2024]
	Month of lactation: For parity=1 1)June 2)September 3)December 4)March	SCC (thou.): 1)247, 2)98, 3)393, 4)403.	Cinar *et al.* [2015]
	Production season: 1)Autumn, 2)Winter., 3)Spring, 4)Summer.	log10(SCC): 1)4.93, 2)5.05, 3)4.88, 4)4.91.	Kul *et al.* [2019]
Lactation period	Lactation period/days/: 1)0-90 2)91-150 3)>150	log10(SCC): 1)5.10, 2)5.17, 3)5.38.	Jónás *et al.* [2016]
	Lactation month: 1)2 2)10	LOGSCC: 1)5.15, 2)5.65.	Tančin [2013]
	Lactation phase: 1)305-day lactation, 2)lactation extension period, 3)full lactation.	SCC (thou.) 1)408, 2)539, 3)426.	Salamończyk and Guliński [2013]
	Lactation month: 1)1-3 2)4-6 3)7-9 4)10-18	log10(SCC): SCC(thou.) 1)4.89, 414, 2)5.20, 473, 3)5.35, 487, 4)5.49. 522.	Salamończyk and Guliński [2023]
	Lactation period/days/: 1)≤100 2)101-200 3)201-300 4)>300	LNSCC: 1)11.35, 2)11.59, 3)12.18, 4)13.02.	Bogucki *et al.* [2011]
	Lactation period/days/: 1)30 2)60 3)90 4)120 5)150 6)210 7)270	log10(SCC): 1)4.85, 2)4.91, 3)4.94, 4)4.95, 5)4.96, 6)5.00, 7)5.06.	Kul *et al.* [2019]
Production level	Daily yield (kg) 1)<20 2)20-30 3)>30	LOGSCC: SCC (thou.): 1)5.33, 505, 2)5.15, 450, 3)5.02. 423.	Salamończyk and Guliński [2023]
	Daily yield /kg/ for parity=5 1)10-21 2)21-31 3)31-41 4)≥41	SCC (thou.): 1)460, 2)350, 3)300, 4)190.	Boland *et al.* [2013]
	Daily yield /kg/: 1)≤15 2)15-25 3)25-35 4)>35	LNSCC: SCC (thou.): 1)6.12, 771, 2)5.11, 393, 3)4.59, 240, 4)4.36. 180.	Guliński *et. al.* [2016]
Milking system	Milking methods: 1)manual milking 2)bucket milking 3)pipeline milking 4)milking parlours	SCC (thou.) 1)108.6, 2)194.1, 3)248.5, 4)251.9.	Barłowska *et al.* [2012]
	Milking system: 1)Automatic 2)Free stall 3)Tie stall	log10(SCC): 1)5.17, 2)5.14, 3)5.02.	Stocco *et al.* [2023]
Cow's breed	Cattle breeds: 1)Holstein 2)Jersey 3)Simmental	SCC (thou.): 1)255, 2)429, 3)376.	Ivanov *et al.* [2017]
	Cattle breeds: 1)Holstein-Friesian 2)Simmental	log10(SCC): 1)5.18, 2)5.02.	Stocco *et al.* [2023]
	Cattle breeds: 1)Simmental 2)Brown Swiss 3)Holstein 4)Red Holstein 5)Jersey	SCC (thou.): 1)211, 2)237, 3)258, 4)252, 5)288.	Kaskous [2021]
	Cattle breeds: 1)Brown Swiss 2)Holstein-Friesian 3)Montbeliarde 4)Red Holstein 5)Simmental 6)Swedish Red	SCC (thou.): 1)205, 2)202, 3)169, 4)199, 5)180, 6)290.	Sahin [2023]

Prevention and possibilities for preventing the increase in SCC in cow milk

Maintaining excellent cow hygiene is a fundamental objective in *mastitis* prevention programs. Numerous scientific studies have demonstrated a direct relationship between cow cleanliness and lower somatic cell count (SCC) in milk. It is evident that exposure of cows to manure contamination increases the risk of udder inflammation. In modern dairy farming, control of critical points for environmental pathogens is primarily focused on pre- and post-milking teat disinfection. Other essential components of hygiene programs in dairy herds include maintaining cleanliness of animals and their stalls, removal of udder hair, trimming or shearing of tail brushes, implementing appropriate milking order, pre-milking routines, and supplementing diets with antioxidants.

Pre-milking disinfection of teats was developed as a simple, effective, and cost-efficient method to combat environmental pathogens by reducing bacterial populations on the skin of teats before milking, thereby minimizing their penetration into the udder canal [Burtscher *et al.* 2023, Nickerson 2001]. In Poland, the introduction of pre-dipping in milking procedures was associated with a reduction in the percentage of milk samples with somatic cell counts exceeding 400,000 cells/mL – from 29.08% to 18.07% [Bogucki *et al.* 2011]. However, the decisive factor in improving milk quality remains post-milking disinfection of teat ends, where the most harmful bacteria are predominantly located. Proper post-milking teat end disinfection can reduce bacterial counts by up to 75%. Numerous dipping products are available on the market today, differing mainly in their active ingredients. The most commonly used substances in Europe and the USA include iodine (at concentrations of 45% and 70%) [Alsari and Rhouma 2002, Boodie and Nickerson 1997], chlorine [Boodie and Nickerson 1996, 1997], and chlorhexidine [Hogan *et al.* 1995]. Other active compounds found in post-milking disinfectants include organic acids, ammonia derivatives, and dodecylsulfonic acid derivatives. Effective dipping products should possess a broad antibacterial spectrum, cause no irritation to teat skin, avoid damage to teat cups, and present no risk of residues in milk [Malinowski 2000]. Bogucki *et al.* [2008], analysing the effectiveness of iodine-, chlorhexidine-, and lactic acid-based disinfectants on milk cytological quality, found these products to be highly effective in post-milking teat disinfection. The implementation of post-milking teat disinfection protocols had a beneficial effect on milk cytological quality. Notably, the lowest bacterial counts were found in milk from cows where hygiene procedures focused exclusively on teat end disinfection.

Removing udder hair is a crucial step in producing high-quality milk [Silk *et al.* 2003]. Udder hair contributes to the accumulation of contaminants, increasing the time needed to clean and prepare the udder for milking. Excessive hair also impedes effective teat disinfection and raises the risk of inadequate drying before milking. Additionally, long hairs around the teats can be pulled into milking cups, potentially transferring millions of *mastitis*-causing microorganisms. Smooth, hairless udders are significantly easier to maintain in a clean condition [Fox 2016]. Currently, the

recommended method for udder hair removal is udder singeing, applied in accordance with proper technological procedures.

The order in which cows are milked can significantly influence the control of *mastitis* spread within a herd. A recommended milking sequence is as follows: first, cows in their first lactation; second, cows with a low somatic cell count (SCC) from the previous lactation; third, cows with a high SCC; and finally, cows exhibiting clinical signs of *mastitis*. This approach helps minimize the transmission of *mastitis* among animals. Additionally, the use of rubber gloves during milking, along with regular disinfection or replacement, plays a crucial role in reducing the incidence of new infections. Pre-milking, the practice of discarding the first 3-4 streams of milk from all four teats, serves several purposes: detecting clinical *mastitis*, removing milk with the highest bacterial load, and facilitating the milk ejection reflex [Bogucki *et al.* 2011].

In the prevention of udder inflammation, rational feeding plays a significant role, particularly the inclusion of ingredients that support and strengthen the immune system. *Mastitis* is associated with the release of free radicals, increased overall oxidative stress, and a reduction in the animal's total antioxidant capacity. Providing vitamins and antioxidant minerals helps protect the organism by directly scavenging free radicals or inhibiting the activity of oxidizing enzymes. Supplementing cows affected by *mastitis* with antioxidants such as vitamins A, C, and E, as well as essential minerals like selenium (Se), zinc (Zn), and copper (Cu), is crucial for mitigating oxidative stress and supporting recovery [Guliński 2017].

Somatic cells in dairy cattle improvement programs – methods and goals of improving cows in this trait

Limits on the number of somatic cells are a key element in national and international regulations concerning milk quality [Moore *et al.* 2013]. The methodology for determining somatic cell count varies depending on the type of dairy farm. In the assessment of dairy cattle production in Poland and worldwide, three basic methods are used: A4, A8, and AT4 [Bucek *et al.* 2016]. In the A4 method, registration takes place at least 11 times per year, each time over a 24-hour period, while in the AT4 method, milk samples are taken alternately in the morning or evening. In the A8 method, registration is carried out 6 times per year, with milk quantity assessed over a 24-hour period. The main methods used in Poland are A4 and AT4 [PFCBDF 2017]. In 2017 they were used to evaluate 94.8% of all cows, with milk sampling and testing conducted every 28 days between measurements.

An important aspect of the practical utility of each method is its accuracy. In the case of milk production evaluation, accuracy depends on the frequency of measurements. The accuracy would be 100% with daily milk recordings. However, such an approach is practically unfeasible in breeding practice due to economic constraints. Therefore, in many countries around the world, including Poland, various methods with different intervals between milk recordings are used. According to Johansson's study [1961],

the measurement error for intervals of 7, 14, 21, and 28 days is 2.5, 3.4, 4.4, and 5.4%, respectively, compared to daily recordings.

Several researchers have analysed the impact of reduced milk recording frequency on the accuracy of lactation performance evaluation. Gantner *et al.* [2008] found that an alternating milk recording method every four weeks resulted in low error and high accuracy when predicting milk yield on the 100th, 200th, and 305th days of lactation. In contrast, methods based on six-week intervals led to greater prediction errors and lower accuracy for the 305th day yield. Crosse and Cliffe [1988] reported that the relative error in predicting lactation milk yield ranged from 2.7% to 6% as the interval between recordings increased from one to ten weeks. Similarly, Cattin-Vidal [1990] observed a rise in prediction error with extended intervals between measurements. Hargrove [1994] and Wangler *et al.* [1996] also reported that increasing the interval between successive recordings decreased prediction accuracy and increased recording costs. Pander *et al.* [1993] determined that using less frequent intervals than the A4 method could reduce costs without a proportional loss of accuracy when estimating milk yield on the 305th day. Moreover, Aleandri and Tondo [2003] found that when evaluating total milk yield during lactation, the accuracy of all tested methods (A4, AT4, A6, and AT6) exceeded 98%. Berry *et al.* [2005] concluded that, for heifers, the A8 scheme produced 305-day yield predictions comparable to those of the A4 method.

Guliński and Zaremba [2021] emphasized the importance of accurately determining the actual somatic cell count (SCC) in cows evaluated in Poland. The authors compared the SCC in milk collected from individual milkings over a one-month lactation period. The average SCC per mL of milk during the 1st, 2nd, 3rd, and 4th weeks of lactation was 297,000, 326,000, 294,000, and 271,000 cells, respectively. Variance analysis using the LOGLKS model did not reveal significant differences between the weekly SCC values. The low assessment error was confirmed by high correlation coefficients between SCC values across the four weeks, which were: 1.00 (reference), 0.72, 0.80, and 0.74, respectively. Based on these results, the authors concluded that SCC remained relatively stable throughout the observed four-week lactation period. Consequently, they determined that the four-week interval used in the official evaluation of dairy cows' production performance provides an accurate representation of the actual somatic cell count across these weekly intervals.

The growing problem of elevated somatic cell counts (SCC) in milk, associated with the intensification of milk production, has prompted livestock breeders to incorporate this trait into cattle improvement programs. Somatic cell count was introduced into dairy cattle breeding programs in Europe and North America at the turn of the 1970s and 1980s [Miglior *et al.* 2017]. Today, SCC is an important component of most selection indices for dairy cattle worldwide. In Western Europe, the United States, and Canada, the percentage contribution of SCC to the total breeding index value ranges from 3% in Canada (LPI) and Spain (ICO), to 14% in the Netherlands (DPS) and Denmark (S-I) – VanRaden [2005]. According to Miglior *et al.* [2005], the highest relative contributions of SCC to selection indices in Holstein

populations were observed in Denmark (14.0%), France (12.5%), and Israel (11.0%) (Fig. 7). In New Zealand, the currently used Breeding Worth Selection Index (BWSI) includes SCC at 6% of the overall index value [Stephen *et al.* 2024]. In Poland, since the 2014 evaluation season, the main selection criterion for bulls has been the revised PF selection index [PFCBDF, NRIAP 2016], in which the breeding value for SCC accounts for 10% of the total index value. These data highlight the increasing importance of selecting sires with favourable SCC traits as a strategy for improving udder health in dairy cattle populations.

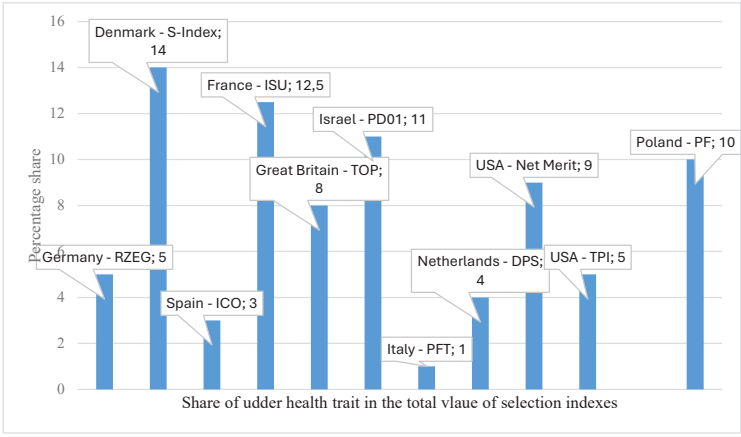

Fig. 7. Relative percentage share of the udder health trait in the total value of the selection indexes for cattle in selected countries of the world [Miglior *et al.* 2005, PFCBDF and NRIAP 2016].

In the discussion about the importance of genetic factors for udder health in cattle, the key element examined in research on this issue is the heritability of this trait, as well as the correlations between quantitative and qualitative traits in cattle and somatic cell count. Schutz *et al.* [1995] estimated the genetic correlation between SCC and milk yield in American Holsteins to be $r_g = 0.12$. In France, Rupp and Boichard [1999], using data from 29284 French Holstein-Friesian cows, reported negative genetic correlations between udder depth, front attachment, and udder shape and SCC, with values ranging from -0.29 to -0.46. Studies by Liu and Dekkers [1998], Schutz *et al.* [1993], and Guliński *et al.* [1996] examined the relationship between cows' external conformation and the occurrence of mastitis. Their results indicated that improvements in udder conformation were associated with a decrease in SCC in 1 mL of milk. Increased udder height was linked to a reduction in the number of somatic cells in 1 mL of milk by 7 000 to 26 000 cells [Guliński *et al.* 1996].

The heritability estimates obtained in the available studies showed significant variation. The heritability of SCC, as estimated in Poland by Sawa and Bogucki [2002] for an active population of cows from the Pomerania and Kuyavia regions, was 0.14. According to Sender [2001], the heritability of SCC ranged from 0.05 to 0.27. A

significant genetic effect on the occurrence of clinical mastitis in cows was indicated by Nash *et al.* [2000]. In a study of Holstein cattle in the USA, they determined the heritability for this trait to range from 0.01 to 0.42. Heringstad *et al.* [2006], in a study of cows in early first lactation, estimated the heritability coefficient to range from 0.03 to 0.08. In an attempt to investigate the influence of genetic factors. Guliński *et al.* [2007] assessed the influence of the sire (bull) on the SCC in the milk of their daughters. Based on data from 44,689 samples from 96 Holstein-Friesian bulls, they determined the phenotypic advantages for this trait and calculated the heritability coefficients. The results confirmed a high variation in SCC among the cows. The phenotypic advantages for the 96 bulls ranged from -200 to +345 thousand cells per mL. However, the calculated heritability coefficients indicated a small genetic contribution to the variation of this trait in the evaluated population ($h^2 = 0.05$).

Genomic selection strategies, marker-assisted selection and their role in improving udder health and milk somatic cell count resistance

In recent years, genomic selection (GS) and marker-assisted selection (MAS) have gained importance as modern breeding tools enabling more efficient and precise improvement of cattle health traits, including *mastitis* resistance and reduced somatic cell count in milk. Traditional phenotypic and pedigree selection, despite its usefulness, has shown limited effectiveness in the case of low heritability traits, such as udder health and SCC indices.

Genomic selection (GS) has revolutionized dairy cattle breeding by enabling more accurate and faster estimation of animals' breeding values. In the article by Wiggans *et al.* [2011], the development, implementation, and practical significance of the genomic evaluation system in the United States are thoroughly described, emphasizing its impact not only on production traits but also on health traits - including udder health and resistance to mastitis. In traditional selection systems, traits such as somatic cell count (SCC) and udder health indicators were difficult to improve effectively due to low heritability and limited availability of reliable phenotypic data. With the genomic approach, it became possible to: include health traits in breeding value estimation with greater accuracy, shorten the generation interval, allowing faster genetic progress in resistance, identify animals with higher potential for maintaining low SCC and lower susceptibility to mastitis, even before their own performance records are available. The authors emphasize that the implementation of genomic estimated breeding values (GEBV) for traits such as SCC and direct resistance to mastitis was made possible by: a large reference population with combined genotype and phenotype data, the use of dense SNP marker panels, collaboration among national breeding organizations (e.g., USDA). Wiggans *et al.* [2011] also point out that this has allowed health traits to be incorporated into official selection indices (such as Net Merit), representing a significant step toward sustainable breeding that considers both production efficiency and animal welfare.

In the search for genetic improvement of cows to increase their resistance to *mastitis*, the polymorphism of the lactoferrin gene is pointed out as a practical element that can be utilized in the selection of cows resistant to *mastitis*. Lactoferrin is an endogenous globular protein from the transferrin group, with antibacterial properties. The mechanism of innate immunity of this protein is based on lactoferrin's high affinity for iron, its capture, and blocking the availability of iron for bacteria. Lactoferrin is present in cow milk. Research results indicate that cows carrying the B allele of lactoferrin are more resistant to *mastitis* than other animals and have a lower SCC in milk. The use of lactoferrin gene polymorphism as a marker for *mastitis* could allow the selection of animals that are less prone to *mastitis* for breeding. Based on the presented results, cows with the BB and AB genotypes can be recommended for breeding, as they exhibit better udder health. Unfortunately, cows with the BB genotype are rare. In the population studied by Sender *et al.* [2012], only 37.2%, or 8% of the cows, had this genotype.

Consequences of increased SCC

The increase in somatic cell count (SCC) is associated with several negative consequences, including a reduction in individual milk yield, deterioration of milk's technological properties, and a decline in cows' reproductive efficiency.

Decrease in milk yield

The main production consequence of an increased SCC is the reduction in milk yield, both daily and lactational [Ermetin *et al.* 2024, Guliński *et al.* 2016, Huang *et al.* 2023, Jakiel *et al.* 2011, Oravcowa *et al.* 2024, Pegolo *et al.* 2021, Sawa and Bogucki 2002]. Milk yield losses during lactation associated with an increase in SCC from 100,000 cells/mL to 1 million cells/mL are estimated at 12%, or approximately 870 kg per lactation. According to Guliński *et al.* [2016], the daily milk yield for cows with the lowest SCC (<200 000 cells/mL), compared to cows with the highest SCC (>800 000 cells/mL), in the population of Polish Holstein-Friesian cows in Podlasie, was 8.7 kg higher (approximately 40%).

At the national level, the economic consequences of elevated SCC in milk are estimated to be several hundred million zlotys annually. Assuming that: 30% of cows have an increased SCC from 200 000 to 700 000 cells/mL, the decrease in milk yield during lactation as a result of this increase is 350 kg of milk, and the price of 1 litre of milk is 2.2 zlotys, then the annual losses in dairy cattle breeding can be estimated at around 500 million zlotys. Table 2 presents the results of several studies regarding the negative impact of elevated SCC on milk yield in cows.

Table 2. The negative impact of elevated somatic cell count on milk yield in cows

Milk yield index – name of the trait	Factor/SCC level	Changes in the milk yield index	Author(s)
Daily milk yield /kg/	1)<100 thou.; 2)100-200 thou.; 3)> 200 thou.	1)43.7; 2)41.1; 3)41.1.	Ermetin *et al.* [2024]
Daily milk yield /kg/	1)<200 thou.; 2)200-400 thou.; 3)400-600 thou.; 4)600-800 thou.; 5)>800 thou.	1)30.3; 2)25.3; 3)23.6; 4)23.7; 5)21.6.	Guliński *et al.* [2017]
Daily milk yield /kg/	1)<50 thou.; 2)>1.5 mln.	1)35.0; 2)15.0.	Huang *et al.* [2023]
Correlation coefficient for daily milk yield /kg/ and the actual number of somatic cells /r/	1)<100 thou.; 2)100-200 thou.; 3)200-400 thou., 4)400-500 thou.	1)-0.142**; 2)-0.133**; 3)-0.084; 4)-0.032.	Jakiel *et al.* [2011]
Daily milk yield /kg/	1)<100 thou.; 2)100-200 thou.; 3)200-400 thou.; 4)400-600 thou.; 5)600 thou .- 1 mln; 6) >1 mln.	1)35.3; 2)33.5; 3)32.7; 4)32.6; 5)32.2; 6)30.5.	Oravcová *et al.* [2024]
Daily milk yield /kg/	SCCP 1)2.3; 2)2.99; 3)3.92; 4)6.17.	 1)36; 2)34; 3)32; 4)30.	Pegolo *et al.* [2021]
Daily milk yield /kg/	1)<200 thou.; 2)200-400 thou.; 3)>400 thou.	1)22.7; 2)21.4; 3)20.9.	Salamończyk and Guliński [2023]
Daily milk yield /kg/	1)≤200 thou.; 2)201-500 thou.; 3)501-999 thou.; 4)≥1 mln.	1)26.78; 2)27.76; 3)25.5; 4)24.0.	Cinar *et al.* [2016]
Daily milk yield /kg/	1)<100 thou.; 2)100-200 thou.; 3)201-500 thou.; 4)>500 thou.	1)33.92; 2)33.49; 3)32.55; 4)31.56.	Kul *et al.* [2019]
Losses in daily milk yield /kg/ as a consequence of the increase in the number of somatic cells	Lactation 1 1)<51 thou.; 2)51-100 thou.; 3)101-201 thou.; 4)201-301 thou.; 5)301-401 thou.; 6)401-1000 thou.; 7>1001 thou.	 2)-0.13; 3)-0.30; 4)-0.50; 5)-0.80; 6)-0.58; 7)-1.52.	Boland *et al.* [2013]
	Lactation 2 1)<51 thou.; 2)51-100 thou.; 3)101-201 thou.; 4)201-301 thou.; 5)301-401 thou.; 6)401-1000 thou.; 7>1001 thou.	 2)-0.60; 3)-1.42; 4)-2.00; 5)-2.23; 6)-1.91; 7)-2.07.	
Expected losses in daily milk yield /kg/ as a consequence of the increase in the number of somatic cells	1)7.4 thou.; 2)50 thou .; 3)100 thou.; 4)250 thou.; 5)750 thou.	 2)-1.55 to -2.14; 3)-2.12 to -2.93; 4)-2.87 to -3.96; 5)-3.77 to -5.21.	Potter *et al.* [2018]

**Correlation coefficient statistically significant at P≤0.01.

Reduction in technological suitability of milk

Mastitis also alters the chemical composition of milk, significantly reducing its technological suitability [Alesio *et al.* 2021, Costa *et al.* 2019, Guliński 2017]. Inflammatory conditions in the udder lead to a decrease in dry matter, fat, and casein content by approximately 1-3, 0.5-1.5, and 9%, respectively. Milk with elevated somatic cell count (SCC) also shows reduced concentrations of key mineral components, including calcium, phosphorus, and potassium, by about 35%, 30%, and 40%, respectively. Additionally, vitamin levels may decline by 10-40%. According to Harmon [1994], milk with elevated SCC contains 9% less fat, 10% less lactose, 18% less casein, 67% less calcium, and 9% less potassium (Fig. 8).

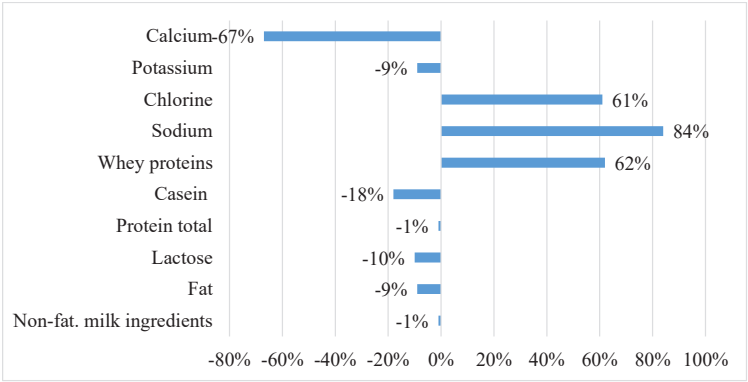

Fig. 8. Percentage changes in milk components with elevated somatic cell count [Harmon 1994].

Due to these negative effects, SCC is considered one of the most important criteria for evaluating milk quality in dairy processing plants, both domestically and internationally. SCC is a crucial factor in milk purchase processes and significantly influences payment systems for raw milk. In the context of the drastic reduction in technological suitability of milk from cows with mastitis, very strict quality standards are implemented in the systems for determining the price of raw milk. These standards aim to motivate producers to improve the cytological quality of their milk. In Poland, 30-50% of the price per litre of raw milk depends on its hygienic and cytological quality [Guliński 2017].

Reduced fertility in cows

Mastitis also leads to decreased fertility in dairy cows, particularly by increasing embryonic mortality [Albaj *et al.* 2017, Hertl *et al.* 2010, Lavon *et al.* 2012, Lavon *et al.* 2016, Nguyen *et al.* 2011, Pindeo *et al.* 2009, Radkowska and Szewczyk 2018, Rekik *et al.* 2008]. The negative impact of *mastitis* on reproductive traits largely depends on the type of *mastitis*, its duration, and the stage of lactation at which it

occurs. The mechanism by which *mastitis* affects fertility is not entirely understood. However, studies indicate that inflammatory conditions often occur around the time of estrus due to the higher levels of estradiol - 17β. This hormone reduces the phagocytic ability of mammary gland cells, decreases the number of macrophages, and lowers the activity of granulocytes, which exacerbates subclinical *mastitis*. Additionally, an elevated body temperature, commonly associated with *mastitis*, negatively affects both oocytes and embryos. Its effects are similar to those of heat stress.

Cytokines, produced in large quantities during *mastitis* and released into the bloodstream, lead to the synthesis of PGF2α in the uterus, which causes premature regression of the corpus luteum. They also inhibit the proliferation of the uterine mucosal cells and fallopian tube epithelium, and reduce the secretion of luteinizing hormone (LH). Cortisol, which is produced during mastitis, also inhibits LH levels in the blood. A low LH level leads to delayed ovulation and the formation of persistent follicles. In cases of fertilization with a mature oocyte, the resulting embryos often die at an early stage of development. The result is a decrease in reproductive performance.

In production conditions, the consequence of increasing SCC is an extension of reproductive indices. According to studies by Barker *et al.* [1998] and Guliński *et al.* [2003], an increase in SCC from <400 000 cells/mL to >400 000 cells/mL was associated with an extension of the calving interval by 44.5 and 14 days, respectively.

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