MARE’S COLOSTRUM QUALITY: A REVIEW

Student:
Cristina Pérez Ramos

Tutor:
María Luisa Díaz-Bertrana Sánchez

Collaborating tutor:
Lidia del Pilar Pitti Ríos

Curso Académico:
2020-2025

UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA
Facultad de Veterinaria

Abstract

The objective of this work is to review the factors related to colostrum quality in mares and its management in order to provide useful material to avoid pathologies caused by passive immunity transfer failure, which is very common in the equine clinic. This review focuses mainly on the concentration of immunoglobulin G, factors affecting colostrum quality (breed, number of foaling, season...), available quality detection methods and the use of thermal methods to improve the microbiological quality.

Key words: colostrum, mare, IgG, BRIX, refractometry, freezing, pasteurization

Index

Introduction

Colostrum, the yellowish “first milk” secreted in the final weeks of gestation, is far more than an energy source for the neonatal foal. Its soluble fraction is richly endowed with immunoglobulins, growth factors, cytokines, lipids and carbohydrates, while the cellular fraction contributes viable lymphocytes, macrophages and neutrophils (Watt & Wright, 2008). Such complexity underpins a dual role: providing immediate systemic and mucosal immunity and promoting maturation of the gastrointestinal tract (LeBlanc, 2001). Due to the specific anatomical structure of the equine placenta, foals are born with an almost complete lack of circulating immunoglobulins and are therefore entirely dependent on the passive transfer of these protective proteins through colostrum intake. Inadequate passive transfer of immunoglobulins significantly increases the foal’s susceptibility to various infectious diseases (Galan et al., 1986).

Colostrum macromolecules traverse the neonatal enterocyte by non-selective pinocytosis. Absorptive efficiency is maximal immediately after birth but wanes precipitously—by 20 h gut uptake falls below 1 %—as enterocytes are replaced and “gut closure” ensues (LeBlanc, 2001). Consequently, foals that nurse within two hours exhibit detectable serum IgG within four to six hours, and secretory IgA and IgG appear on the nasopharyngeal mucosa, conferring early resistance to respiratory pathogens such as *Streptococcus equi* (Galan et al., 1986).

The half-life of maternal IgG in foals is approximately 20 to 30 days. As the concentration of maternally derived immunoglobulins decreases, the foal begins to synthesize its own immunoglobulins. As a result, colostrum-fed foals exhibit low serum IgG concentrations between the first and third months of life, which gradually increase until reaching adult levels around six months of age. (LeBlanc, 2001).

Serum thresholds used to categorise failure of passive transfer (FPT) differ among investigators and influence reported prevalence. A comprehensive risk-factor review defined total FPT as IgG < 4 g/L at 24 h, partial FPT (PFPT) as 4–8 g/L, and adequate transfer as > 8 g/L; using these criteria, population studies have documented FPT incidences ranging from 2.9 % to 25 % and PFPT up to 18.6 % (Franco & Oliver-Espinosa, 2016). On four New South Wales Thoroughbred studs, specific-gravity screening revealed FPT in 16 % and PFPT in 17 % of foals, underscoring the continuing clinical relevance even on well-managed farms (Tyler-McGowan et al., 2008).

The link between inadequate passive transfer and infectious morbidity has been recognised for almost five decades. In a classic prospective study, 78 % of foals with IgG < 400 mg/dl developed sepsis compared with only 3 % of foals that reached ≥ 400 mg/dl (McGuire et al., 1977). Experimental deprivation work later confirmed causality: seven of eight colostrum-deprived foals became septicaemic despite barrier management, whereas none of six colostrum-fed controls did so (Robinson et al., 1993). Even partial deficits increase risk; Standardbred foals with PFPT were 3.5-times more likely to require medical treatment in the first 90 days of life than adequately supplemented herd mates (Clabough et al., 1991).

Colostrum quality in mares is influenced by several factors, including maternal age, breed, nutritional status, premature lactation, and early parturition. Additionally, reduced colostrum production—often observed in mares experiencing stress, mastitis, or structural abnormalities of the udder—can further compromise its quality. One of the most significant contributors to poor colostrum quality in mares is fescue-associated toxicosis (Franco & Oliver-Espinosa, 2016). The foal’s ability to ingest colostrum promptly after birth is also critical and may be impaired in cases where the neonate is unable to stand and nurse effectively. This is commonly seen in weak foals, those with musculoskeletal deformities, or foals suffering from neonatal maladjustment síndrome (Franco & Oliver-Espinosa, 2016). Furthermore, the efficiency of colostral immunoglobulin absorption in the intestine may be reduced in premature foals due to the immaturity of the intestinal mucosa, which limits the uptake of macromolecules (Franco & Oliver-Espinosa, 2016). Colostral IgG concentration varies widely between mares (Morris et al., 1985). Bottle-feeding, premature lactation and low specific gravity (SG < 1.060) each predict lower serum IgG in foals (Morris et al., 1985). Management influences are equally important: inadequate supervision of dystocia, poor hygiene and delayed nursing narrow the already brief window for absorption (Tyler-McGowan et al., 2008).

Single radial immunodiffusion (SRID) remains the laboratory gold standard for IgG concentration determination but requires up to 72 h. Field assays including zinc-sulfate turbidity, latex agglutination and glutaraldehyde coagulation tests offer rapid screening, yet vary in accuracy, particularly at higher titres (Morris et al., 1985). Automated turbidimetric immunoassays and ELISA kits demonstrate sensitivities exceeding 80 % for detecting IgG < 4 g/L (Franco & Oliver-Espinosa, 2016), enabling intervention while the gut is still partially permeable. For foals older than 24 h or already ill, intravenous plasma, purified IgG products and antibiotics remains the treatment of choice; dosing guidelines recommend 20–200 mg/kg of IgG in healthy foals and up to 500 mg/kg in septic cases (LeBlanc, 2001).

Materials and Methods

Articles from the Web of Science database were used for this review, filtering them according to the following criteria:

- Topic: Mare and colostrum
- Filters: Review and research articles, English, from 1980 to 2025.

The result was a list of 354 articles from which those dealing with any of the following topics were selected:

Topic	Used items
Passive immunity transfer	9 articles
Chemical composition of colostrum	27 articles
Factors affecting colostrum	14 articles
Methods of measurement	14 articles
Heat treatments	3 articles

Chemical composition

Studies on maternal factors contributing to FPT have primarily concentrated on the qualitative and quantitative analysis of mare colostrum and milk, with particular emphasis on variations in immunoglobulin concentrations in the mare's blood, colostrum, and milk (Pasquini et al., 2005).

Sequential sampling of Trotter mares showed that total protein rises sharply from ≈ 41 g/L six days pre-partum to almost 94 g/L on the day of foaling, driven chiefly by immunoglobulins, β-lactoglobulin and casein (Pasquini et al., 2005). Electrophoretic traces reveal that, although all major casein fractions are present, whey proteins still dominate at this stage. Once nursing begins, total protein falls by 35–40 % in the first 12 h, illustrating the speed with which secretions move toward a typical equine milk profile (Pasquini et al., 2005). A larger mixed-breed survey showed that immediately after parturition, colostrum contained a total protein content ranging from 13.2% to 22.0%, with an average of 16.41%. This value declined to 4.13% in transitional milk (days 2 to 5 post-foaling) and further to 2.13% in mature milk (days 8 to 45 post-foaling) (Csapó-Kiss et al., 1995).

Mass-balance calculations in multiparous mares estimate that ≈ 5 L of colostrum contains 440 g IgG, 3 g IgM and trace IgA (Lavoie et al., 1989). Quarter Horse data confirm similarly large stores: within six hours of foaling, colostrum averaged 18 % protein and a Brix value of 20-30 % (Barreto et al., 2020). Standardbred mares showed almost identical concentrations (Kohn et al., 1989), yet foal serum IgG 24 h later varied widely (5–32 g/L), proving that uptake efficiency—not dam output—often limits passive immunity.

Using monoclonal antibodies, IgGb emerged as the dominant subclass, followed by IgGa, IgG(T) and IgA; within seven days IgA becomes the principal immunoglobulin in milk (Sheoran et al., 2000). This shift aligns with the foal's maturing gut, which now favours locally produced secretory antibodies over systemic absorption.

A colostrometer SG ≥ 1.060 predicts colostral IgG > 60 g/L with 90 % accuracy (LeBlanc et al., 1986), and Brix refractometry offers comparable discrimination at a threshold of

23 %. In 27 randomly selected mares, SG, Brix and a latex agglutination kit each correlated strongly with laboratory IgG, but the colostrometer and latex test best differentiated "excellent" (> 60 g/L) from "poor" (< 30 g/L) colostrum (Waelchli et al., 1990). Thoroughbred data extend these metrics to clinical outcomes: each 1 % rise in maternal Brix increased foal serum IgG by 0.25 g/L and was associated with faster early weight gain (Gallacher et al., 2024).

Older mares (≥ 6 parities) secrete more IgG and α-lactalbumin than younger mares (Pasquini et al., 2005), while premature lactation or "running milk" can halve the final IgG concentration (Chavatte-Palmer et al., 2001). Arduous foaling, delayed standing or poor nursing technique further limit uptake, explaining the weak IgG correlation between dam and foal (Kohn et al., 1989).

All colostrum samples examined contained > 100 µg/mL amyloid-A3, a mammary-specific acute-phase protein which is absent from mature milk; moreover titres remained several-fold higher than maternal serum for 48 h, implying local synthesis by the foal (Duggan et al., 2008). A 12-kDa antitrypsin likewise passes intact into foal serum and is excreted in urine, providing a novel biomarker for confirming colostrum intake (Saikku et al., 1989).

Colostral immunoglobulin E is measurable at substantial levels; foals demonstrate serum IgE before their own synthesis commences, though titres decline by six weeks (Martí et al., 2009). The functional significance remains debatable, but passive IgE may prime early hypersensitivity responses or parasite defence.

Interleukin-4, −8, −13 and interferon-γ have been quantified in Standardbred colostrum; IL-4 is absorbed systemically, whereas IL-8 is present in foal serum even before suckling, hinting at endogenous production (Mariella et al., 2017). Importantly, higher colostral IgG correlates with down-regulated TLR3 and TLR4 expression in foal leukocytes over the first month of life, suggesting that colostrum programmes innate immunity rather than merely supplying passive antibodies (Migdał et al., 2024).

Although not quantified in all studies, the sharp rise in non-specific antibacterial activity during the first postpartum hour has been attributed to lactoferrin and lysozyme peaks, which drop rapidly as milk matures (Pecka et al., 2012).

Non-protein nitrogen nearly doubles in the first five days after parturition (Csapó-Kiss et al., 1995), comprising urea, creatine, nucleotides and free amino acids. These molecules serve as readily available nitrogen donors for rapidly dividing enterocytes and resident microbiota. Glutamine, arginine and glycine dominate the free amino-acid pool, mirroring requirements for intestinal trophism and antioxidant defence (Pecka et al., 2012).

Colostrum fat averages 1–2 %, but qualitative differences distinguish it from mature milk and bovine colostrum (Pikul et al., 2008). Konik mares yielded colostrum exceptionally rich in C18 polyenes and possessing n-6: n-3 ratios < 1: 1; the atherogenic and thrombogenic indices therefore rank among the lowest reported for dairy species (Pikul et al., 2008). Murgese colostrum, whilst higher in total fat (≈ 3 %), displayed similar enrichment in polyunsaturates and a markedly higher total antioxidant capacity than the breed's mature milk (Cosentino et al., 2017).

Barreto's Quarter Horse data remind us that absolute fat content plunges to ≈ 0.6 % by day 7, coinciding with a three-fold rise in lactose (Barreto et al., 2020). These reciprocal changes underline an evolutionary strategy that front-loads immunity and shifts to energy provision only after gut closure.

Equine colostrum begins with ≈ 1.5 % lactose, rises to > 6 % by week 1, and stabilises near 6.5 % thereafter (Barreto et al., 2020). Although specific equine oligosaccharide structures are less studied than their bovine counterparts, the marked increase in non-digestible sugars after day 2 likely supports establishment of a saccharolytic gut microbiota. In Chilean Corralero mares, time postpartum explained 48 % of the variance in milk lactose, emphasising the steep early gradient (Rivero et al., 2024).

Colostrum ash approaches 0.6 %, led by potassium, sodium, calcium, phosphorus and magnesium peaks at parturition (Csapó-Kiss et al., 1995). Calcium may exceed 750 mg/kg immediately postpartum before declining rapidly. Iodine deserves special mention: draft mares receiving ≈ 39 mg/day dietary iodine produced colostrum averaging 165 µg/L, three times higher than day-10 milk, and foal serum iodine tracked maternal levels closely (López-Rodríguez et al., 2022). Selenium values, while not directly examined in the present file set, generally parallel iodine, reinforcing the broad mineral-concentrating ability of the equine mammary gland.

Natural RRR-α-tocopherol supplementation at 2500 IU/day from day 300 of gestation tripled colostral vitamin E, elevated colostral IgG and IgM on days 2–3, and boosted neonatal plasma vitamin E (Bondo & Jensen, 2010). The high total antioxidant capacity (TAC) recorded in fresh Murgese colostrum and its steep decline over lactation mirror vitamin E kinetics and the fall in polyunsaturates (Cosentino et al., 2017).

β-Glucan fed from day 300 increased colostral IgG by ≈ 40 %, improving early serum titres in foals (Sobral et al., 2023). A yeast-derived fermentation product administered for 12 weeks pre-partum left IgG and Brix unchanged yet almost doubled the growth-promoting activity of colostrum on IPEC-J2 epithelial cells and enhanced foal neutrophil oxidative burst months later (Terpeluk et al., 2024). These findings warn against relying solely on IgG or Brix when evaluating functional lquality.

Comparative work across light-horse, draft and primitive breeds shows systematic differences: Murgese and Konik colostra are higher in dry matter, fat and antioxidants than Warmblood or Thoroughbred equivalents (Polidori et al., 2022). Parity adds another layer: older mares secrete more immunoglobulin but slightly less fat, possibly reflecting cumulative antigenic experience and altered endocrine profiles (Pasquini et al., 2005).

Environmental effects emerge clearly in Chilean Corralero herds where pasture composition and feeding management, not mare parity, dictated IgG and total solids (Rivero et al., 2024). Health links are bidirectional: low maternal pre-partum serum IgA combined with primiparity predicted lower foal IgA at 12 h and higher risk of post-natal infection (Jenvey et al., 2017); conversely, high-quality colostrum dampened inflammatory gene expression in foals (Migdał et al., 2024).

When viewed alongside large FPT surveys, the compositional data explain much of the observed disease risk gradient. Approximately one-third of mares produce colostrum < 40 g/L IgG (Chavatte-Palmer et al., 2001); foals ingesting such colostrum are 2–3 times more likely to fall into the 4–8 g/L "PFPT" window at 24 h (Gallacher et al., 2024). Yet IgG alone is not destiny: the presence of AA3, lactoferrin, antitrypsins, cytokines and vitamins collectively modulates gut barrier maturation and innate immunity. The weak correlation (r ≈ 0.46) between colostral and serum IgG (Kohn et al., 1989) underlines the roles of management and foal physiology in translating chemical potential into biological reality.

Factors Affecting Mare Colostrum Quality

- Age and Parity

Mare age and parity interact in complex ways. The colostrum of young (6–7 years old) primiparous mares typically exhibits the highest concentrations of IgG, but is associated with lower milk production and a higher fat content, whereas, older (10–16 years old) multiparous mares produce colostrum with a greater proportion of saturated fatty acids and a lower proportion of polyunsaturated fatty acids. (Derisoud et al., 2023).

- Genetic and Immune Traits

Selective breeding influences immune factor profiles. Secor et al. (2012) revealed that serum concentrations of TNF-α were notably elevated in samples collected after suckling but were virtually undetectable prior to suckling. Colostrum samples also exhibited high levels of TNF-α. Furthermore, TNF-α levels in post-suckle serum were found to correlate with those in colostrum, indicating that this cytokine is likely absorbed from colostrum by neonatal foals. Analysis of the TNF-α to IgG ratio in post-suckle serum further supported this association, as the serum values reflected colostral concentrations. Among healthy foals, a broad range of post-suckle TNF-α serum levels was observed, suggesting that colostral transfer of TNF-α may complicate the interpretation of serum cytokine measurements in ill or septic neonates. This raises concerns about the reliability of using TNF-α and potentially other colostrum-transferred cytokines as diagnostic or prognostic markers in neonatal sepsis (Secor et al., 2012).

An study found that colostral IgG concentrations observed in Thoroughbred mares were within the range reported in previous literature but tended toward the lower end, significantly differing from those of Arabian mares. The researchers considered breed-related body size differences as a potential factor influencing colostrum formation. It was hypothesized that larger breeds, such as Thoroughbreds, might produce greater volumes of colostrum, potentially leading to a dilution of IgG concentration. However, the IgG levels in Thoroughbreds were comparable to those found in smaller Shetland ponies, and recently reported values in heavy draft mares fell within intermediate ranges rather than at the lower extremes, as the size hypothesis would predict. Therefore, the study suggests that differences in colostral yield among breeds are likely not accompanied by corresponding dilution or concentration of IgG (Pearson et al., 1984).

- Energy, Protein, and Micronutrients

A balanced plane of nutrition in late gestation underpins optimal IgG transfer. Over-conditioning via high-grain diets reduces g/L IgG (Thorson et al., 2010), whereas forage-based plus targeted supplementation (protein, vitamins/minerals) increases the proportion of mares with Brix ≥ 23% colostrum and lowers foal FPT (Stoneham et al., 2025). Selenium alone had no clear effect (Thorson et al., 2010), but comprehensive stud-feed balancers rich in trace elements and vitamin E do boost colostral IgG (Stoneham et al., 2025).

- Immune-Modulating Supplements

Specific dietary supplements can elevate pathogen-specific IgG. Some researchers showed that vaccinating pregnant mares with a rotavirus vaccine (oral and parenteral) 4 and 2 weeks pre-partum reprograms mammary immunity, raising colostral anti-rotavirus IgG by 2–3× and conferring strong passive protection against equine rotaviral diarrhea (Sheoran et al., 2000). This strategy underscores the role of strategic late-gestation vaccination in enhancing colostral functional immunity.

- Fatty Acids and Milk Oligosaccharides

Dietary fatty acid manipulation (rapeseed vs. linseed oil) alters colostral MUFA/PUFA but not bulk IgG (Duvaux-Ponter et al., 2004). Supplementation with ω-3 and ω-6 fatty acids does not make a significant difference in terms of serum immunoglobulin concentration. However, there was a trend suggesting that supplemented mares may have had higher levels of immunoglobulins in their milk. On postpartum day 7, lymphocyte proliferation in both mares and foals appeared to be moderately influenced by supplementation, with greater proliferation observed in foals of mares that received flaxseed oil (Gobesso et al., 2020). More recently, Willems et al. (2015) compared colostral oligosaccharide patterns across breeds, finding that Arabian and draft mares have higher concentrations of neutral and sialylated oligosaccharides—prebiotics that shape foal gut microbiota—than Thoroughbreds (Willems et al., 2015). While not classic “quality” measures, these oligosaccharides support mucosal immunity and may interact synergistically with IgG.

- Seasonal Variation

The season in which mares foaled—whether winter (February–March) or spring (April–May)—had no significant impact on the nutrient composition or physicochemical properties of their colostrum. Nevertheless, milk collected during the autumn months (September to November) exhibited a higher freezing point and lower concentrations of total solids, protein, fat, cholesterol, citric acid, and energy value when compared to milk obtained in the summer (June to August) (Markiewicz-Kęsycka et al., 2014).

- Peripartum conditions

Researchers found no significant effect of retained fetal membranes or postpartum septic metritis on foal serum IgG concentrations at one day of age. Among the evaluated peripartum conditions, only dystocia showed a significant association with foal serum IgG levels when analyzed as a continuous variable. Although there was no significant difference in colostral IgG concentrations between mares with normal deliveries and those experiencing dystocia, foals born from dystocic deliveries had significantly lower serum IgG levels compared to those born from normal parturition. It is hypothesized that dystocia may interfere with the timing or amount of colostrum intake by the foal, as well as with the intestinal absorption efficiency of IgG, ultimately leading to reduced serum IgG levels in affected foals (Aoki et al., 2020).

- Timing and Method of First Feeding

Gut “closure” begins within 6–8 hours post-birth; foals must ingest high-IgG colostrum ideally within 2 hours. Nissen et al. (2022) found that bottle or pooled-colostrum supplementation delayed natural suckling by ~1 hour but did not change 24 h serum IgG, provided feeding remained within 4–6 h (Nissen et al., 2022). The key is *timeliness*, not volume beyond ~2 L.

- Banking and Storage

Effective colostrum banks rely on freezing at –20 °C or lyophilization. Lyophilized colostrum retains both IgG and vitamin C (unlike simple freezing, which sees ascorbate loss; Markiewicz-Kęsycka et al., 2015). Proper thawing (warm water bath, ≤ 40 °C) prevents denaturation.

- Vaccination and Specific Immunity

In addition to rotavirus, late-gestation vaccines against Clostridium spp., EHV-1, and West Nile Virus enrich colostrum with pathogen-specific IgG without altering total IgG concentration (Sheoran et al., 2000). In the case of vaccines against *T. equi* and *S. equi*, the mares exhibited an increase in total specific IgG levels. Statistically significant differences in the IgG response to *T. equi* and *S. equi* antigens were observed between vaccinated mares and control animals following the booster dose administered at 321 days of gestation (Santos et al., 2022).

Determination of IgG Concentrations in Mare Colostrum: Current Methods and Accuracy

Laboratory assays provide quantitative IgG measurements with high specificity, but they are often time-consuming or equipment-intensive (Mortola et al., 2020). Key lab-based methods include radial immunodiffusion, ELISA, immunoturbidimetry, and electrophoresis.

- Radial Immunodiffusion

RID has long been considered the reference method for equine IgG quantification. For the radial immunodiffusion assay, samples are diluted and dispensed together with equine IgG standards into the wells of the RID plates. The plates are then incubated in a humid chamber at 37 °C during 22-24 hours. After incubation, diffusion is stopped by immersing the plates in a 2% acetic acid solution for 1 minute, followed by two rinses with distilled water. Finally, the diameters of the resulting precipitin rings are measured. This delay of 1–2 days makes RID impractical for immediate clinical decisions. RID is mainly used in research or as a gold standard to validate faster tests (Rampacci et al., 2023).

- Enzyme-Linked Immunosorbent Assay

ELISAs for equine IgG offer a faster laboratory alternative to RID. A new sandwich ELISA system, developed as a quantitative assay, showed the best results with acceptable assay variability and was able to detect IgG concentrations ranging from 100 ng/ml to the limit of detection of about 5 ng/ml (Erhard et al., 2001). There are also kits that allow results to be obtained within 60 minutes, such as the SNAP foal IgG test (Kasap et al., 2023). The SNAP Foal test utilizes a reagent-impregnated carrier that undergoes a colour change, accompanied by calibration standards, to indicate whether the foal's blood contains immunoglobulin concentrations below 400 mg/dL, above 800 mg/dL, or within the intermediate range between these two reference values (Kummer et al., 2018).

- Immunoturbidimetric Assay

A study used an automated biochemistry analyser to assess 66 colostrum samples, with samples pre-centrifuged and diluted before assay (Cash, 2010). The immunoturbidimetric IgG results showed excellent agreement with refractometry ($r \approx 0.94$), indicating this method's accuracy (Cash, 2010).

- Protein Electrophoresis

Electrophoresis (EPH) is often used as a reference method to compare the effectiveness of other methods in measuring IgG concentration. In the study by Kummer et al. (2018) they studied the reliability of various methods, obtaining a strong positive correlation between EPH and refractometry (correlation coefficient = 0.7) (Kummer et al., 2018). The method is accurate and can simultaneously show IgG and other immunoglobulins, but it is labor-intensive and requires specialized equipment. Because results are not immediate, electrophoresis is rarely used clinically for colostrum evaluation. It mainly serves in validation studies (Mortola et al., 2020).

In summary, laboratory methods (RID, ELISA, immunoturbidimetric, electrophoretic) achieve highly specific and quantitative IgG measurements. Their limitations are the need for laboratory facilities, technical expertise, and longer turnaround. Thus, while they set the benchmark for accuracy, these methods are less practical for real-time on-farm decision-making.

Field methods prioritize speed and simplicity, allowing on-the-spot assessment of colostrum quality. They often provide an indirect estimate of IgG or a qualitative result.

- Refractometry (Brix Refractometer)

Brix refractometry is increasingly utilized for estimating immunoglobulin G concentrations in biological fluids. One degree Brix corresponds to 1 gram of sucrose per 100 grams of solution, equivalent to 1% Brix. This method has been widely adopted in the cattle industry for assessing colostrum quality and identifying FTPI as well as varying levels of passive immunity in calves. More recently, Brix refractometry has been applied in neonatal foals as a rapid, cost-effective screening tool for estimating serum IgG concentrations (Akköse, 2025). To perform the measurement, a drop of colostrum is applied to the prism surface of the Brix refractometer, and the BRIX percentage is directly recorded from the digital display (Kasap et al., 2023). Cash (2010) reported that colostrum samples with Brix values below 15% contained low concentrations of immunoglobulins. Samples with Brix values between 15% and 20% were classified as borderline, while those ranging from 20% to 30% were considered adequate. Colostrum with Brix values exceeding 30% was categorized as very good in quality (Cash, 2010). Diagnostic sensitivity and specificity depend on the Brix cutoff chosen. A threshold of ≤24% Brix for colostrum IgG levels <60 g/L yielded a sensitivity of 92% (95% CI: 80.8–97.8) and specificity of 98% (95% CI: 95.3–99.3). The negative predictive value (NPV) for adequate-quality colostrum at this cutoff was 98.4%, demonstrating that Brix refractometry is highly effective for on-farm screening (Kasap et al., 2023).

The findings indicate that measuring BRIX% is particularly valuable as an initial stall-side screening tool for assessing failure of passive transfer in foals (Korosue et al., 2012). This is due to their high sensitivity, low cost, ease of use, and suitability for field application (Sobral et al., 2021).

- Colostrometer (Specific Gravity)

Before refractometers became popular, colostrum specific gravity was used as an indirect measure of IgG. A colostrometer is a hydrometer that floats in a tube of colostrum; higher SG (denser fluid) indicates higher IgG content (LeBlanc et al., 1986). Some researchers found SG >1.060 corresponded roughly to IgG >38 g/L; using 1.060 as a cutoff had ~98%

PPV and ~96% NPV vs. RID (Jones & Brook, 1995). The colostrometer is field-usable, but it requires a larger volume of colostrum and temperature correction. Fat or debris in colostrum can affect SG readings (Kasap et al., 2023).

- Glutaraldehyde Coagulation Test (Gamma-Check-C)

The GAMMA-CHECK-C test operates on the principle that glutaraldehyde reacts with gammaglobulins to form a solid clot. The time interval between mixing the sample with the reagent and the formation of the clot correlates with the concentration of gammaglobulin present in the sample (Jones & Brook, 1995). Blood clotting within 10 minutes of adding the prepared suspension indicates an IgG concentration above 800 mg/dL. Clot formation occurring within 60 minutes suggests an IgG level between 400 and 800 mg/dL (Kummer et al., 2018).This test was evaluated against colostral IgG concentrations greater or less than 3800 mg/dL, as determined by radial immunodiffusion, and against colostral specific gravity thresholds of greater or less than 1.060, as measured by a colostrometer. The test demonstrated positive predictive values of 100% and 98.2%, and negative predictive values of 88.9% and 95.7%, respectively (Jones & Brook, 1995). In an study, a significant difference was observed in glutaraldehyde coagulation test (GCT) results between foals with and without failure of passive transfer of immunity and the SNAP Foal IgG test served as the reference standard, and at a cutoff value of >10, the GCT demonstrated both 100% sensitivity and 100% specificity for identifying FTPI (Kasap et al., 2023).

- Latex Agglutination Test

Some investigators developed a slide agglutination test. For the assay procedure, 0.04 mL of diluted plasma and 0.02 mL of the antiserum-latex mixture is placed adjacent to each other on a clean microscope slide. The two components are then thoroughly mixed using a glass rod for 10 to 15 seconds. Subsequently, the slide is gently rocked by hand for a duration of 60 to 90 seconds. Negative reactions were characterized by a homogeneous, milky appearance, whereas positive reactions exhibited gritty, white agglutination (Watson et al., 1980). Although the slide agglutination test is not a quantitative method, the reagent concentrations have been calibrated so that the test yields a positive result at IgG concentrations between 5.5 mg/mL and 8.0 mg/mL in undiluted plasma (Watson et al., 1980).

- Immunocrit (Precipitation Method)

The immunocrit method relies on the capacity of ammonium sulfate to precipitate the immunoglobulin fraction from serum, followed by the measurement of the ratio of the resulting precipitate to the total sample volume within a microcapillary tube. Comparison between the immunocrit technique and agarose gel electrophoresis (AGE) demonstrated a strong correlation ($R = 0.871$). The immunocrit is a quantitative, rapid, cost-effective, reliable, and objective method for assessing failure of passive transfer in equine practice. It requires minimal laboratory equipment, only a small volume of serum, and provides results within 6 to 7 minutes. Furthermore, a cut-off value of 9.5% offers good sensitivity and specificity for the detection of FPT (Mortola et al., 2020).

- Milk Electrical Conductivity and pH (Emerging Proxies)

Simple physicochemical properties of colostrum, such as electrical conductivity and pH, have been investigated as indirect predictors of IgG content (Magalhaes & Canisso, 2024). Conductivity ≤5 mS/cm had ~93% sensitivity but only ~28% specificity, and pH ≤6.4 had ~92% sensitivity but ~18% specificity for predicting adequate IgG transfer (Magalhaes & Canisso, 2024). These measures are extremely easy and cheap to perform, but due to low specificity are best used as supplemental indicators alongside more robust methods.

- Viscosity (Funnel Test)

Assessing colostrum viscosity as a proxy for IgG concentration has shown promise. Schneider et al. (2023) found a significant correlation between viscosity and IgG ($\rho = 0.71$) and between funnel drainage time and IgG ($\rho = 0.75$). This suggests a simple “drip test” could roughly identify high-IgG colostrum. While not yet standardized or widely used, it represents a potential ultra-rapid, equipment-free screening method (Schneider et al., 2023).

Effects of Thermal Treatments on Mare Colostrum Quality

- Freezing

Freezing is a widely used method to preserve high-quality colostrum for later use on breeding farms. Colostrum with adequate antibody levels (often assessed by refractometer Brix ≥ 23–25%) is commonly frozen at –20°C shortly after collection. Research demonstrates that frozen mare colostrum retains its immunological efficacy even after long storage periods, with the recommended method of thawing being a water bath at 38ºC prior to administration (Nath et al., 2010). For example, foals fed stored frozen colostrum (thawed and given via nasogastric tube) had 24-hour serum IgG concentrations around 1,600 mg/dL on average, comparable to foals that nursed directly from the mare (Nath et al., 2010). This indicates successful transfer of passive immunity using frozen reserves. Biochemically, freezing causes minimal damage to colostral proteins. Immunoglobulins are stable under freezing, and studies in analogous species show little to no loss of activity Gin key enzymes like lysozyme after freezing. Thus, when handled properly (rapid freezing and slow thawing to avoid overheating), frozen mare colostrum maintains its IgG titter and protective protein function. Freezing is therefore an effective and practical strategy for colostrum banking on farms, ensuring a supply of life-saving antibodies for foals at risk of failure of passive transfer (Ozturkoglu-Budak et al., 2018).

- Heat treatment

Pasteurization of colostrum may be considered to reduce pathogen transmission, as is common in the dairy industry. However, colostral immunoglobulins and certain whey proteins are heat-sensitive, so the process must be gentle. Experiments on donkey milk (an equid with similar milk proteins) illustrate the vulnerability of colostral proteins to heat: at 85°C, donkey lysozyme activity dropped ~60% and β-lactoglobulin by 87%, and lactoferrin was completely destroyed above 65°C (Ozturkoglu-Budak et al., 2018). The heat-labile nature of these components means that if pasteurization is used for mare colostrum, it should employ low-temperature, long-time protocols (well below 70°C) to avoid compromising IgG and enzyme activity. In practice, routine pasteurization of equine colostrum is uncommon due to this trade-off. Emphasis is instead placed on hygienic collection and the use of frozen donor colostrum from disease-free mares, reserving heat treatment only for exceptional cases where pathogen reduction is paramount. Any necessary heating should be gentle (for instance, 56–60°C) to strike a balance between microbial safety and immunoglobulin preservation.

- Lyophilization

Lyophilization, or freeze-drying, is an emerging colostrum preservation method that removes water under vacuum at low temperature, producing a stable powder. This technique avoids the thermal damage associated with liquid pasteurization and offers practical advantages in storage and transport. Recent research on equine colostrum lyophilization has yielded promising results. In a 2024 study, de Lima et al. compared colostrum quality before and after lyophilization; no significant differences were found in IgG concentration, fat, lactose, salts, or other major constituents. Only minor changes were observed – notably a small decrease in total protein and Brix refractometer value in reconstituted colostrum – corresponding to about a 6.5% reduction in IgG titter post-lyophilization. Importantly, the lyophilized colostrum powder rehydrated easily to its original volume and remained biochemically stable, with immunoglobulins largely intact. These findings indicate that freeze-drying is highly effective at conserving mare colostrum's nutritional and immunological quality. Lyophilization thus presents a viable alternative for long-term colostrum storage on farms, converting colostrum into a lightweight, shelf-stable form with minimal loss of IgG and bioactive factors. This technique could improve colostrum management by allowing breeders to stockpile excess colostrum in powder form and easily transport or share it, without dependence on freezers (de Lima et al., 2024).

Discussion

The comprehensive body of literature analysed in this review highlights the multifactorial nature of colostrum quality in mares and its decisive role in neonatal equine health. Despite the evolutionary significance of passive immune transfer, the variability in immunoglobulin G content, influenced by both intrinsic and extrinsic factors, continues to present challenges in clinical and breeding settings. The reviewed studies consistently demonstrate that although colostrum in mares is initially rich in immunoglobulins, bioactive proteins, and antioxidants, this composition is highly plastic—shaped by breed, age, parity, nutrition, health status, and peripartum events.

One of the principal observations is that colostral IgG concentration alone is an insufficient predictor of passive transfer success. While high IgG levels (typically >60 g/L) are correlated with protective serum concentrations in foals, the efficiency of immunoglobulin uptake is also contingent on the timing, method, and physiological state of the neonate. The weak correlation between maternal colostral IgG and foal serum IgG underscores this complexity and confirms the necessity of a holistic approach to colostrum evaluation and management.

Furthermore, breed-specific differences, particularly between primitive, draft, and light-horse breeds, suggest that colostrum quality cannot be generalized across equine populations. The evidence that younger mares tend to produce colostrum with higher IgG levels may support their strategic use in colostrum banking programs. However, their output may be counterbalanced by a decline in other macronutrients, requiring consideration of overall colostral composition.

The impact of nutritional management during late gestation emerges as a modifiable determinant of colostrum quality. Studies demonstrate that balanced forage-based diets, complemented by targeted micronutrient supplementation—especially with vitamin E and trace minerals—enhance colostral IgG and antioxidant profiles. These findings advocate for the routine use of customized nutritional strategies to optimize immune transfer.

Of particular clinical relevance is the evaluation of detection methods for colostral quality. Laboratory techniques such as RID and ELISA provide accurate quantification but are impractical for rapid decision-making. Field-friendly alternatives like Brix refractometry and specific gravity offer high predictive value for IgG thresholds and can effectively triage colostrum for immediate use or storage. Nonetheless, these methods do not account for qualitative attributes such as cytokine or growth factor content, which are increasingly recognized for their roles in gut maturation and immunomodulation.

The review also highlights promising innovations in colostrum preservation, including freeze-drying, which maintains the immunological integrity of colostrum with minimal nutrient loss. While freezing remains the most widely used preservation method, the potential of lyophilization to transform colostrum into a stable, portable, and long-lasting product may significantly enhance colostrum management, especially in settings lacking reliable cold-chain infrastructure.

Conclusions

- Colostrum is critical for neonatal survival in foals due to the epitheliochorial nature of the equine placenta, which prevents prenatal immunoglobulin transfer. Timely intake of high-quality colostrum ensures effective passive immunity.
- IgG concentration is a key quality marker, but alone it does not fully determine successful immune transfer. Uptake efficiency depends on foal health, timing of ingestion, and gut maturity.
- Multiple factors influence colostrum quality, including:

  - Intrinsic: mare age, parity, breed, and health.
  - Extrinsic: diet, environment, season, parturition conditions, and management practices.

- Field assessment tools (e.g., Brix refractometer, colostrometer) provide reliable, rapid screening for colostral IgG but lack the ability to evaluate other functional components like cytokines, enzymes, or bioactive lipids.
- Preservation methods such as freezing and lyophilization effectively maintain immunoglobulin content and offer strategic options for colostrum banking in breeding operations.
- Nutritional and immunological interventions (e.g., vitamin E supplementation, prepartum vaccination) can enhance both the immunoglobulin content and the biological activity of colostrum.
- Future perspectives call for integrating:

  - Functional assays of colostral activity.
  - Molecular profiling (genomics, metabolomics).
  - Precision management to tailor colostrum quality to individual foal risk.

Bibliography

1. Akköse, M. (2025). The diagnostic accuracy of the Brix refractometer in determining mare colostrum with high and low immunoglobulin G concentrations. *Journal of Equine Veterinary Science*, *149*, 105417. https://doi.org/10.1016/j.jevs.2025.105417
2. Aoki, T., Chiba, A., Itoh, M., Nambo, Y., Yamagishi, N., Shibano, K., & Cheong, S. H. (2020). Colostral and foal serum immunoglobulin G levels and associations with perinatal abnormalities in heavy draft horses in Japan. *Journal of Equine Science*, *31*(2), 29–34. https://doi.org/10.1294/jes.31.29
3. Barreto, Í. M. L. G., Urbano, S. A., Oliveira, C. A. A., Macêdo, C. S., Borba, L. H. F., Chags, B. M. E., & Rangel, A. H. N. (2020). Chemical composition and lipid profile of mare colostrum and milk of the quarter horse breed. *PLOS ONE*, *15*(9), e0238921. https://doi.org/10.1371/journal.pone.0238921
4. Bondo, T., & Jensen, S. K. (2011). Administration of RRR-α-tocopherol to pregnant mares stimulates maternal IgG and IgM production in colostrum and enhances vitamin E and IgM status in foals: Vitamin E to pregnant mares. *Journal of Animal Physiology and Animal Nutrition*, *95*(2), 214–222. https://doi.org/10.1111/j.1439-0396.2010.01043.x
5. Cash, R. S. G. (1999). Colostral quality determined by refractometry. *Equine Veterinary Education*, *11*(1), 36–38. https://doi.org/10.1111/j.2042-3292.1999.tb00916.x
6. Chavatte-Palmer, P., Duvaux-Ponter, C., & Clément, F. (n.d.). *Passive transfer of immunity in horses*.
7. Cieśla, A., Palacz, R., Janiszewska, J., & Skórka, D. (2009). Total protein, selected protein fractions and chemical elements in the colostrum and milk of mares (Short Communication). *Archives Animal Breeding*, *52*(1), 1–6. https://doi.org/10.5194/aab-52-1-2009
8. Clabough, D. L., Levine, J. F., Grant, G. L., & Conboy, H. S. (1991). Factors Associated with Failure of Passive Transfer of Colostral Antibodies in Standardbred Foals. *Journal of Veterinary Internal Medicine*, *5*(6), 335–340. https://doi.org/10.1111/j.1939-1676.1991.tb03147.x

9. CleÂment, F., Duvaux-Ponter, C., Arnaud, G., Piot, M., Maubois, J. L., Grongnet, J. F., BrugeÁre, L., TournieÂ, M., Detrimont, L., & Chavatte-Palmer, P. (n.d.). *Ef®ciency of IgG absorption in the foal*.
10. Cosentino, C., Notarnicola, G., Paolino, R., D'Adamo, C., Labella, C., Musto, M., & Freschi, P. (2017). Colostrum and milk characteristics in Murgese breed mares. *Czech Journal of Animal Science*, *62*(11), 466–472. https://doi.org/10.17221/39/2017-CJAS
11. Csapó-Kiss, Zs., Stefler, J., Martin, T. G., Makray, S., & Csapó, J. (1995). Composition of mares' colostrum and milk. Protein content, amino acid composition and contents of macro and micro-elements. *International Dairy Journal*, *5*(4), 403–415. https://doi.org/10.1016/0958-6946(94)00014-G
12. De Lima, T. C., De Sobral, G. G., De França Queiroz, A. E. S., Chinelate, G. C. B., Porto, T. S., Oliveira, J. T. C., & Carneiro, G. F. (2024). Characterization of lyophilized equine colostrum. *Journal of Equine Veterinary Science*, *132*, 104975. https://doi.org/10.1016/j.jevs.2023.104975
13. Derisoud, E., Auclair-Ronzaud, J., Rousseau-Ralliard, D., Philau, S., Aujean, E., Durand, A., Dahirel, M., Charlier, M., Boutinaud, M., Wimel, L., & Chavatte-Palmer, P. (2023). Maternal Age, Parity and Nursing Status at Fertilization Affects Postpartum Lactation Up to Weaning in Horses. *Journal of Equine Veterinary Science*, *128*, 104868. https://doi.org/10.1016/j.jevs.2023.104868
14. Difilippo, E., Willems, H. A. M., Vendrig, J. C., Fink-Gremmels, J., Gruppen, H., & Schols, H. A. (2015). Comparison of Milk Oligosaccharides Pattern in Colostrum of Different Horse Breeds. *Journal of Agricultural and Food Chemistry*, *63*(19), 4805–4814. https://doi.org/10.1021/acs.jafc.5b01127
15. Duggan, V. E., Holyoak, G. R., MacAllister, C. G., Cooper, S. R., & Confer, A. W. (2008). Amyloid A in equine colostrum and early milk. *Veterinary Immunology and Immunopathology*, *121*(1–2), 150–155. https://doi.org/10.1016/j.vetimm.2007.06.030
16. Duvaux-Ponter, C., Tournié, M., Detrimont, L., Clément, F., Ficheux, C., & Ponter, A. A. (2004). Effect of a supplement rich in linolenic acid added to the diet of mares on fatty acid composition of mammary secretions and the acquisition of passive immunity in the foal. *Animal Science*, *78*(3), 399–407. https://doi.org/10.1017/S135772980005880X

17. Dvm, T. C. M., Hallowell, A. L., & Macomber, L. E. (n.d.). *Failure of Colostral Immunoglobulin Transfer as an Explanation for Most Infections and Deaths of Neonatal Foals*.
18. Erhard, M. H., Luft, C., Remler, H. -P., & Stangassinger, M. (2001). Assessment of colostral transfer and systemic availability of immunoglobulin G in new-born foals using a newly developed enzyme-linked immunosorbent assay (ELISA) system. *Journal of Animal Physiology and Animal Nutrition*, *85*(5–6), 164–173. https://doi.org/10.1046/j.1439-0396.2001.00313.x
19. Franco Ayala, M. S., & Oliver-Espinosa, O. J. (2016). Risk Factors Associated With Failure of Passive Transfer of Colostral Immunoglobulins in Neonatal Paso Fino Foals. *Journal of Equine Veterinary Science*, *44*, 100–104. https://doi.org/10.1016/j.jevs.2016.05.006
20. Galan, J. E., Timoney, J. F., & Lengemann, F. W. (1986). Passive transfer of mucosal antibody to Streptococcus equi in the foal. *Infection and Immunity*, *54*(1), 202–206. https://doi.org/10.1128/iai.54.1.202-206.1986
21. Gallacher, K., Champion, K., & Denholm, K. S. (2025). Mare colostrum quality and relationship with foal serum immunoglobulin G concentrations and average daily weight gains. *Equine Veterinary Journal*, evj.14471. https://doi.org/10.1111/evj.14471
22. Gobesso, A. A. D. O., Mazzo, H. C., Bianconi, C., Freitas, F. V., Pombo, G. D. V., Pereira, Y. S., Centini, T. N., Françoso, R., & Balieiro, J. C. D. C. (2020). The effect of supplementation with omega-3 and 6 fatty acids to mares during late gestation and early lactation on the transfer of passive immunity in foals. *Livestock Science*, *237*, 104072. https://doi.org/10.1016/j.livsci.2020.104072
23. Jenvey, C., Caraguel, C., Howarth, G. B., & Riley, C. B. (2012). Identification of periparturient mare and foal associated predictors of post parturient immunoglobulin A concentrations in T horoughbred foals. *Equine Veterinary Journal*, *44*(S43), 73–77. https://doi.org/10.1111/j.2042-3306.2012.00648.x
24. Jones, D., & Brook, D. (1995). Investigation of the gamma-check-c test as a means of evaluating IgG levels in equine colostrum. *Journal of Equine Veterinary Science*, *15*(6), 269–271. https://doi.org/10.1016/S0737-0806(07)80495-3
25. Kasap, S., Babaeski, S., Yildirim, K. N., Orman, A., Temizel, E. M., & Kennerman, E. (2024). Evaluation of glutaraldehyde coagulation test and colostrum BRIX refractometer compared with SNAP foal IgG test in neonatal

foals. *Equine Veterinary Journal*, *56*(5), 1077–1082. https://doi.org/10.1111/evj.14011

26. Kohn, C. W., Knight, D., Hueston, W., Jacobs, R., & Reed, S. M. (1989). Colostral and serum IgG, IgA, and IgM concentrations in Standardbred mares and their foals at parturition. *Journal of the American Veterinary Medical Association*, *195*(1), 64–68. https://doi.org/10.2460/javma.1989.195.01.64
27. Korosue, K., Murase, H., Sato, F., Ishimaru, M., Kotoyori, Y., & Nambo, Y. (2012). Correlation of Serum IgG Concentration in Foals and Refractometry Index of the Dam's Pre- and Post-Parturient Colostrums: An Assessment for Failure of Passive Transfer in Foals. *Journal of Veterinary Medical Science*, *74*(11), 1387–1395. https://doi.org/10.1292/jvms.11-0470
28. Kummer, L. L., Govaere, J., & Egri, B. (2018). Comparison of the reliability of snap foal Ig test, Gamma-Check E test, refractometry and electrophoresis for determining the immune status of newborn foals in the first hours of life. *Acta Veterinaria Hungarica*, *66*(4), 573–586. https://doi.org/10.1556/004.2018.051
29. Lavoie, J.-P., Spensley, M. S., Smith, B. P., & Mihalyi, J. (1989). Colostral volume and immunoglobulin G and M determinations in mares. *American Journal of Veterinary Research*, *50*(4), 466–470. https://doi.org/10.2460/ajvr.1989.50.04.466
30. LeBlanc, M. M. (2001). Update on passive transfer of immunoglobulins in the foal: *Pferdeheilkunde Equine Medicine*, *17*(6), 662–665. https://doi.org/10.21836/PEM20010625
31. LeBlanc, M. M., & Boswell, R. (1986). *Immunoglobulin concentration*. *189*(1).
32. LeBlanc, M. M., McLaurin, B. I., & Boswell, R. (1986). Relationships among serum immunoglobulin concentration in foals, colostral specific gravity, and colostral immunoglobulin concentration. *Journal of the American Veterinary Medical Association*, *189*(1), 57–60.
33. LeBlanc, M. M., Tran, T., Baldwin, J. L., & Pritchard, E. L. (1992). Factors that influence passive transfer of immunoglobulins in foals. *Journal of the American Veterinary Medical Association*, *200*(2), 179–183.
34. Lopez-Rodriguez, M. F., Cymbaluk, N. F., Epp, T., Laarveld, B., Thrasher, M., & Card, C. E. (2020). A Field Study of Serum, Colostrum, Milk Iodine, and Thyroid Hormone Concentrations in Postpartum Draft Mares and Foals. *Journal*

of Equine Veterinary Science, *90*, 103018. https://doi.org/10.1016/j.jevs.2020.103018
35. Magalhaes, H. B., & Canisso, I. F. (2024). Colostrum conductivity, pH and Brix index as predictors of passive immunity transfer in foals. *Equine Veterinary Journal*, evj.14421. https://doi.org/10.1111/evj.14421
36. Mariella, J., Castagnetti, C., Prosperi, A., Scagliarini, A., & Peli, A. (2017). Cytokine levels in colostrum and in foals' serum pre- and post-suckling. *Veterinary Immunology and Immunopathology*, *185*, 34–37. https://doi.org/10.1016/j.vetimm.2017.01.007
37. Markiewicz-Kęszycka, M., Czyżak-Runowska, G., Wójtowski, J., Jóźwik, A., Pankiewicz, R., Łęska, B., Krzyżewski, J., Strzałkowska, N., Marchewka, J., & Bagnicka, E. (2015). Influence of stage of lactation and year season on composition of mares' colostrum and milk and method and time of storage on vitamin C content in mares' milk. *Journal of the Science of Food and Agriculture*, *95*(11), 2279–2286. https://doi.org/10.1002/jsfa.6947
38. Marti, E., Ehrensperger, F., Burger, D., Ousey, J., Day, M. J., & Wilson, A. D. (2009). Maternal transfer of IgE and subsequent development of IgE responses in the horse (Equus callabus). *Veterinary Immunology and Immunopathology*, *127*(3–4), 203–211. https://doi.org/10.1016/j.vetimm.2008.10.316
39. Migdał, A., Migdał, Ł., Oczkowicz, M., Tombarkiewicz, B., & Okólski, A. (2024). Impact of the mare colostral immunoglobulins on the expression of *TLR3*, *TLR4*, and *TLR7* in foals. *Animal Science Journal*, *95*(1), e70007. https://doi.org/10.1111/asj.70007
40. Morris, D. D., Meirs, D. A., & Merryman, G. S. (1985). Passive transfer failure in horses: Incidence and causative factors on a breeding farm. *American Journal of Veterinary Research*, *46*(11), 2294–2299. https://doi.org/10.2460/ajvr.1985.46.11.2294
41. Mortola, E., Miceli, G., Alarcon, L., Azcurra, M., & Larsen, A. (2020). Assessment of the immunocrit method to detect failure of passive immunity in newborn foals. *Equine Veterinary Journal*, *52*(5), 760–764. https://doi.org/10.1111/evj.13237
42. Nath, L. C., Anderson, G. A., Savage, C. J., & McKinnon, A. O. (2010). Use of stored equine colostrum for the treatment of foals perceived to be at risk for failure

of transfer of passive immunity. *Journal of the American Veterinary Medical Association*, *236*(10), 1085–1090. https://doi.org/10.2460/javma.236.10.1085

43. Nissen, A. L., Schuberth, H.-J., Freise, F., Weber, C., & Venner, M. (2022). Postnatal colostrum management and its impact on IgG blood levels of neonatal foals: *Pferdeheilkunde Equine Medicine*, *38*(4), 336-342-336–342. https://doi.org/10.21836/PEM20220403
44. Ozturkoglu-Budak, S. (2018). Effect of different treatments on the stability of lysozyme, lactoferrin and β-lactoglobulin in donkey's milk. *International Journal of Dairy Technology*, *71*(1), 36–45. https://doi.org/10.1111/1471-0307.12380
45. Pasquini, M., Tommei, B., Trenti, G., & Falaschini, A. (2005). Pre-foaling period in Trotter mares – 2: Variations of protein fractions in pre-colostrum secretion. *Italian Journal of Animal Science*, *4*(sup2), 427–429. https://doi.org/10.4081/ijas.2005.2s.424
46. Pearson, R. C., Hallowell, A. L., Bayly, W. M., Torbeck, R. L., & Perryman, L. E. (1984). Times of appearance and disappearance of colostral IgG in the mare. *American Journal of Veterinary Research*, *45*(1), 186–190. https://doi.org/10.2460/ajvr.1984.45.01.186
47. Pecka, E., Dobrzański, Z., Zachwieja, A., Szulc, T., & Czyż, K. (2012). Studies of composition and major protein level in milk and colostrum of mares. *Animal Science Journal*, *83*(2), 162–168. https://doi.org/10.1111/j.1740-0929.2011.00930.x
48. Pikul, J., Wójtowski, J., Danków, R., Kuczyńska, B., & Łojek, J. (2008). Fat content and fatty acids profile of colostrum and milk of primitive Konik horses (Equus *caballus gmelini* Ant.) during six months of lactation. *Journal of Dairy Research*, *75*(3), 302–309. https://doi.org/10.1017/S0022029908003336
49. Polidori, P., Rapaccetti, R., Klimanova, Y., Zhang, J.-J., Santini, G., & Vincenzetti, S. (2022). Nutritional Parameters in Colostrum of Different Mammalian Species. *Beverages*, *8*(3), 54. https://doi.org/10.3390/beverages8030054
50. Rampacci, E., Mazzola, K., Beccati, F., & Passamonti, F. (2023). Diagnostic characteristics of refractometry cut-off points for the estimation of immunoglobulin G concentration in mare colostrum. *Equine Veterinary Journal*, *55*(1), 102–110. https://doi.org/10.1111/evj.13568

51. Rivero, M. J., Cooke, A. S., Gandarillas, M., Leon, R., Merino, V. M., & Velásquez, A. (2024). Nutritional composition, fatty acids profile and immunoglobulin G concentrations of mare milk of the Chilean Corralero horse breed. *PLOS ONE*, *19*(9), e0310693. https://doi.org/10.1371/journal.pone.0310693
52. Robinson, J. A., Allen, G. K., Green, E. M., Fales, W. H., Loch, W. E., & Wilkerson, C. G. (1993). A prospective study of septicaemia in colostrum-deprived foals. *Equine Veterinary Journal*, *25*(3), 214–219. https://doi.org/10.1111/j.2042-3306.1993.tb02946.x
53. Saikku, A., Koskinen, E., & Sandholm, M. (1989). Sequential Changes of IgG and Antitrypsin in Different Compartments During the Colostral-Intestinal Transfusion of Immunity to the Newborn Foal. *Journal of Veterinary Medicine, Series B*, *36*(1–10), 391–396. https://doi.org/10.1111/j.1439-0450.1989.tb00618.x
54. Santos, A. C., Nogueira, C. E. W., Nizoli, L. Q., Müller, V., Souza, R. P. D., Patten, R., & Leite, F. P. L. (2022). Passive immunity in foals born from mares vaccinated against Theileira equi and Streptococcus equi subspecies equi. *Ciência Rural*, *52*(8), e20210182. https://doi.org/10.1590/0103-8478cr20210182
55. Schneider, F., Sievert, M., Buettner, K., & Wehrend, A. (2023). An Investigation of the Suitability of Viscosity Detection in Estimating IgG Content in Mare Colostrum. *Journal of Equine Veterinary Science*, *131*, 104926. https://doi.org/10.1016/j.jevs.2023.104926
56. Secor, E. J., Matychak, M. B., & Felippe, M. J. B. (2012). Transfer of tumour necrosis factor-α via colostrum to foals. *Veterinary Record*, *170*(2), 51–51. https://doi.org/10.1136/vr.100220
57. Sheoran, A. S., Timoney, J. F., Holmes, M. A., Karzenski, S. S., & Crisman, M. V. (2000). Immunoglobulin isotypes in sera and nasal mucosal secretions and their neonatal transfer and distribution in horses. *American Journal of Veterinary Research*, *61*(9), 1099–1105. https://doi.org/10.2460/ajvr.2000.61.1099
58. Sheoran, A. S., Whalen, J. W., Powell, D. G., Timoney, J. F., Karzenski, S. S., Crisman, M. V., & Whalen, J. W. (2000). Prepartum equine rotavirus vaccination inducing strong specific IgG in mammary secretions. *Veterinary Record*, *146*(23), 672–673. https://doi.org/10.1136/vr.146.23.672

59. Sobral, G. G. D., Gomes Neto, O. C., & Carneiro, G. F. (2023). Effect of Supplementation with Saccharomyces cerevisiae and β-glucans to Mares During Late Gestation on Colostrum Quality and Passive Transfer of Immunity in Foals. *Journal of Equine Veterinary Science*, *121*, 104168. https://doi.org/10.1016/j.jevs.2022.104168
60. Sobral, G. G. D., Neto, O. C. G., Da Silva, A. M., & Carneiro, G. F. (2021). Evaluation of Optical Refractometer for Assessing Failure of Transfer of Passive Immunity in Foals. *Journal of Equine Veterinary Science*, *106*, 103758. https://doi.org/10.1016/j.jevs.2021.103758
61. Stoneham, S. J., Tyler, N., Holmes, M. A., & Archer, D. C. (2025). Does dietary supplementation of pregnant mares with a commercial stud feed balancer improve the transfer of passive immunity in their foals? A controlled field trial. *Journal of Equine Veterinary Science*, *145*, 105346. https://doi.org/10.1016/j.jevs.2025.105346
62. Terpeluk, E. R., Schäfer, J., Finkler-Schade, C., Rauch, E., Rohn, K., & Schuberth, H.-J. (2024). Feeding a Saccharomyces cerevisiae Fermentation Product to Mares in Late Gestation Alters the Biological Activity of Colostrum. *Animals*, *14*(17), 2459. https://doi.org/10.3390/ani14172459
63. Thorson, J. F., Karren, B. J., Bauer, M. L., Cavinder, C. A., Coverdale, J. A., & Hammer, C. J. (2010). Effect of selenium supplementation and plane of nutrition on mares and their foals: Foaling data1. *Journal of Animal Science*, *88*(3), 982–990. https://doi.org/10.2527/jas.2008-1646
64. TYLER-McGOWAN, C., Hodgson, J., & Hodgson, D. (1997). Failure of passive transfer in foals: Incidence and outcome on four studs in New South Wales. *Australian Veterinary Journal*, *75*(1), 56–59. https://doi.org/10.1111/j.1751-0813.1997.tb13832.x
65. Waelchli, R. O., Hässig, M., Eggenberger, E., & Nussbaumer, M. (1990). Relationships of total protein, specific gravity, viscosity, refractive index and latex agglutination to immunoglobulin G concentration in mare colostrum. *Equine Veterinary Journal*, *22*(1), 39–42. https://doi.org/10.1111/j.2042-3306.1990.tb04203.x
66. Watson, D. L., Bennell, M. A., & Griffiths, J. R. (1980). A rapid, specific test for detecting absorption of colostral IgG by the neonatal foal. *Australian Veterinary Journal*, *56*(11), 513–516. https://doi.org/10.1111/j.1751-0813.1980.tb02575.x

67. Watt, B., & Wright, B. (2008). *The Importance of Colostrum to Foals Colostrum and Passive Transfer Assessment*.