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On the role of mid-infrared predicted phenotypes in fertility and health dairy breeding programs[1]

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ABSTRACT

Fertility and health traits are of prime importance in dairy breeding programs. However, these traits are generally complex, difficult to record, and lowly heritable (<0.10), thereby hampering genetic improvement in disease resistance and fertility. Hence, indicators are useful in the prediction of genetic merit for fertility and health traits as long as they are easier to measure than direct fitness traits, heritable, and genetically correlated. Considering that changes in (fine) milk composition over a lactation reflect the physiological status of the cow, mid-infrared (MIR) analysis of milk opens the door to a wide range of potential indicator traits of fertility and health. Previous studies investigated the phenotypic and genetic relationships between fertility and MIR-predicted phenotypes, most being related to negative postpartum energy balance and body fat mobilization (e.g., fat:protein ratio, urea, fatty acids profile). Results showed that a combination of various fatty acid traits (e.g., C18:1 *cis*-9 and C10:0) could be used to improve fertility. Furthermore, occurrence of (sub)clinical ketosis has been related to milk-based phenotypes such as fat:protein ratio, fatty acids, and ketone bodies. Hence, MIR-predicted acetone and β-hydroxybutyrate contents in milk could be useful for breeding cows less susceptible to ketosis. Although studies investigating the genetic association among mastitis and MIR-predicted phenotypes are scarce, a wide range of traits, potentially predicted by MIR spectrometry, are worthy of consideration. These include traits related to the disease response of the cow (e.g., lactoferrin), reduced secretory activity (e.g., casein), and the alteration of the blood-milk barrier (e.g., minerals). Moreover, direct MIR prediction of fertility and health traits should be further considered. To conclude, MIR-predicted phenotypes have a role to play in the improvement of dairy cow fertility and health. However, further studies are warranted to (1) grasp underlying associations among MIR-predicted indicator and fitness traits, (2) estimate the genetic parameters, and (3) include these traits in broader breeding strategies.
Key words: health, fertility, mid-infrared spectrometry

INTRODUCTION

For several decades, in many countries, breeding goals in dairy cattle have focused mainly on increased milk production, leading to the deterioration of most functional traits, some reaching a critical point and needing to be restored. This was particularly true for female fertility, mastitis resistance, longevity, and metabolic disorders (Boichard and Brochard, 2012). Improved management practices and the inclusion of functional traits in broader breeding goals have restricted, to some extent, the deterioration in these traits or even to reverse the trends (Miglior et al., 2012). However, genetic selection for disease resistance and fertility is still hampered by the low heritability of these traits and the difficulty in routinely collecting, at low cost, a sufficient amount of relevant direct phenotypes. The collection of high-quality direct phenotypes can still be a major bottleneck, especially for disease traits (Egger-Danner et al., 2015). Therefore, indicator traits could be very useful as indirect traits (i.e., traits included in the selection index) to improve dairy cow fertility and health, which are the breeding goal traits. Indicator traits have to be readily measurable at a low cost and highly correlated with direct fertility and health phenotypes (Shook, 1989). For instance, SCC has been widely used as an indicator trait to breed for reduced incidence of both clinical and subclinical mastitis (Heringstad et al., 2000; Rupp and Boichard, 2003). Also, several traits have been investigated as potential indicators traits for fertility, most being related to negative postpartum energy balance (**EB**) and body fat mobilization such as

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BCS, BW (Berry et al., 2003), and milk composition traits (Bastin et al., 2014). Because changes in the biochemical profile of milk can be used to mirror a cow's physiological status (Hamann and Krömker, 1997), the variation in milk composition could be related to fertility and health of dairy cows.

Over the range of potential indicator traits of fertility and health, milk-based traits that could be obtained through regular milk recording schemes are of particular interest because collection is noninvasive, and a new data collection channel would not need to be implemented. Mid-infrared (**MIR**) spectrometry is the method used worldwide in regular milk recording schemes and milk payment systems to quantify the major milk components (i.e., fat, protein, casein, lactose, and urea). Over the last decade, the usefulness of MIR spectrometry to obtain new milk phenotypes such as detailed milk composition, technological properties of milk, or cow physiological status has been demonstrated (De Marchi et al., 2014). Hence, MIR spectrometry is a rapid and cost-effective tool to obtain new milk phenotypes that could be used as indicator traits in dairy breeding programs for enhanced fertility and health.

Therefore, this paper will discuss the opportunity of using MIR-predicted phenotypes as indicators of health and fertility in dairy breeding programs. First, to understand the underlying relationships between milk composition and fitness traits, we will review the phenotypic association of fertility and health with milk components that can be predicted by MIR spectrometry. The focus will be on MIR-predicted phenotypes that are related to (1) negative postpartum EB, and (2) the inflammatory response of the cow to an udder infection. Second, we will examine the genetic associations of MIR-predicted phenotypes with fertility, mastitis, and other disease traits based on the recent literature and also on a study investigating the genetic correlations between clinical mastitis and several MIR-predicted traits by using data from 7,033 Walloon Holstein cows. Finally, we will discuss the inclusion of MIR-predicted indicator traits in broader breeding programs.

CHANGES IN THE BIOCHEMICAL PROFILE OF MILK IN RELATION TO FERTILITY AND HEALTH

Postpartum Changes in Milk Composition

Typically, high-yielding cows experience a period of negative EB in early lactation when nutrient requirements for growth, activity, maintenance, and lactation exceed the energy intake of the animal. In response to the energy deficit, the cow mobilizes tissue reserves. The duration and the magnitude of the postpartum negative EB are critical for productivity, health status, and fertility. Severe and long negative EB is related to lower fertility in dairy cows through effects exerted both early in lactation and later during the breeding period (Butler, 2003). Additionally, any physiological imbalance of the cow might reduce tolerance or resistance of the cow to the infection. Hence, cows that experience severe postpartum negative EB are at higher risk of health disorders (Collard et al., 2000). In particular, severe negative EB has been related to an impairment of udder defense mechanisms (Suriyasathaporn et al., 2000).

Previous studies reported that the biochemical profile of milk in early lactation is affected by the postpartum EB status of the cow (e.g., de Vries and Veerkamp, 2000; Reist et al., 2002). Hence, changes in milk composition due to negative EB could be associated with reproductive performance (i.e., the ability of the cow to conceive and to maintain pregnancy) and health. Only milk components that are (potentially) predicted by MIR spectrometry are examined in this paper.

Fat, Protein, and Fat:Protein Ratio. During energy balance in early lactation, mobilization of body fat reserves results in an elevated fat percentage in milk (de Vries and Veerkamp, 2000; Reist et al., 2002). Moreover, a decrease in fat percentage over the first 15 wk of lactation was significantly correlated with the extent and the duration of the postpartum negative EB (de Vries and Veerkamp, 2000). In addition, a lower protein percentage is expected in early lactation because of inadequate energy intake (Negussie et al., 2013). Consequently, a high fat:protein ratio (**FPR**) in early lactation has been related to more severe energy balance (de Vries and Veerkamp, 2000; Reist et al., 2002; Buttchereit et al., 2011). These patterns were confirmed over a range of studies (Table 1) indicating that poor fertility performances were associated with elevated fat content and low protein content in early lactation, and therefore to high FPR. Moreover, Heuer et al. (1999) indicated that cows with an FPR >1.5 at the first test-day were at higher risk for mastitis, ketosis, and other postpartum disorders. Finally, it should be noted that other studies reported associations of limited magnitude between fertility and fat content (Reksen et al., 2002; Podpecan et al., 2008; Madouasse et al., 2010; Martin et al., 2015), protein content (de Vries and Veerkamp, 2000; Reksen et al., 2002; Demeter et al., 2010; Martin et al., 2015), or FPR (Reksen et al., 2002; Madouasse et al., 2010; Martin et al., 2015).

Fatty Acids. Altered activities in the 2 major pathways for the production of milk fatty acids are expected when cows experience negative EB (Palmquist et al., 1993; Gross et al., 2011). The 2 major pathways for production of milk fatty acids are (1) de novo synthesis of fatty acids in the mammary gland, and (2) excretion