Australian milk fat—Seasonal and regional variation of melting properties

Cornelis Versteeg,* Amy Logan,^{*1} and Warren Müller†

*CSIRO Food and Nutrition, 671 Sneydes Road, Werribee, Victoria, Australia, 3030

†CSIRO Digital Productivity, GPO Box 664, Canberra, ACT, Australia 2601

ABSTRACT

The solid fat content and dropping point of milk fat obtained over 2 yr and from 19 bulk milk production sites across Australia were characterized. Solid fat content at 5°C and 20°C, respectively, ranged between 49.9 and 66.1% and between 14.6 and 29.6% across all sites. Dropping point ranged between 30.5 and 35.4°C. The dropping point did not correlate with solid fat content at lower temperatures across several sites, indicating that it is not an accurate or useful measure of functionality at temperatures of 15°C or below. Although at times, considerable variation was observed in milk fat melting properties between sites located in similar geographic regions, statistical analysis by means of boxplots and multidimensional scaling revealed broad similarities within regions over the 24 mo. Multidimensional scaling also revealed similarities between some quite distant and diverse regions (e.g., Queensland and South Australia with constant and seasonal production, respectively). These analyses were used to make 5 groups from the 19 sites to describe seasonal melting properties. The groups with sites in west Victoria, southeast Victoria, and Tasmania showed the largest seasonal variation and range of values, with peaks and lows in southeast Victoria and Tasmania occurring up to 3 mo later than in west Victoria. The group with sites in New South Wales, Queensland, and South Australia had the least variation and range of values, which were relatively high throughout. The group with Western Australian sites showed medium levels of variation but distinct seasonal patterns, with solids fats typically below and dropping points higher than the national average. The Victorian group's lows in dropping point occurred about 2 mo later than did the low values of solid fat content. No single factor stood out as determining the variation in melting properties.

Key words: milk fat, melting properties, solid fat content, dropping point

INTRODUCTION

Considerable regional variation occurs from country to country, or regions thereof, in milk composition and functionality with diet, stage of lactation (Kefford et al., 1995), and season (Johnson, 1965; Precht, 1994). This includes the melting properties of milk fat based on the solid fat content (Cox and McDowall, 1948; Norris et al., 1973; Auldist et al., 1998; Walker et al., 2013). Melting properties are an important characteristic of milk fat for processors and consumers alike, as they affect properties such as butter spreadability (Norris et al., 1973), oiling off (Cullinane et al., 1984) and “stand up” (i.e., the relative change in height of a plug of butter) in hot climates (Banks et al., 1983); suitability of milk fat for pastry and other baked products (Deffense, 1993); the whipping properties of cream (Smith et al., 2000); foam stability (Bazmi et al., 2007; Huppertz, 2010); oxidative stability (Hillbrick and Augustin, 2002); and the suitability of milk fat for further processing such as blending and fractionation (Deffense, 1993; Shen et al., 2001).

Milk fat has a large melting temperature range of about −40 to 40°C (Kankare and Antila, 1988; Lopez et al., 2007) and contains both liquid and solid fat fractions under refrigerated storage conditions. Using differential scanning calorimetry (DSC), Kankare and Antila (1988) noted 84.1% of milk fat to be in a solid state at 0°C. This decreased to 64.8% at 10°C and the fat was completely melted at 38°C. As such, milk fat exhibits melting over a wide temperature range rather than the sharp melting point of pure substances (Deman et al., 1983) or the narrow range exhibited by some other edible fats, such as hardened coconut oil (Kaisersberger, 1989). Measures for melting and solidification points quantify the end and starting points of this range to some level of certainty (McCarthy, 2006). Common methods of analysis for solid fat content (SFC) and the melting properties of a sample as a function of temperature include low-field nuclear magnetic resonance (NMR; Knightbridge and Black, 1978; Auldist et al., 1998), DSC (Kankare and Antila, 1988), near-infrared (NIR) spectroscopy (Meagher et al., 2007), and ultrasound velocity (McClements and

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¹Corresponding author: amy.logan@csiro.au

Povey, 1987). Analysis using NMR and NIR can quantitatively determine the proportion of solid to liquid milk fat at a given temperature, whereas DSC and ultrasound techniques provide information about the melting profile of a sample over a temperature range. All measures, however, can be influenced by tempering or temperature cycling (Boode et al., 1991) and it is essential that samples be completely melted before analysis (usually to 60–70°C) to remove the thermal history, and cooled under standardized conditions. The solid fat content measured by NMR and that derived from DSC measurements can be quite different (Walker and Bosin, 1971), which must be kept in mind when comparing literature values.

A study investigating the thermal properties of milk fat in New Zealand found that the degree of fat in a liquid state was higher in July (mid-winter) compared with October and November (mid- to late-spring), so that SFC increased as the first half of the milking season progressed. The amount of SFC was then observed to decrease into autumn, although not returning to the original July value (Norris et al., 1973). This agrees with Auldist et al. (1998), and as such, maximum hardness in New Zealand butter occurs in mid-summer, whereas the softest butters are made in the spring (Cox and McDowall, 1948; Dolby, 1949; MacGibbon and McLennan, 1987). A study measuring butter firmness and milk fat SFC from factories in the southeast (Gippsland), southwest, and northern regions of Victoria in Australia showed a significant difference in SFC based on region at 5 and 15°C, but not at 25°C (Knightbridge and Black, 1978). This was similar to the observations of Meagher et al. (2007) in New Zealand butter for SFC between 10 and 20°C. Knightbridge and Black (1978) found higher levels of SFC from samples collected in the southwest region compared with the other Victorian locations between December and March (summer). Moreover, the SFC of milk fat from both southwest and southeast Victoria progressively decreased from March onward but remained constantly high between December and May in samples from the northern region. All regions recorded low SFC levels during the winter period.

Following the work of Knightbridge and Black (1978), a 2-yr Australian-wide survey was conducted in 1994 and 1995. In that study, milk fat properties were determined each month from 19 bulk collection or processing sites in broadly 8 geographic regions spread across Australia. A small part of the data was previously published with limited interpretation (Papalois et al., 1996; Thomas and Rowney, 1996). Considering the richness of the data set, we believe that it is important to further analyze, interpret, and publish the results of this reference work in much more detail. This survey is

unique as it covered 2 complete consecutive years and a large number of geographical, climatic, and production system differences within Australia. This work will provide benchmarks for any changes in milk fat properties that may be found in future studies. Furthermore, the confidentiality on the locations of the participating sites has been lifted, allowing a more meaningful interpretation and reporting of the results than was possible at the time of the survey.

In this examination, the geographical, climate, and some farming practices of the surveyed production regions will be detailed. Low-field NMR analysis was used to define the SFC of milk fat extracted from the collected milks and products at 0, 5, 10, 15, 20, 25, 30, and 35°C. Further, the milk fat Mettler dropping point (DP) was measured, which determines the temperature at which the first drop of milk fat is detected upon heating from a chilled start-point (Timms, 1978). The fatty acid compositions and triglycerides will be presented, together with any correlations between properties and composition, in subsequent publications.

MATERIALS AND METHODS

Sample Sites

Nineteen bulk milk collection sites were surveyed (most of these were also dairy product manufacturing factories). These were located in New South Wales (1 site at the central coast), Queensland (2 sites in the southeast), South Australia (1 site in the southeast), Tasmania (3 sites in the north of the island), Victoria (3 sites in the southwest, 3 sites in the north, and 3 sites in the southeast, or “Gippsland”), and Western Australia (3 sites in the southwest). A single herd research farm in Ellinbank, eastern Victoria, also took part in the survey. Figure 1 shows the geographic location of the participating sites. Seasonal milk production data were made available by several of the participating sites, and weather data and typical farming data were collected where possible. Tables 1 and 2 list the participants and detailed locations of the sites.

Sample Collection and Preparation

Whole milk, cream, butter, or anhydrous milk fat (AMF) samples were collected at 2 different times of 2 consecutive days in the middle of the month and sent refrigerated overnight to the laboratory. Samples were frozen until further processing within a month. The same type of product sample was collected from each location for the duration of the survey and AMF prepared accordingly with the remaining steps required;

Figure 1. Locations of regions and milk collection sites (1 to 20) for the milk fat survey. ©Commonwealth of Australia (Geoscience Australia) 2016. This product is released under the Creative Commons Attribution 4.0 International Licence. <http://creativecommons.org/licenses/by/4.0/legalcode>.

for example, cream was skimmed by centrifuging for whole milk samples. Refrigerated cream was churned into butter by vigorous shaking in glass flasks. Butter was melted and centrifuged ($1,500 \times g$, 70°C , 5 min), to separate the AMF and serum into layers. The top AMF layer was collected and the AMF sealed in amber glass ampoules under nitrogen and stored in the dark at -18°C until further analyses. The physical properties of all samples were analyzed within 2 mo after sample receipt.

SFC Analyses

For SFC measurements, the fats were melted, 1.8 mL was transferred to NMR tubes (18 cm tall, 1 cm diameter), and held for 45 min in an oven or for 30 min in a water bath at 60°C , and then placed in an ice-water bath for 90 min. Using a daily calibrated Minispec PC120 Nuclear Magnetic Resonance instrument (Bruker, Preston, Australia), with standards of 0, 31.5, and 73.0%, SFC were measured starting at 0°C and sequentially at 7 further increments of 5°C after a

30-min incubation each time in a water bath until the fat was completely melted at 40°C .

Dropping Point

The DP was determined as described in Timms (1978) using a Mettler FP83 dropping-point cell with a FP80HT central processor (Mettler Toledo, Port Melbourne, Australia). The milk fat was melted at 70°C and aliquots transferred into chilled ME-18732 sample cups (Mettler Toledo) and tempered at -18°C in the freezer for 1 h before being transferred to the dropping point cell and measurement. From a starting temperature of 25°C , the sample is held for 30 s before a heating rate at $1^{\circ}\text{C}/\text{min}$ is applied. The temperature at which the milk fat becomes liquid and drops past a sensor is recorded by the instrument.

Statistical Methods

All statistical analyses were conducted using GenStat (GenStat, 2013). Box plots were prepared for the 8 SFC

Table 1. Description of milk collection and processing sites and associated farming practices

Site	State and location	Herd	Typical calving and production	Milk flow ¹	Pasture type	Pasture available and growth	Irrigation practices	Supplement practices
1	New South Wales, central coast Gloucester	Mainly Friesian/Holstein; some Jersey and Guernsey	Evenly distributed	78%	Rye grass Apr–Nov; kikuyu Nov–May; oats Apr–Jun; some sorghum and millet	Availability and active growth varied during and between years	Limited use all year but not all farms can irrigate	Pasture or maize silage, pasture hay, lucerne hay, barley and wheat all year; pellets May–Nov; some lupin, cottonseed, or dairy meal
2	Queensland, southeast Nambour	—	Evenly distributed	80%	Kikuyu, rye grass, and clover (data incomplete)	—	General use (data incomplete)	Used all year; variety of pellets, lucerne, molasses, silage, and barley (data incomplete)
3	Queensland, southeast Monto	Friesian/Holstein 83%, Jersey 5%, Guernsey 7%, Ayrshire 3%, other 2%	Some seasonality; maximum Sep, minimum May–Jul	50%; first year of survey	Rye grass and clover May–Nov; lucerne all year except Jun–Jul; sorghum Jan–Apr; some kikuyu	Sufficient to plenty most of year; active growth all year	General use all year	Maize or pasture silage used all year; lucerne hay, cottonseed, and barley used all year; intermittent sorghum, molasses, and palm kernel
4	South Australia, southeast Murray Bridge	Friesian/Holstein 80%, Jersey 10%, other 10%	Seasonal winter (and some split?) calving; milk Oct maximum, April/May minimum	17%	Lucerne all year; clover all year except Dec; rye Apr–Oct; kikuyu Nov–Mar	Plenty Aug–May; short Jun–Jul; active growth all year	Mainly not used (former swamp) but used in higher pastures	Barley, pellets, and lupin used all year; extra pasture hay Apr–Sep
5	Tasmania, north (about 30 km inland) Devonport	Friesian/Holstein 60%, Jersey 10%, Guernsey 1%, mixes 25%, red breeds 4%	Seasonal spring calving; milk Nov maximum, Jul/Aug minimum	9%	Perennial rye and “weeds” all year; turnips and cocksfoot Jan–Apr; clover Aug–Nov	Both varied greatly during survey period, growth all year	Used Oct–Apr; mainly Nov–Feb, not May–Sep	Generally used Jun–Nov; variety of hay, pasture and maize silage, barley and pellets
6	Tasmania, north Legerwood	Friesian/Holstein 70%, Jersey 15%, mixes 15%	Strong seasonal; spring calving; milk Nov maximum, Jul/Aug minimum	9%	Perennial rye and “weeds” all year; clover Sep–Jan, turnips Jan–Mar and Jun–Aug, Cocksfoot Oct–May, oats Jul–Aug	Short May–Aug; sufficient to plenty other months; active growth all year	General use Oct–Apr; not in other months	Barley year round; pellets most of year except Nov–Dec; silage Feb–Aug; hay May–Jul
7	Tasmania, north Wynyard	Friesian/Holstein 10%, Jersey 2%, mixes 88%	Seasonal spring calving; milk Nov maximum, Jul/Aug minimum	9%	Perennial rye and “weeds” all year; clover Sep–Nov, turnips Jan–Mar and Jun–Aug; cocksfoot Nov–May	Sufficient Oct–Dec; short in other months; senescence Jun–Aug	Some used Oct–Apr; not in other months	Hay Feb–Aug except May–Jun; all other months, barley, pellets, and silage Jan–Mar and Jul. During May–Jun, only extra feed is hay.
8	Victoria, west Koroff	—	Seasonal winter (and some split?) calving; milk Oct maximum and April/May minimum	17%	Rye and clover except from Feb–Mar; rape and turnips Jan–Mar; oats Jun–Jul	Sufficient to plenty Apr–Jun and Sep–Nov; senescence Jan–Mar	Some used only Dec–Mar; not at all in other months	Barley, wheat, and pellets used all year; pasture silage, hay, and oats from Jan–Aug
9	Victoria, west Allansford	—	Seasonal winter (and some split?) calving; milk Oct maximum and April/May minimum	17%	—	—	—	—

Continued

Table 1 (Continued). Description of milk collection and processing sites and associated farming practices

Site	State and location	Herd	Typical calving and production	Milk flow ¹	Pasture type	Pasture available and growth	Irrigation practices	Supplement practices
10	Victoria, west Simpson	Friesian 90%, Jersey 9%, Guernsey 1%	Seasonal winter and some split calving; milk Oct maximum and April/May minimum Seasonal	17%	Rye and clovers all year, plus turnips Jan-Mar	Sufficient to plenty Apr-Dec; low Jan-Mar	Not used, except Feb-Mar	Used all year; barley and oats consistently; pasture and maize silage, wheat, pasture hay, and pellets intermittently (no repeated seasonal patterns)
11	Victoria, north Rochester	Friesian/Holstein and mix 70%, Jersey and mix 30%	Seasonal Seasonal	—	Rye and clover all year; oats Jul-Sep; paspalum and millet Dec-Feb	Sufficient to plenty Sep-Jan; short Feb-Aug; active all year except senescence in Jan	Used all year, except May-July	Pasture and maize silage, barley, wheat, pasture, and lucerne hay; pellets used all year; oats Jan-Jun
12	Victoria, north Cobram	Friesian/Holstein 75%, Jersey 20%, other 5%	Seasonal winter and some split calving; milk Oct/Nov maximum and Jul minimum Seasonal	18%	Rye and clover year round; paspalum Jan-Feb	Sufficient to plenty Sep-Feb; short Mar-Aug; senescence Jun-Aug	Used all year	Used but little Nov-Dec; barley all year; hay Apr-Aug
13	Victoria, north Kiewa	—	—	—	—	—	—	—
14	Victoria, east Maffra	60% Friesian, 20% Friesian mix, 10% Jersey, and 10% Jersey mix	Seasonal mainly winter calving; milk Oct/Nov maximum and Jul minimum Seasonal	10%	Clover and paspalum year round	Plenty Oct-Feb; short Mar-Sep; active growth all year	Used Aug-Apr; not May-Jul	Used year round; barley, wheat, and pellets plus hay Apr-Jun
15	Victoria, east Drouin	Friesian, some Jersey, and Jersey/Friesian/Ayrshire	Seasonal Seasonal	—	Rye and clover	—	Not used	Apr-Sep barley, oats, wheat, and pellets as well as silage and hay
16	Victoria, east Ellinbank (single farm)	—	Seasonal, single herd, most cows dry July	<5%,	Rye and white clover all year; cocksfoot Jan-Apr; turnips Feb-Mar	Short supply most of the time	Not used	Year-round barley; extra silage Jan-Apr
17	Victoria, east Leongatha	90% Friesian/10% Jersey	Seasonal	—	—	—	—	—
18	Western Australia, southwest, Margaret River	97% Friesian/Holstein, 2% Jersey, 1% Guernsey	Seasonal; lowest production Nov-Mar	—	Rye and clover Jun-Nov; kikuyu Dec-May	Plenty Jul-Nov; short supply and senescence Dec-Jun	Not used	Year-round barley, lupin, and pellets; extra hay Jan-Jul; extra silage and wheat Jan-Apr
19	Western Australia, southwest, Harvey	98% Friesian/Holstein, 2% Jersey	Seasonal; lowest production Nov-Mar	—	Rye and clover May-Nov; kikuyu and paspalum Oct-Jun	Plenty Oct-Mar; short Apr-Sep; active growth all year	General use Nov-May; not in other months	Year-round barley, lupin, and pellets; extra hay Jan-Jun; silage Mar-May; oats Aug-Sep; and wheat Jan-Mar
20	Western Australia, southwest, Bently	96% Friesian/Holstein, 4% Jersey	Seasonal; lowest production Nov-Mar	—	Rye and clover Jun-Dec; kikuyu Jan-May	Plenty Jun-Oct; short supply and senescence Nov-May	Not used	Year-round with barley, hay, lupin, and pellets; extra pasture silage and wheat Jan-Apr

¹Relative range (minimum as percent of maximum) of monthly variation in milk flow over 24 mo.

measurements and DP to represent the variability of each measurement over the 24 mo, and relationships between the measurements were examined by calculating all pair-wise correlations and testing their significances (Fisher and Yates, 1963). Samples were unavailable from some sites for some months (12.1% of all site × year × month combinations) so a nonorthogonal linear mixed model (LMM) analysis was performed on data available for each site using REML (Patterson and Thompson, 1971; Robinson, 1987). From the LMM analyses, an estimate for each site of variability within months was obtained. As the 2 to 4 replicate samples were taken sequentially at different times on the same or next day in the middle of the month, these estimates represented the sampling variation of the solid fat measurements. Bartlett’s tests of homogeneity of variation (Bartlett, 1937) were performed for each variable across the 20 sites to determine whether all measurements could be combined into a single statistical analysis.

The single herd research farm in Ellinbank, east Victoria, was excluded from further analyses because of its atypical characteristics and responses. To determine similarity between the remaining 19 sites in SFC and DP over the 2 yr, multidimensional scaling (Cox and Cox, 2010) was done on the variables. The similarity matrix was calculated in each case using the “city block” metric (Digby and Kempton, 1987; Gordon, 1999), which for each pair of sites calculates the absolute difference between their values for the 24 mo and calculates the mean of these differences. This metric was preferred as it does not give undue weight to outlying values, and months with missing values are ignored, providing a good estimate of the “distances” between responses over 24 mo. Metric and nonmetric multidimensional scaling were performed at both 2 and 3 dimensions. Examination of stress calculated from the scaling showed that nonmetric scaling in 3 dimensions performed best, with lower stress values than the other combinations for most variables, and it was used to examine groupings of the 19 sites.

RESULTS AND DISCUSSION

As it was not feasible to report the details of seasonal variation of melting properties at all temperatures, we focused on 3 melting properties for presentation and discussion. This was supported by the high correlation between most melting properties at most sites. Selected were SFC (%) at 5°C, representing properties at refrigerator temperatures; SFC (%) at 20°C, representing properties at ambient temperatures; and DP (°C), representing the melting temperature of the milk fats. The complete dataset for all SFC results across all temperatures is provided as supplementary data to support

Table 2. Site weather summary [annual (Year) and quarterly (Q1 to Q4) averages of 1994 and 1995] over the 2 yr of the survey

Site	State and location	Average maximum temperature (°C)				Average minimum temperature (°C)				Rainfall (mm)						
		Year	Q1	Q2	Q3	Q4	Year	Q1	Q2	Q3	Q4	Year	Q1	Q2	Q3	Q4
1	New South Wales, coast	25.3	28.7	22.9	21.9	27.7	12.1	17.4	9.7	6.4	14.7	956	448	157	86	265
2	Queensland, southeast	26.1	28.8	23.8	23.0	28.8	13.9	19.3	12.1	8.2	15.9	1,417	757	272	81	308
3	Queensland, southeast	27.9	31.4	24.9	24.1	31.4	11.4	17.8	8.1	4.6	15.3	570	277	61	27	204
4	South Australia, southeast	22.6	27.6	19.6	18.1	25.1	9.4	12.8	8.2	5.7	10.6	289	38	104	69	78
5	Tasmania, north	16.4	20.3	14.9	12.8	17.6	7.5	11.3	6.4	4.0	8.1	616	104	211	171	130
6	Tasmania, north	16.9	21.7	14.8	12.5	18.8	6.8	10.5	5.9	3.5	7.3	801	167	290	195	149
7	Tasmania, north	16.4	20.4	14.8	12.9	17.6	6.6	10.6	5.3	3.2	7.2	888	116	300	292	180
8	Victoria, west	17.5	22.3	15.6	13.7	18.5	8.0	11.2	7.3	5.4	8.2	805	106	267	275	157
9	Victoria, west	17.5	22.3	15.6	13.7	18.5	8.0	11.2	7.3	5.4	8.2	805	106	267	275	157
10	Victoria, west	17.1	23.0	14.5	12.5	18.4	7.8	11.3	7.1	5.0	8.1	1,010	138	304	348	220
11	Victoria, north	21.8	28.6	17.7	15.4	25.6	8.4	13.9	6.4	3.2	9.9	349	81	126	82	59
12	Victoria, north	22.0	28.8	17.9	15.6	25.8	8.9	14.1	6.6	3.5	11.3	505	152	128	111	113
13	Victoria, north	21.6	28.4	17.6	15.0	25.2	8.2	13.7	5.5	2.9	10.8	681	161	194	169	159
14	Victoria, east	19.3	24.1	17.0	15.4	20.9	8.2	12.6	6.6	4.2	9.6	656	197	140	91	228
15	Victoria, east	19.1	24.5	16.5	14.8	20.8	7.8	12.0	6.2	4.2	9.0	872	190	219	209	255
16	Victoria, east	18.0	23.6	15.4	13.6	19.5	8.3	12.2	7.2	4.9	9.0	1,060	184	289	306	281
17	Victoria, east	17.9	23.0	16.8	14.5	18.1	9.2	12.7	8.8	6.3	9.4	1,124	207	354	302	262
18	Western Australia, southwest	21.7	26.3	20.4	17.8	22.5	13.3	15.9	13.0	11.0	13.1	767	12	340	342	74
19	Western Australia, southwest	23.7	30.3	21.3	18.1	25.1	11.7	15.5	10.7	8.9	11.8	819	13	315	415	76
20	Western Australia, southwest	25.0	31.6	22.4	19.5	26.3	13.2	17.8	11.3	9.6	13.9	701	19	256	350	76

the findings in this paper and for further examination if desired (<http://dx.doi.org/10.3168/jds.2015-10146>).

Characterization of Participating Sites

The locations of participating sites are indicated in Figure 1, and further details and associated farming, milk production, and climate data are summarized in Tables 1 and 2. The quarters in Table 2 approximate the official Australian seasons, which start 1 mo earlier; for example, summer is from December 1 to February 28. Sites range from the subtropics in Queensland to cold climates in Tasmania.

Rainfall

Annual rainfall varied from less than 400 mm/yr in South Australia and 1 site in northern Victoria to more than 1,000 mm/yr in 1 of the Queensland sites and some of the Victorian sites. In New South Wales and Queensland, the highest rainfalls were in the first and last quarters of the year, whereas in Western Australia, there was virtually no rainfall in the first quarter, and most rain (more than 85%) fell in the second and third quarters. All other sites had more evenly distributed rainfall in all quarters.

Temperatures

Daily minimum temperatures in the third quarter (~winter) averaged about 3°C in northern Victoria and Tasmania to about 8 to 11°C in parts of Queensland and Western Australia. Daily average maximum temperatures were highest in the first quarter (~summer) for all sites, except for the sites in New South Wales and Queensland, in which temperatures were about equal to those in the fourth quarter (~spring). The first-quarter average maximum temperatures varied from about 20°C in Tasmania to over 28°C in New South Wales, Queensland, northern Victoria, and 1 site in Western Australia.

Breeds

It is important to note that many sites collected milk from large areas, which could be more than 200 km away from the collection point, sometimes overlapping with the intake areas of other sites involved in this study. Friesian/Holstein breeds dominated in all districts, accounting, on average, for 60 to 90% of all animals, with the exception of site 7 in Tasmania, which had 88% “mixed breeds,” and in Western Australia, where

the Friesian/Holstein breed contributed to about 96% or more of all animals. Pure Jersey (10% or more of the herd) were found in South Australia, 2 of the sites in Tasmania, and 1 site in Northern Victoria. There were very small proportions of other breeds such as Guernsey, Ayrshire, and “red breeds” in some districts.

Seasonality of Milk Production

The New South Wales and Queensland sites had relatively stable year-round production systems with split and continuous calving, resulting in a continuous milk supply. The South Australia site and all Victorian and Tasmanian sites had strong seasonal production and associated seasonal calving patterns, with peak production in spring and early summer. All Western Australia sites also had seasonal production with milk volume peaks in winter and early spring and low production from November to March (the opposite production seasons of South Australia, Victoria, and Tasmania). Typically, cows were not housed across the season in any of the regions.

Pasture

Pasture types varied strongly by region and season. In several of the warmer regions, Kikuyu grass was an important feed for 4 to 6 mo between November and May of each year, as was reported for sites in New South Wales, Queensland, South Australia, and Western Australia. In most areas, rye grass and clover contributed significantly to the pasture feed for at least part, and often all, of the year. In South Australia and Victoria, clover was available virtually all year, whereas in Queensland, Tasmania, and Western Australia, clover was mainly available in winter and spring. Rye grass was available almost all year in Tasmania, in all districts in Victoria, and seasonally in New South Wales, Queensland, South Australia, and Western Australia, typically from late autumn (April/May) to the end of spring (November/December). One site in Queensland and the South Australia site stood out with year-round availability of lucerne pastures. Pasture availability varied greatly by region, typically being short from mid-summer to mid-winter in Tasmania and in most northern and eastern Victorian sites.

As may be expected from the rainfall patterns, Western Australia generally had the best pasture supplies in winter and spring but were short in summer and autumn. Pasture availability in western Victoria was low in summer (December to March) but generally good in the other seasons.

Table 3. Within-month variance and CV for solid fat content (SFC; %) at 5°C and 20°C and dropping point (°C) for the 20 sites

Site	SFC at 5°C		SFC at 20°C		Dropping point	
	Variance	CV (%)	Variance	CV (%)	Variance	CV (%)
1	0.463	1.16	0.274	2.60	0.053	0.70
2	0.199	0.77	0.128	1.81	0.068	0.78
3	0.509	1.23	0.488	3.45	0.137	1.09
4	0.499	1.21	0.373	3.05	0.075	0.83
5	0.126	0.60	0.074	1.36	0.038	0.59
6	0.872	1.62	0.097	1.65	0.057	0.73
7	0.630	1.34	0.165	2.02	0.063	0.76
8	0.442	1.14	0.413	3.12	0.102	0.97
9	0.285	0.90	0.287	2.55	0.060	0.73
10	0.538	1.28	0.348	3.05	0.073	0.82
11	0.772	1.47	0.916	4.60	0.178	1.28
12	0.292	0.91	0.433	3.15	0.119	1.04
13	0.490	1.20	0.236	2.39	0.074	0.82
14	0.376	1.08	0.334	3.13	0.122	1.08
15	1.575	2.18	1.262	5.74	0.169	1.24
16	4.083	3.28	3.433	7.60	0.153	1.16
17	0.306	0.97	0.156	2.03	0.033	0.55
18	0.404	1.13	0.213	2.46	0.074	0.82
19	0.210	0.80	0.247	2.53	0.093	0.91
20	0.987	1.80	0.450	3.51	0.169	1.21

Irrigation

Irrigation was used virtually all year by most farms in New South Wales, Queensland, and northern Victoria, more seasonally in summer in Tasmania and western Victoria, and in winter in 1 district in Western Australia. Typically, no irrigation was used in regions of South Australia and the other 2 sites in Western Australia

Supplements

Supplementary feeds were used in all districts; the most consistent year-round supplements were used in New South Wales, Queensland, South Australia, and Western Australia. Barley and pellets featured as a supplementary feed in nearly all districts, for at least some part of the year. Other than that, there was a great variety in supplementary feeds, depending on the district or season, with oats, wheat, pasture, and maize silage, and pasture and lucerne hay featuring prominently. Cottonseed, sorghum, molasses, and palm kernels were used in only a few regions, and lupin was commonly used in Western Australia.

Farming Practices

From this overview, it is clear that a large diversity of farming practices and climates were represented in the survey. Significant climatic and farming practice differences may also occur in sites relatively close to each other; for example, rainfall in Queensland (sites 2

and 3) and northern Victoria (sites 11 and 13). Farming practices have changed since 1995, particularly in South Australia and Victoria, with less seasonal milk production occurring. In the 2014–2015 season, the average low (relative to peak) milk production volume for South Australia was about 75% and for all regions combined in Victoria, it was about 55% (Dairy Industry in Focus, 2015) compared with <20% for both at the time of the survey (Table 1). This increase in off-peak production was achieved by changed calving patterns from seasonal to split and extended calving and often, but not always, by more intensive feeding systems that rely less on pasture (Hauser and Lane, 2013). Tasmania still had a strong seasonal milk production with a low of about 25% of the peak (Dairy Industry in Focus, 2015).

Variability Between Duplicates

Variability between duplicate measurements (from 2 to 4 separate samples taken sequentially at different times on same or next day) within months was estimated from the separate LMM analyses performed for measurements at each site. Within-month variances for SFC at 5°C and 20°C and DP are presented in Table 3. We found substantial differences in within-month variance between sites for SFC at all temperatures and for DP, with all Bartlett's tests being highly significant ($P < 0.001$). Site 16 showed much higher variability than the other sites from 0°C to 30°C, and was at the high end of the variances for DP. Some other sites showed

consistently higher variability (e.g., 11 and 15) or lower variability (e.g., 2 and 5), whereas relative variability in some sites changed as temperature increased (e.g., 3 and 6). This wide range of variability across sites meant that a single statistical analysis for each variable across all sites could not be performed due to violation of the assumption of homogeneity of variation. Therefore, comparisons between sites or across time within sites were made using standard errors derived from the separate LMM analyses for each site. Within-month coefficients of variation (CV) for DP and for SFC up to 15°C were typically around 1% and well below 5% for all sites (results for 5°C and DP in Table 3). For SFC at 20, 25, and 30°C, the CV were below 10% for all sites; however, those for 35°C were much higher and ranged

between 22 and 67% due to the very low SFC (0–2.4%), at that temperature (results for 20°C in Table 3, other results not shown). Hence, determination of SFC at 35°C could be regarded as unreliable. We detected no apparent association between levels of variability and regions from which milk samples were obtained (Tables 1 and 3). For example, Queensland sites 2 and 3 showed substantial differences in variability.

Melting Properties

The previous report by Papalois et al. (1996) examined these samples based on just 2 groupings; all of Australia (i.e., all sites combined) and Victoria (i.e., sites 8–17 combined). They found that both SFC and DP

Figure 2. Box plots of (A) solid fat at 5°C, (B) solid fat at 20°C, (C) dropping point (°C) of all samples from each site, with median, interquartile range, which contains 50% of the values, whiskers covering values up to 1.5× interquartile range, and outliers (×); and (D) solid fat at 5°C and 20°C, and dropping point, for all samples from sites grouped into 5 regions (A to E), and from all sites except site 16 (All).

Figure 3. Melting curves of individual samples selected to represent the range of solid fat content (SFC) values. Site numbers for the samples are given in the caption. Lowest S0 = sample with lowest SFC at 0°C; highest S0 and S20 = sample with highest SFC at both 0°C and 20°C; lowest S20 = sample with lowest SFC at 20°C; largest range = highest and lowest samples from the site with the largest SFC range at 0°C.

were similar across geographical region combinations, with milk fat being hardest in the summer months and softest across the winter. Similarly, peaks in DP were observed in the summer to autumn months, whereas troughs were recorded between winter and spring. Box plots for the current analysis of SFC at 5°C, SFC at 20°C, and DP of all individual sites are shown in Figure 2A, B, and C, respectively.

SFC

Although our range of SFC values is wider than reported in the cited studies, the SFC values reported herein were broadly consistent with those of Meagher et al. (2007) for New Zealand milk fat at 5°C and 20°C, and similar to those of Knightbridge and Black (1978) in the SFC of Victorian milk fat measured at 5°C. Similarities between some sites can be observed. Sites 1 to 4, which encompass sites in New South Wales, Queensland, and South Australia, had SFC over a narrow interquartile range at both temperatures and several outliers on the high side, ranging from about 55 to 62.5% solid fat at 5°C and 16°C to 24% solid fat at 20°C. Sites 18 to 20 in Western Australia also had narrow interquartile ranges, but with outliers mainly on

the low side, and values ranging from about 50 to 60% solid fat at 5°C, and from 15 to 24% at 20°C. All other sites had much wider interquartile and extreme value ranges, with virtually no outliers. Site 16 in eastern Victoria, the single-herd research farm in Ellinbank, stood out, with a wide range in SFC and the highest median values at both temperatures (60.8 and 23.2%, respectively). Although beyond the scope and purpose of this survey, the exceptional results of this 200-head herd in eastern Victoria show that any desirable milk fat melting properties could be supplied in bulk to manufacturers if the right incentives were given to the relevant farms in the region.

Of the bulk milk collection sites, the highest SFC values at 5°C were 66.1% for site 11 in northern Victoria and 65.2% for site 5 in Tasmania. The site with the lowest median SFC at 5°C was site 20 in Western Australia (55.4%), which also had the lowest measured value of the survey at 5°C of 49.9% SFC. Site 11 also had the sample with the highest SFC at 20°C of 29.6%, followed by site 9 in western Victoria with 28.5% SFC. The lowest value was found at site 14, in eastern Victoria, with 14.6%. The lowest median values at 20°C were recorded on eastern Victorian sites on sites 14 and 17. Stage of lactation and seasonal variation have also been

shown to influence SFC at 10°C in cows throughout a year (Auld et al., 1998). Although stages of lactations were not captured directly in this survey, milk production data provide a strong indicator of calving patterns. Sites 1 and 2 had very stable milk production systems and site 4 had very strong seasonal production. Nevertheless, the range and median SFC of these 3 sites were very similar.

To better indicate the wide range of different melting curves at the bulk milk sites, a selection of SFC at all measuring temperatures is presented in Figure 3. Shown are samples from July 1994 at site 20 (Western Australia), which had the lowest measured SFC of any sample at 0°C; September 1995 of site 12 (northern Victoria), which had the lowest SFC of any site at 20°C; March 1995 of site 11 (northern Victoria), which had

Figure 4. Correlations between solid fat content (SFC) at 0°C (S0), 10°C (S10), 20°C (S20), 30°C (S30), 35°C (S35), and dropping point (DP) for all samples (A) from all sites over 2 yr ($n = 1,397$) and (B) from site 1 over 2 yr ($N = 94$).

Figure 5. Nonlinear multidimensional scaling of solid fat at 5°C, with site numbers and selected groupings (A to E) of similar sites in all 3 dimensions.

the highest SFC at both 0°C and 20°C and 2 curves of site 5 (Tasmania), which had the widest range of SFC at 0°C of any bulk milk site; December 1994 with the highest curve; and August 1995 with the lowest curve for that site. The melting curves of some sites cross over: the SFC of site 12 are higher than those of sites 5 and 20 at 15°C and below that temperature but lower at 20°C and above.

DP

Dropping point values were in range of that in the literature for milk fat produced in Australia (Timms, 1978) and elsewhere (Deman et al., 1983). Similarities between sites were less clear for DP than for SFC. The highest readings were for site 3 in Queensland and site 20 in Western Australia of 35.4°C, which also had the highest median values of 34 and 34.1°C, respectively. Similarities between sites 1 to 4 and sites 18 to 20 are not as obvious as they were for the SFC at 5 and 20°C; however, as groups, these sites exhibited relatively high DP compared with most other sites. In contrast, sites 1 to 4 were about average and sites 18 to 20 were lower in SFC at 5 and 20°C than most other sites. The lowest DP were observed for sites 12 in northern Victoria (30.5°C) and 14 in eastern Victoria (30.6°C). Site 14 also had the lowest median DP of 32.5°C. Timms (1978) found that the dropping point method as used in our survey

gives similar results to the softening point, as measured by the ball-and-tube method (Barnicoat, 1944). The range and values of softening points measured by Cox and McDowall (1948) from 9 locations over 4 yr in New Zealand (30.6 to 34.6°C) were close to our results. Precht (1994) determined the DP from milk fat collected weekly from 4 German regions over a period of a year. The values (of about 200 samples) ranged from a low of 29.7°C and a high of 33.9°C, which, although about 1°C lower, reflect the range and values presented in the current work. This range was broadly discussed by Papalois et al. (1996), who reported a range across sites of 2.5 to 3.5°C in summer and 4°C in winter. Further, in an earlier Australian study, Parodi (1979) observed a range in softening point between 31.2 and 34.1°C over a 12-mo period (the study involving 37 samples from 2 Queensland sites, different from those reported herein).

Correlations

Correlations between melting properties (SFC between 0°C and 35°C at 5°C intervals and DP) were calculated for all sites combined and for each site individually. For all sites combined, the melting properties were all positively correlated and highly significant ($P < 0.001$), although the correlation coefficients for SFC decreased at greater temperature differences (Figure 4A). For example, the correlation coefficient between SFC at 0°C (S0) and 10°C (S10) was 0.969 and that between 0°C and 35°C (S35) was 0.412. Note that with the approximately 1,400 observations, a correlation coefficient of 0.07 is sufficient for significance at the 99% level (Fisher and Yates, 1963). For some individual sites, the correlations were less pronounced; nevertheless, correlations between SFC at 0°C and 35°C were still significant at the 99% level for all individual sites except for sites 1 and 19. To characterize melting properties at higher temperatures, the DP, as shown in the "Variability Between Duplicates" section, is a much more accurate analysis than SFC at 35°C and is typically between 30°C and 35°C. Although from different geographic regions, sites 5, 9, 11, and 16, with correlation coefficients of >0.8 , showed the strongest positive correlations between DP and SFC at 0°C. For sites 1 and 19, the correlation coefficient between DP and SFC at the low temperatures decreased rapidly to become insignificant and became negative for site 1 (Figure 4B).

Monthly replicates of the melting data for sites 1 and 19 were similar, with CV of 1% or less for SFC at 5°C and DP. This confirms that for these 2 sites, SFC at low and high temperatures were independent of each other. Thus, for these sites, from an analytical and operational perspective, the relatively easy to perform DP

analyses provide no information about the likely SFC and functionality at low temperatures, which would need to be separately determined. Norris et al. (1973) showed a positive correlation between milk fat softening and the temperature at which 94% of fat was in the liquid state. However, they observed no correlation between softening point and the amount of liquid fat at any temperatures between -20 and 30°C, except for a weak negative correlation at 22°C (with a correlation coefficient of -0.5; $P = 0.05$).

Seasonal Variation

Nonlinear multidimensional scaling (MDS) in 3 dimensions was conducted on melting properties to describe variation between sites across seasons for the 2 yr. The MDS analysis showed that each of the areas had their own characteristics. The results for SFC at 5°C are shown in Figure 5, together with the groupings that could be made. The stress in the MDS was 0.060; values below 0.1 are considered to provide good ordination and values below 0.05 indicate excellent ordination (Cox and Cox, 1992; Clarke, 1993).

Grouped based on similarity in range and median melting properties from the box plots (Figure 2 A to C) and their seasonal variation in the MDS were group A with the New South Wales (site 1), Queensland (sites 2 and 3), and South Australia (site 4) sites; group B with the western Victoria sites (8, 9, and 10); group C with the northern Victoria sites (sites 11, 12, and 13); group D with Tasmanian (sites 5, 6, and 7) and eastern Victoria (sites 14, 15, and 17) sites; and group E with the Western Australia sites (18, 19, and 20). The preliminary MDS, which included site 16, yielded patterns indicating that this site was clearly separated from other sites in the graph of the first 2 dimensions. This confirmed site 16 as an atypical site for the region, as indicated by the box plots. Therefore, site 16 was not included in any of the regional groupings, as discussed earlier.

Results of the MDS of SFC at 20°C and of DP were broadly similar, with stresses of 0.076 and 0.067, respectively (MDS graph results not shown). At 20°C, the 5 groups were clearly discernible albeit with the 3 sites in the WA group being much less scattered than at 5°C and site 4 clearly separated from sites 1 to 3 in dimension 3. For DP, sites 3 and 20 were well away from the other sites in their group in all dimensions, site 11 was clearly separated from sites 12 and 13 in dimensions 2 and 3, but the remaining sites remained in their groupings.

The monthly melting properties for the grouped sites are shown in Figure 6A to C. No distinct seasonal variation was shown by group A for SFC at 5°C and 20°C and

only a relatively small seasonal pattern was observed for DP, with a low point around August. Sites 1 to 3 used irrigation all year and had a relatively stable year-round milk supply, but site 4 did not; no irrigation was used on site 4 and it had a very seasonal milk supply. Most pastures in site 4 were reclaimed swamp so they

did not need irrigation to give active growing pasture year round, and the supplement feeds were reported to be the same for the whole survey period. Walker et al. (2013) reported that SFC at 10°C increased by about 0.2% for every kilogram of DM concentrate fed/cow per day. Most likely, the supplementary feeding regimens

Figure 6. Solid fat at 5°C (panel A), solid fat at 20°C (panel B), and dropping points (°C; panel C) over 2 yr of milk fats from all Australian regions combined (excluding site 16) and of sites grouped in 5 regions (A to E). Differences between the curves are highly significant; SEM at each month (for panels A, B, and C, respectively) are as follows: all regions = 0.10, 0.08, and 0.04; group A = 0.16, 0.14, and 0.07; group B = 0.20, 0.18, and 0.09; group C = 0.21, 0.21, and 0.10; group D = 0.20, 0.13, and 0.07; and group E = 0.30, 0.22, and 0.14. NSW = New South Wales; QLD = Queensland; SA = South Australia; WA = Western Australia; West Vic = western Victoria; North Vic = northern Victoria; East Vic = eastern Victoria; Tas = Tasmania.

helped to avoid the lows in SFC for site 4, as was found for all other seasonal production sites, so that it could be grouped with sites that had constant milk volume productions. The Western Australia sites (group E) showed some seasonal variation with a clear low SFC around July and more stable higher values throughout the year. All sites with no or small seasonal variation were also the only sites that reported kikuyu grass as part of the pasture at least part of the year; that is, sites of groups A and E (Table 1). From the available data, it is not possible to determine if kikuyu grass has some specific nutritional qualities affecting milk fat properties or is merely an indicator for general climate and growing conditions. Fulkerson et al. (2007) showed that grasses had a much higher hemicellulose content than legumes and kikuyu higher than other grasses. In an extensive review, Walker et al. (2004) concluded that high starch feed is associated with higher concentrations of saturated fatty acids, whereas a pasture diet would result in higher unsaturated fatty acids in the milk fat. This would most likely result in higher and lower solid fat contents, respectively, as shown by Couvreur et al. (2006), who found that the proportion of fresh grass to corn silage significantly affected fatty acid composition and butter hardness. Here they showed butter from cows fed a 30% fresh grass diet exhibited maximum hardness compared with the softest butter coming from cows on a 100% fresh grass diet. In our results, the seasonal variation in SFC and DP of sites in Victoria and Tasmania (groups B, C, and D) was mainly manifested through seasonal lows in winter and spring, when most fresh grass is available within those regions. Site 19 of group E (results not shown separately) had the least seasonal variation of the other sites in the group, and was the only site with seasonal irrigation in the low rainfall months and active pasture growth all year (Tables 1 and 2). The DP in Western Australia (group E) moved largely in parallel with SFC at 20°C, except that the highs and lows lagged by about a month during 1995. Compared with the “national average” of all sites, the SFC at 5°C of group E tended to be lower, whereas the DP tended to be higher than that of all sites combined. This may provide some useful functionality, such as better spreadability for butter at refrigerated temperatures and, at the same time, having good resistance against melting and usability at elevated temperatures (e.g., for pastry sheeting).

In Victoria and Tasmania, groups B, C, and D showed strong seasonal variation across all melting properties. The SFC of group B (western Victoria) varied the most, and that of group C (northern Victoria), particularly at 5°C, varied the least of these 3 groups, whereas DP showed a similar magnitude of variation for all 3 groups. The seasonal variations in SFC

of group B (western Victoria) and group D (eastern Victoria and Tasmania) were very similar, except that the lows of group D occurred about 2 to 3 mo later in both years (approximately August vs. June). Regional differences were also noted by Knightbridge and Black (1978), who observed differences in the length of time for which SFC was at its lowest. Sites 11 and 12 in northern Victoria (group C) used irrigation all year, so less seasonal variation in melting properties might have been expected than was observed. It was noted that, in spite of irrigation, pasture availability was in short supply for about 6 mo of the year, unlike most sites in group A and site 19 in group E.

High values for SFC and DP were obtained at the end of spring and summer months. However, there appeared to be a shift in onset and decline of the curves, with high values of SFC at 5°C (~November 1994) being reached about a month before high values of SFC at 20°C (~December 1994) followed by high values of DP a month later (~January 1995). Although less pronounced, the same observations could be made for the curves of all sites combined, which were heavily influenced by the results of the Victorian and Tasmanian sites. The values at the peak for group B are higher than those of group C and D; however, the peaks of groups C and D are broader and the high SFC and DP are maintained longer into autumn or even into June, the beginning of winter, for group C.

From a study in northern Victoria, it was concluded that stage of lactation was the most significant factor affecting SFC (%) in milk fat, with the amount of feed concentrate being a small contributing factor and other farm management factors and nutrition not having an influence (Walker et al., 2013). In our study, the SFC at 10°C was found to be more than 5% higher in early lactation than in mid to late lactation (data not shown). Therefore, from group A, the relative seasonal stability in SFC of sites 1 to 3 may be understandable. However, site 4 in our survey had strong seasonal milk production, with minimum flow being 17% of the maximum (Table 1); therefore, a strong seasonal calving profile and considerable seasonal variation in melting properties could be expected. If variation in SFC is mainly due to stage of lactation, then the same seasonal variation as observed for groups B, C, and D (sites 5 to 17, see Table 1) is to be expected. However, the variation in group C, the same northern Victorian area as studied by Walker et al. (2013), showed much less seasonal variation than the other 2 groups (Figure 6A), whereas the seasonal production variation of site 12 (minimum flow 18% of the maximum) in northern Victoria in group C was much the same as that of sites 8, 9, and 10 in group B (17%; Table 1). Therefore, it would appear that the degree of seasonal variation is

affected considerably by feed, particularly in winter and early spring, when the milk fat in groups B and D has much less solid fat than that in group C. The “bumps” in SFC and DP, such as for group D in June–July 1995 (see Figure 6A, B, and C), are likely to be caused by local feed quality and availability. There may also be an effect from different breeds; although the data sets are not complete and no region had single breeds (Table 1), the northern Victoria group C had more of the Jersey breed and fewer Friesians compared with the other 2 Victorian regions. MacGibbon (1996) noted that, at 10°C, milk fat from Friesian herds had a lower SFC than that of Jersey herds, which is broadly consistent with our results for SFC at 5°C for the western and eastern Victorian regions compared with northern Victoria (Figure 6A). In addition, the Western Australia sites with the highest proportion of Friesians (96–98%, Table 1) showed a relatively low SFC at 5°C compared with all other regions (group E; Figure 2D and 6A). The degree of variation in DP of group C was similar to that of groups B and D, and may, therefore, be attributed mainly to stage of lactation and less to nutrition, breed, or other farming practices.

From these results, no single factor stood out as determining the seasonal variation or lack thereof in milk fat melting properties. The milk from regions with no or small variation is mostly used in liquid milk products. Milk fat melting properties are unlikely to have a significant effect for these consumer products. The regions with the largest variations were in Victoria and Tasmania, which produce about 75% of Australia’s milk, and which is mostly processed into cheese, milk powders, butter, and AMF for domestic and international markets (Dairy Industry in Focus, 2015). Milk fat melting properties are important in many applications and for users of butter, AMF, and whole milk powder. The variability in these regions highlights both the difficulty of producing consistent product and the opportunity to produce differential products for particular applications and markets. Milk fat dry fractionation is used on a large scale in many countries, although not in Australia, to make more functional milk fat-based products, such as spreadable butters and pastry butters (Kaylegian et al., 1993). Our analysis shows that some of the benefits of differentiated milk fat melting properties can be achieved by purposeful sourcing of milk. For instance, milk fat that is softer under refrigerated conditions (i.e., 5°C) could be sourced from regions B and D between June and October. On the other hand, milk fat that is more solid at ambient temperature (i.e., 20°C) could be sourced from these same regions from November to March, or from the region of group C between November and April. As such, it is possible to select desirable melting properties

for certain products or markets for long periods of the year by staggered sourcing of produce or ingredients from different regions. This approach would be feasible for companies who have facilities in several regions in the same or different states. However, it is necessary and prudent to monitor milk properties during the season, as every year can be different in timing and magnitudes of peaks and troughs in melting properties (Figure 6A, B, and C). By doing this, the milk supply could be tailored to particular markets and applications. Functional properties affected by melting properties include the consistency and spreadability of butter associated with softer milk fat at ambient temperatures (Norris et al., 1973); the desired resistance to melting and plasticity of butter and AMF required for pastry production associated with a higher SFC (Deffense, 1993; Kaylegian and Lindsay, 1995); the whipability of cream, where a critical level of solid fat is required to promote coalescence (Darling, 1982); the suitability for blending of cream, butter, and AMF with other oils and fats for spreads; best use and conditions for further processing, such as fractionation for desirable fractions (Timms, 1980); and consistent performance in chocolate production, such as resistance to fat bloom and release from the mold (Lohman and Hartel, 1994; Dimick et al., 1996). Changes in farming practices over the last 20 yr may have reduced seasonal variations in milk fat properties with associated opportunities and problems in some regions. It is worth noting that the physical characteristics governing melting properties, including SFC and DP, are a function of the milk fat triglyceride fatty acid composition (Norris et al., 1973; Kaylegian and Lindsay, 1995) and will be the focus of a subsequent paper.

CONCLUSIONS

Differences in melting properties of milk fat from 19 bulk milk production sites across Australia were considerable and showed a clear seasonal pattern for the Victorian and Tasmanian sites, a moderate seasonal pattern for the Western Australia sites, and very little or no pattern for the New South Wales, Queensland, and South Australia sites that participated in the survey. In general, SFC at low temperatures and DP, which is a good measure of the melting properties at elevated temperatures, were highly correlated. Nevertheless, the time points for peaks and lows did not correlate and DP tended to lag by up to several months. For the site in New South Wales and one site in Western Australia, we detected no correlation between SFC at low temperatures and high temperatures or DP. Seasonally, the Western Australia sites showed lower SFC at low temperatures and higher DP than the national average.

No single factor stood out as determining variation in melting properties. Sites with good availability, more active pastures with no senescence, and constant supplementary feed practices year round showed the least variation. To provide the most consistent functionality, it is recommended to select seasonal supplies from different regions for specific applications and products, which is best done in close collaboration with end users. Regular testing is also recommended because melting properties and timing of seasonal variation may differ from year to year.

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