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Research Article
Physical Properties of Nonfat Dry Milk and Skim Milk Powder

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Abstract

Background: Measuring of particle size, particle size distribution, viscosity and colour of powder is essential as it is directly related to powder behaviour and physical properties. **Materials and Methods:** In this study, physical quality parameters of nonfat dry milk (NFDM) and skim milk powder (SMP) including, particle size, particle size distribution at diameters d_{10}, d_{50} and d_{90} in a cumulative size distribution, colour and viscosity were determined. Low, medium and high heat NFDM/SMP samples from US domestic producers were utilized. **Results:** Original powder samples had significant variations in lightness value L* (93.85-96.37) as well as b* value (12.32-17.99) based on the product source. The particle size in volume weighted mean, D [4, 3] of milk powders showed significant variations with a range of 29.32-94.24 µm. Significant differences in the viscosity of reconstituted milk were found with high heat treated powders having greater viscosity. **Conclusion:** Differences were noted between processors indicating differences in processing conditions between manufacturers, rather than the actual type of milk powder product.

Key words: NFDM/SMP, physical properties, colour, particle size, viscosity

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Nonfat dry milk (NFDM) and Skim Milk Powder (SMP) are the most produced and important dairy products. They are very similar products and are produced by water removal in a process that usually includes heat treatment, evaporation and spray-drying. The process of spray drying involves atomizing concentrated milk into a hot air stream. A pressure nozzle or a centrifugal disc could be utilized in the atomization process. Almost all the water in milk could be evaporated by controlling droplets size, air temperature and airflow while exposing milk solids to low temperatures[1]. Spray drying process gives milk powder with outstanding solubility, flavor and colour.

The NFDM and SMP are the main dry milk products manufactured in the US. The NFDM and SMP are used in many food applications for developing the body, texture and flavor of products. There are three main heat classes of NFDM and SMP (high, medium and low heat) based on Whey Protein Nitrogen Index (WPNI)[2].

During processing and marketing some foods are in the form of powder (fine particles). Physical properties of powder include particle size distribution, bulk density, particle density, occluded air, interstitial air and flowability[3]. Many of these properties have been subjected to broad research[4-7]. Measuring of particle size distribution in powder is essential as it is directly related to powder behaviour and physical properties. In addition, particle size distribution is one of the factors that affect the flowability of powders[7]. Physical properties such as bulk density, compressibility and flowability of powder are extremely dependent on particle size and its distribution[3]. Differences in particle sizes result in separation in a free flowing powder mixture[7].

Milk powder quality can be greatly affected by particle size and is of critical importance when evaluating quality standards in milk powder. The size of the milk powder particles used in manufacturing of various food products can influence the possible end use behavior of these products[8]. Particle size in milk powder can affect powder reconstitution properties, wettability and dispersibility. Small particle size and regular shape can improve close packing of particles. Large particles of dry milk powders exhibit good wettability and dispersibility. Flowability also depends on particle size and shape[9].

There are many factors which can influence physical characteristics of milk powders such as processing conditions/parameters used during spray drying (type of spray dryer, nozzles/wheels, pressure) and the conditions of the air (temperature, relative humidity, velocity), as well as original raw milk composition and characteristics of the concentrate before spraying[3,10,11]. Characterization of particle size distribution of food powders including dairy powders becomes important for purpose quality control[7].

The aim of this study was to characterize the variation in domestically produced NFDM/SMPs in terms of some physical parameters including particle size, particle size distribution, colour and viscosity.

MATERIALS AND METHODS

Powder samples: The present study utilized 23 samples from four domestic producers of NFDM/SMP in the US. Samples were 50 pound bags of low, medium and high heat NFDM/SMP that have not been agglomerated or instantized and were approximately 6-9 month old.

Colour analysis of the original powders: Colour analysis of the original powder samples was done using a spectrocolourimeter (Colour flex®-HunterLab). The reference illuminant used was D65 (standard day light). The colour parameters L*, a* and b* were determined. Hunter colourimeter was standardized using black and white reference plates. Ten grams of powder samples were utilized and were placed in glass cup and covered with a black metal cover to prevent light interferes with the samples readings. Colour was measured for 3 replicates per sample. Colour parameters were obtained using the CIELAB space, where L* corresponds to lightness/darkness (0 dark to 100 light), a* to green/red (-green/+red) and b* to blue/yellow (-blue/+yellow).

Particle size: Particle size was measured using the Malvern mastersizer device (Mastersizer 2000, Malvern, Inc., Southborough, MA). Particle size is measured by the instrument using the principle of low-angle laser light scattering (laser diffraction) combined with Mie theory to solve the equations of light and object interaction. Approximately 5 g of powder was used. The parameters of volume weighted mean D [4, 3], surface area weighted mean D [2, 3] and diameters d_{10}, d_{50} and d_{90} represent particle size at 10, 50 and 90% in a cumulative size distribution respectively were determined for further analysis.

Viscosity: The NFDM/SMP powders were reconstituted to 9% total solids solution at 25°C. The solution was stored at 7°C overnight and viscosity was measured at 25°C using Rheometer Paar Physica MCR301 device (Anton Paar, VA) with the double gap measuring system Ms. C. under increasing shear rate from 0.02-1000 sec^{-1}.

Statistical analysis: All of the analysis were done in duplicates and data are presented as Mean±Standard Deviation. Analysis of variance (ANOVA) was determined using the software Statistical Analysis Systems (SAS) version 9.2 for windows (SAS Institute Inc., Cary, NC, USA). Mean comparisons were performed using the Tukey's multiple comparison test in SAS. The probability level of 5% ($\alpha = 0.05$) was used to indicate the significance.

RESULTS AND DISCUSSION

Original powder colour: Hunter colour scale values for the NFDM/SMP samples as it was received are given in Table 1. The same table groups the values according to processor and heat treatment. Original powder samples had significant variations in lightness value L* as well as b* and a* value based on the product source. There was no significantdifference in the L* (lightness) and b* (blue/yellow) values for the NFDM/SMP based on the type of the product. All powders were very close to the maximum L* value of 100 indicating very white powder. The a* (green/red) values also were very similar for all companies. The a* values indicated a slight green colour for the powders. Differences were apparent in the b* (blue/yellow) values. The powders all were in the yellow part of the scale with processor 3 having the least yellow tint to their NFDM/SMP followed by processor 4, processor 1 and finally processor 2. No differences were noted between NFDM and SMP. Differences were not apparent when the powders were grouped according to heat treatment. Powders that had higher heat treatments were not darker than low heat powders and in fact there was a slight trend towards increasing whiteness with increasing heat treatment.

Particle size

Volume weighted mean, D [4, 3]: The size of particles in a powder could be indicated in many ways. Methods generally assume the particles are spherical and therefore, easily described and quantified by their diameter. Volume weighted mean and surface area weighted mean are used to describe particle size. In volume weighted mean, the diameter of the sphere is cubed (x^3). The volume weighted mean particle size for the NFDM/SMP is given in Fig. 1. Larger particles have a greater influence on the volume weighted mean, therefore, this method of measuring particle size is useful for indicating the presence of larger particles. Processor 2 powders had the largest particles when the method which emphasizes larger particles is used, followed by processor 4, processor 1 and processor 3. Processor 2 also had the greatest range of particle sizes between their powders. It is well known that atomization parameters influence particles shape and size distribution of powder[9]. Also it is possible to control powder particle size by controlling atomization parameters. In addition, using centrifugal atomization gives a larger particle than the pressure nozzle atomization[12]. Differences between NFDM and SMP were not apparent.

Surface area weighted mean, D [3, 2]: Surface area weighted means use the square of the diameter (x^2) and is useful for evaluating properties such as reactivity, rate of dissolving, etc. Surface area weighted means are most sensitive to the presence of small (fine) particles. The surface weighted mean particle size for the NFDM/SMP is given in Fig. 2. Processor 2 powders had the largest particles when the method which emphasizes smaller particles is used, followed by processor 4, processor 1 and processor 3. Processor 2 again had the greatest range of particle sizes between their powders. Differences between NFDM and SMP were not apparent.

Cumulative particle size: Table 2 gives the results for the particle size distributions of NFDM/SMP samples. Diameters d_{10}, d_{50} and d_{90} represent particle size at 10, 50 and 90% in acumulative size distribution respectively. Ten percent of processor 1 NFDM has a particle size diameter less than 11 µm, while 50% has a diameter less than 38 µm and 90% less than 88 µm. The information provides insight into the particle size

Table 1: Hunter colour scale values of the original NFDM/SMP samples

Processors	Types	Heat treatment	L* Mean±SD	a* Mean±SD	b* Mean±SD
1	NFDM	HH	95.01±0.68	-2.84±0.03	14.30±0.38
1	NFDM	HH	95.15±0.07	-3.26±0.04	15.67±0.02
1	SMP	MH	94.96±0.23	-3.42±0.03	15.20±0.02
1	SMP	MH	95.25±0.04	-3.34±0.02	15.29±0.05
1	NFDM	LH	94.74±0.07	-2.24±0.01	13.89±0.04
1	NFDM	LH	94.53±0.07	-2.20±0.01	14.15±0.07
2	SMP	MH	94.84±0.03	-2.85±0.01	16.11±0.02
2	SMP	MH	94.80±0.05	-2.89±0.01	16.28±0.04
2	NFDM	HH	94.88±0.04	-3.24±0.02	17.76±0.05
2	NFDM	HH	94.71±0.04	-3.29±0.02	17.91±0.09
2	NFDM	MH	94.82±0.13	-3.22±0.03	16.51±0.08
2	NFDM	MH	95.20±0.10	-3.10±0.06	15.54±0.19
2	NFDM	MH	95.26±0.31	-2.97±0.01	13.80±0.11
2	NFDM	LH	94.00±0.05	-2.72±0.02	16.37±0.03
2	NFDM	LH	93.96±0.11	-2.61±0.01	16.44±0.08
2	NFDM	LH	94.64±0.01	-2.60±0.02	14.61±0.10
2	SMP	LH	94.43±0.01	-2.59±0.01	16.11±0.03
3	NFDM	LH	95.61±0.05	-2.24±0.01	12.40±0.08
3	NFDM	LH	95.41±0.06	-2.30±0.02	12.90±0.06
3	NFDM	HH	96.27±0.11	-2.31±0.02	12.45±0.08
3	NFDM	HH	95.92±0.20	-2.63±0.03	13.12±0.06
4	NFDM	LH	95.25±0.11	-2.09±0.01	12.82±0.08
4	NFDM	LH	94.49±0.09	-2.39±0.01	14.51±0.04

L*: Lightness, a*: Redness, b*: Yellowness

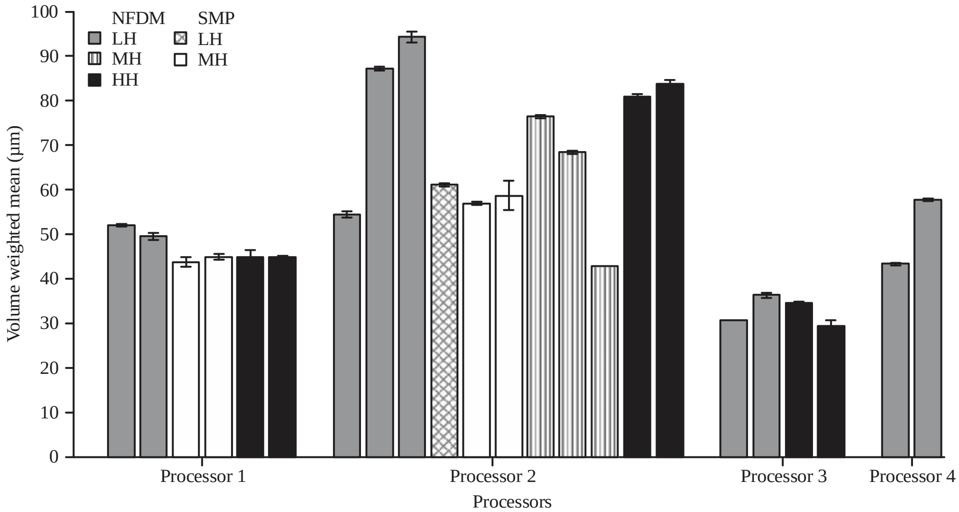

Fig. 1: Particle size (µm) of NFDM/SMP samples based on processor and heat class. Particle size in volume weighted mean, D [4, 3]

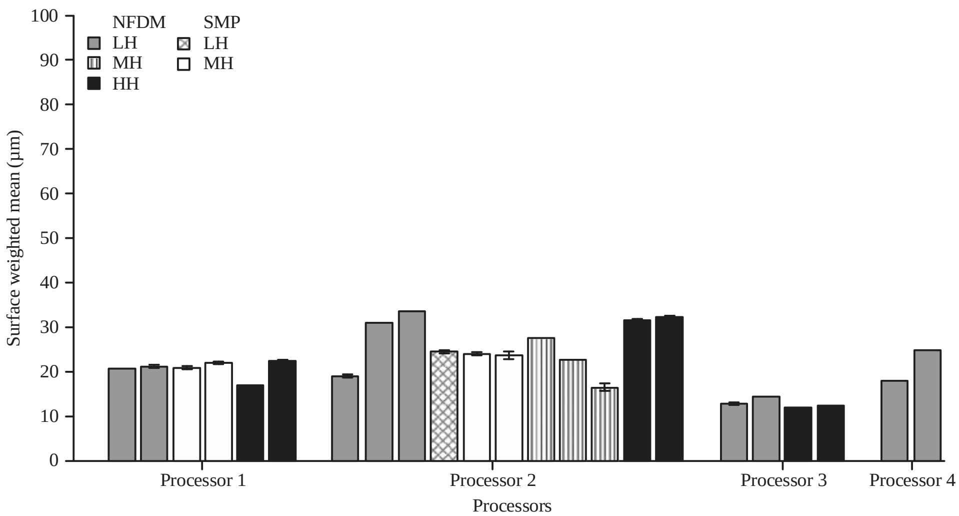

Fig. 2: Particle size (µm) of NFDM/SMP samples based on processor and heat class. Particle size in surface area weighted mean, D [3, 2]

distribution. All powders have similar populations of small particles or fines (10% values). Differences become apparent at 50% and are especially notable at 90%. Processor 2 had the largest particle diameters at <90% while processor 3 had the smallest. Processor 1 and processor 4 results fell in between processor 2 and processor 3. Processor 2 also had the largest range between in particle diameters between their powders.

Table 2 gives the difference between particle size at <90 and <10. The results are an indication of the range of the particle sizes in the powder. Processor 3 to have a very tight distribution of particle sizes. Processor 1 and processor 4 are similar and intermediate in particle size distribution. Processor 2 has the greatest spread in particle sizes for a given powder. The occurrence of particles of different shape in the same sample can be attributed to the different drying conditions to which the particles were exposed[9]. Particle size can be controlled by the milk composition, processing conditions and the type of equipment utilized in the drying process[1]. Differences based on NFDM/SMP were not apparent (Table 3).

Viscosity: The viscosity of NFDM/SMP is given in Fig. 3. The viscosity was measured at a spindle speed of 67.2 rnln" and a solution temperature of 25°C. The NFDM/SMP solutions were prepared to 9% total solids. There was considerable variation within companies for powders having the same heat

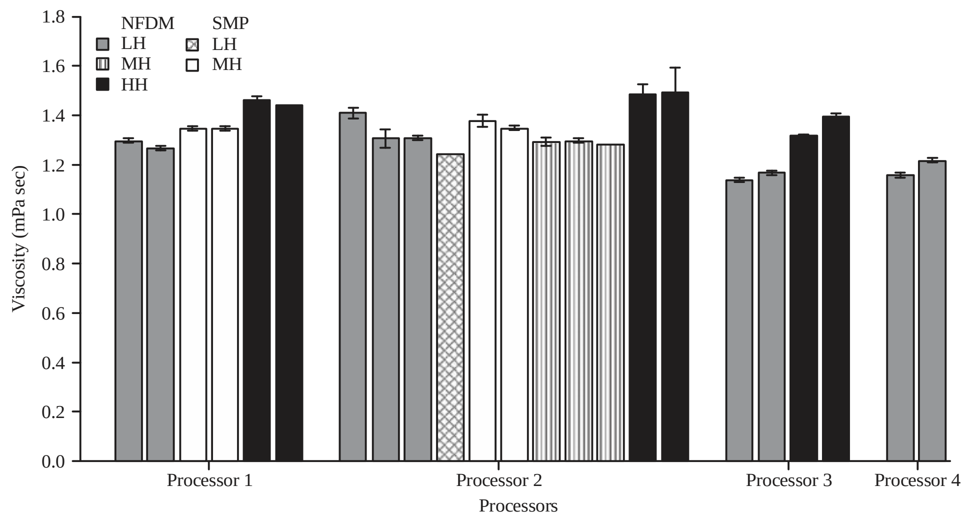

Fig. 3: Viscosity (mPa sec) of NFDM/SMP samples based on processor and heat class

Table 2: Particle diameters (μm) d_{10}, d_{50} and d_{90} representing particle size at 10, 50 and 90% of NFDM/SMP samples in a cumulative size distribution respectively

Processors	Types	Heat treatment	d_{10} Mean±SD	d_{50} Mean±SD	d_{90} Mean±SD
1	NFDM	HH	8.47±0.1	33.22±0.1	84.01±1.8
1	NFDM	HH	12.37±0.1	39.56±0.5	83.52±1.0
1	SMP	MH	11.27±0.2	37.77±0.4	81.17±0.0
1	SMP	MH	11.82±0.2	39.66±0.5	84.50±1.1
1	NFDM	LH	10.68±0.0	38.10±0.1	88.37±0.7
1	NFDM	LH	10.99±0.1	39.52±0.1	90.52±0.7
2	SMP	MH	12.10±0.1	48.09±0.2	108.14±0.9
2	SMP	MH	11.82±0.4	48.81±1.7	110.17±0.9
2	NFDM	HH	16.44±0.3	59.85±0.8	171.80±1.5
2	NFDM	HH	16.73±0.2	62.56±0.5	179.88±1.1
2	NFDM	MH	13.40±0.1	59.13±0.3	157.18±2.1
2	NFDM	MH	10.18±0.0	51.79±0.2	146.41±0.9
2	NFDM	MH	9.21±0.1	30.17±0.2	87.84±1.5
2	NFDM	LH	8.92±0.0	43.87±0.3	114.43±2.4
2	NFDM	LH	14.67±0.0	71.03±0.1	179.12±0.6
2	NFDM	LH	16.27±0.0	73.80±0.2	196.72±1.7
2	SMP	LH	11.95±0.1	52.05±0.1	119.89±0.0
3	NFDM	LH	7.75±0.1	26.65±0.0	59.02±0.1
3	NFDM	LH	8.91±0.0	29.32±0.0	66.64±0.2
3	NFDM	HH	6.93±0.0	23.86±0.3	59.13±0.2
3	NFDM	HH	8.13±0.1	21.11±0.1	48.24±0.2
4	NFDM	LH	9.37±0.1	34.76±0.0	82.02±0.2
4	NFDM	LH	12.91±0.1	47.46±0.0	115.25±0.3

treatment. Also, it would be expected that viscosity should increase with heat treatment. The powders for several companies do not consistently follow this trend. The viscosity of the powders grouped according to heat treatment is given in Fig. 3. The results follow the expected trend of higher heat treated powders having greater viscosity however, the range of values for any heat treatment indicates considerable overlap between categories. It is well known that during heat treatment, whey proteins become denatured and attached to the casein micelles which cause larger micelles and more thick milk. The degree of whey protein attachment to the micelles is straight related to the severity of the heat treatment[13].

Table 3: Summary for statistical analysis of physical properties of NFDM/SMP samples

Parameters	Sources	Type(NFDM/SMP)	Heat class
L*	SN (<0.0001)	NSN	SN (0.0096)
a*	SN (0.0001)	SN (0.023)	SN (<0.0001)
b*	SN (<0.0001)	NSN	NSN
d_{50}	SN (<0.0001)	NSN	NSN
D [4, 3]	SN (<0.0001)	NSN	NSN
D [3, 2]	SN (<0.0001)	NSN	NSN
Viscosity	SN (0.001)	NSN	SN (<0.0001)

SN: Significant, NSN: Not significant

CONCLUSION

Differences in physical properties of NFDM/SMP samples both between manufacturers and products produced by the same manufacturer were reported. Differences noted between processors indicating differences in processing conditions between manufacturers, rather than the actual type of milk powder product.

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