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Improving Physicochemical Properties of Milk Powder and Lactose-Free Milk Powder with the Prebiotic Carrier

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Abstract— A lactose-free diet is imperative for those with lactose intolerance and experiencing milk intolerance. This entails eliminating milk-based products, which may result in dietary and nutritional challenges. The main problems of Lactose hydrolyzed milk powder during production were the adhesion in the drying chamber and low-yield and low-quality powder. The use of lactose-free milk to produce lactose-free milk powder was studied here. Development of two milk powder formulas from cow's milk and lactose-free cow's milk by using a substitute for maltodextrin, Resistant Starch (RS), Cellobiose (CB), and Resistant Maltodextrin (RMD) to improve quality and reduce the glycemic index from maltodextrin, which are carriers that were used in industry at three experimental levels the properties of milk powder were studied such as color, moisture content, percentage yield, and solubility index. The experiment revealed that prebiotic carriers could replace maltodextrin and improve quality, such as solubility and percentage yield, as well as enriched nutrients, such as dietary fiber. CB and RMD are possible carriers, which are applied to both regular cow's milk formula and lactose-free cow milk.

Keywords— ***Prebiotic carrier, Lactose-free milk powder, co-particle***

I. INTRODUCTION

The lactose-free dairy market has continued growing concerning the lactose intolerance population, which is nutritionally more attractive than alternative non-dairy products because of their superior protein and calcium. Lactose hydrolyzation is an easy, low-cost method specific to lactose that uses suitable conditions. The technique is adding the enzyme lactase to milk, which predigests sugar into glucose and galactose. Then, heating for enzyme inactivation by pasteurization or UHT process. The product will look darker and taste slightly sweeter than regular milk.

Lactose-free milk powder (LFMP) has low heat resistance by glass transition temperature or T_g value decreased from 61ºC (Regular milk powder) to 36ºC (Lactose hydrolyzed milk with lactase enzymes) [1]. Moreover, the milk powder industry's production of lactose-free milk powder remains a challenge. The specific technical problems, such as toughness during drying due to the lactose being in a single molecule, affect the chemical and physical behavior of the milk powder. The structure of lactose hydrolyzed milk powder is more of a monosaccharide around the milk proteins than that found in regular formula [2], [3].

The spray-drying of LFMP showed water content to the control regardless of drying conditions, which directly resulted from the difficulties encountered in drying the product. For a lab scale, the LFMP produced at Inlet temperature 145°C was quality parameters: water content <5% (w/w), aw <0.20 and luminosity value >93, particle sizes similar to general milk powder [4],[5]. Nowadays, LFMP drying is not widely used in food industries due to the problem of spray drying and powder yield depending on types of materials, as well as obtaining a dried product with pre-specified properties relating to the properties and costing. Processing factors affecting particle size, color, insoluble index, loose density, and nutrient contents of the spray-dried powder include drying temperature, humidity, feed flow rate, humidity, feed flow rate, liquid material, and atomizer speed [6]. Among these factors, spray drying carriers or aids can facilitate spray drying.

Maltodextrin (MDX) in spray drying was more efficient than others but unhealthier due to its structure as a simple carbohydrate and high glycemic index (GI=85-105). The glycemic index (GI) is the amount of glucose in food absorbed by blood vessels within 2 hours. When compared with glucose, GI is equal to 100. High GI foods lead to more diabetes risk and unsteady GI values. Therefore, adding MDX may lead to a higher GI value in the product. Prebiotic carriers are nondigestible carbohydrates that potentially improve glycemic control and reduce intestinal permeability [7].

A review found that the carbohydrate carrier such as Maltodextrin (MDX), Resistant Maltodextrin (RMD), Resistant Starch (RS), and Cellobiose (CB) as co-particles in the spray drying process [8]-[11] and the four-carbohydrate carrier (CB, RMD and RS) was prebiotic. LFMP is necessary to find a suitable carrier for productivity, and prebiotic carriers have never been used in milk powder production. This study investigated co-particle substances between 2 types of milk with carriers compared to the control with no carrier. It estimated the glycemic index of milk powder combined carriers in each sample.

II. MATERIALS AND METHODS

A. Materials and Milk Preparation

Cow's milk raw materials collected from the Dairy Farming Promotion Organization of Thailand in Muaklek district, Saraburi province, Thailand. Milk was produced as a method to prepare plain milk and lactose-free pasteurized milk. Then, it was transported at 4 °C to the Mahidol University laboratory during the day and stored, which was desirable for evaporating and drying. Partially evaporated milk to 25% total solid, and the mixture was prepared by adding the carrier agents to the diluted milk according to Fig.1-3.

The prebiotic carrier used in the formula was compared to maltodextrin, as in the prototype. Prebiotic carriers (resistance maltodextrin (RMD), resistance starch (RS)), ranging from 10%, 15%, and 20% of milk solids Except for the cellobiose (CB), only used in a range from 1%, 3%, and 5% instead of maltodextrin (MDX). The carrier experiment used 12 treatments of Completely Randomized Design with three replications.

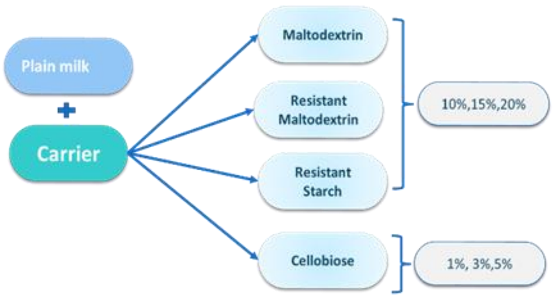

Fig. 1 Plain milk mixture of drying experimental design

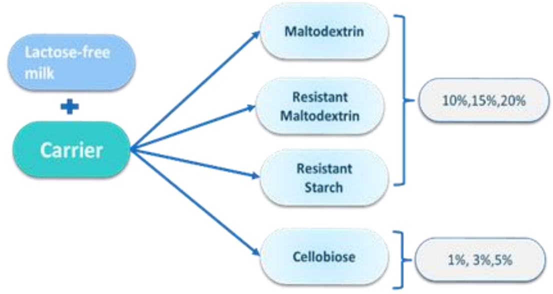

Fig. 2 Lactose-free milk mixture of drying experimental design

Heat the evaporated milk and carrier mixture until the temperature is 65 °C before homogenizing the sample with a homogenizer (T25, IKA brand, USA) and putting it in a spray dryer. Then, the sample will be collected to examine viscosity, total soluble solids, and pH, and a hot plate will be used to heat and stir the mixture and feed it constantly. Based on experimental plans, set the injection speed for sample level 7-10, air pressure within 0.10 Mpa, and inlet/outlet hot air temperature.

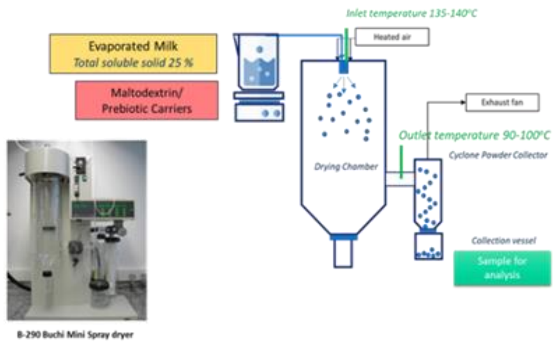

Fig. 3 Schematic illustration of the spray dryer process and its equipment

B. Spray Drying

Spray drying with a spray dryer (Mini Spray Dryer B-290, Switzerland) with a two-fluid nozzle size of 2 - 25 µm. Determine the inlet-outlet hot air temperature of 130-140 °C and 90-100°C, respectively. Stir the mixture, feed constantly, and set the injection speed for sample level 7-10, with air pressure within 0.10 Mpa. Finally, keep the powdered milk, such as plain milk powder (MP) and Lactose-free milk powder (LFMP), in plastic-coated aluminum bags and vacuum sealed. They were stored at 4 °C until analyzed, as shown in Fig.3.

C. Evaluation of Physicochemical Properties

Chemical properties

Chemical properties, including moisture, protein, fat, dietary fiber, and color, are analyzed by the Moisture Analyzer (HE53, Mettler Toledo, USA), Kjeldahl method (AOAC 2001.14), Gerber method (AOAC 989.05), total dietary fiber (TDF) in foods (AOAC, 2001.03), titrimetric method (AS, 1994), and spectrophotometer specified value in CIE (L *, a *, b *) system, respectively.

Insolubility Index

The insolubility index of the obtained powders was determined using the IDF Standard 129A method (1988), with some modifications. Briefly, 13 g of dried plain milk was mixed with 100 mL of water at 50 °C. After 5 min of mixing at high speed, stir with a spatula. A sampling of 50 mL into a graduated 50 mL centrifuge tube. Then, centrifuged at 5070 rpm for 5 minutes. The sediment was filled up again with water and centrifuged for 5 min at the same speed; after that, the residue level on the graduated bottom was weighed. Moreover, the sediment was dried in an air oven at 70 °C overnight and, in any case, until it reached a constant weight. The analyses were performed in duplicate.

Powder Yield Rate

The yield rate of the milk powder is calculated as the mass of the powder in grams divided by the total solid content of the concentrated liquid milk initially spray-dried multiplied by 100.

Predicted Glycemic Index

A method modified from an in-vitro technique was used to estimate food GI [12],[13]. The method is based upon enzymatic starch hydrolysis measured over 0, 15, 30, 60, 90, 120, and 180 min. The hydrolysis index was calculated as the area under the curve (AUC) for hydrolysis (0-180 min) with the product as a percentage of the corresponding white reference bread. The PGI was calculated using the following equation:

$$PGI = 39.71 + (0.549 \times HI) \quad (1)$$

D. Evaluation of Physicochemical Properties

All analyses were performed in duplicate for each sample. The results were presented as mean and standard deviation (SD) values. A two-way analysis of variance (ANOVA) was conducted to evaluate any significant differences between means. SPSS Statistics 18.0 (SPSS Inc., Chicago, IL, USA) was used to perform the statistical analyses and significant differences ($p < 0.05$).

III. RESULT AND DISCUSSION

Chemical Properties

The chemical properties of plain milk and lactose-free milk were investigated, including protein, fat, dietary fiber, and carbohydrate content. A study showed that the result of milk powder's chemical composition after drying has shown that adding a prebiotic carrier to milk powder can impact the chemical composition of milk powder. Plain milk powder with the carrier (MDX and RMD) at 20% provides protein and fat, decreasing significantly compared to 10%. It also differs from plain milk powder without the carrier. In this study, CB1 addition in plain milk powder has a chemical composition (carbohydrate, protein, and fat) that does not differ from plain milk powder without a carrier. At the same time, CB3 and CB5 tend to decrease protein and fat content like other formulas. All formulas with carriers increase carbohydrate content and decrease protein and fat, but milk powder with RMD and RS can increase unavailable carbohydrates or dietary fiber. The CIE L*a*b* color system quantitatively represents the color of milk powder on three axes. The milk powder with a 5 % CB carrier had the lowest L* value, potentially due to CB, a disaccharide that darkens the color when heated. Heat and moisture in the product accelerate the Maillard's reaction, causing milk powder to become less bright with more yellow and red values. Adding a carrier to the lactose-free milk powder with RMD formulation did not result in a significant difference in moisture content compared to the formulation without a carrier. Torres et al. (2017) found that LF produced more brown color when the lactose hydrolysis rate increased. This will affect the ability to recover [14].

Table 1 Chemical composition of plain milk powder with carbohydrate carriers.

Carriers	%Protein	%Fat	%DF	%CHO
MP+10%MDX	22.52±0.44 [cd]	30.49±0.44 [d]	-	40.42±0.61 [e]
MP+15%MDX	22.29±0.29 [cd]	29.10±0.85 [ef]	-	42.99±1.12 [d]
MP+20%MDX	19.19±1.15 [g]	27.86±0.80 [g]	-	47.17±0.20 [a]
MP+10%RMD	23.31±0.22 [bc]	32.47±0.50 [c]	9.24±0.01 [c]	38.23±0.13 [f]
MP+15%RMD	22.43±0.30 [cd]	30.46±0.29 [d]	13.70±0.14 [b]	41.18±0.06 [e]
MP+20%RMD	20.73±0.14 [ef]	27.78±0.38 [g]	18.42±0.32 [a]	45.69±0.12 [b]
MP+10%RS	22.46±0.00 [cd]	30.25±0.35 [de]	4.15±0.21 [f]	40.25±0.07 [e]
MP+15%RS	21.56±0.77 [de]	29.83±0.77 [de]	6.50±0.07 [e]	41.16±0.16 [e]
MP+20%RS	20.62±0.29 [ef]	28.22±0.29 [fg]	8.37±0.23 [d]	44.15±0.21 [c]
MP+1%CB	25.79±0.56 [a]	34.49±0.57 [a]	-	32.54±0.12 [i]
MP+3%CB	24.06±0.56 [bc]	32.82±0.56 [bc]	-	36.01±0.09 [g]
MP+5%CB	24.54±0.49 [b]	32.15±0.48 [c]	-	36.49±0.42 [g]
MP no carrier	25.71±0.11 [a]	33.75±0.35 [ab]	-	33.56±0.04 [h]

Table 2 Chemical composition of lactose-free milk powder with carbohydrate carriers.

Carriers	%Protein	%Fat	%DF	%CHO
LF+10%MDX	23.34±0.55 [bc]	32.65±0.55 [cd]	-	35.83±0.37 [ef]
LF+15%MDX	23.65±0.59 [b]	32.45±0.58 [cd]	-	36.87±0.15 [e]
LF+20%MDX	21.28±0.63 [def]	29.56±0.78 [ghj]	-	41.76±0.82 [c]
LF+10%RMD	23.72±0.63 [b]	33.43±0.76 [bc]	9.29±0.06 [c]	34.49±0.18 [fg]
LF+15%RMD	21.88±0.52 [d]	31.70±0.52 [def]	13.78±0.04 [b]	38.45±0.01 [d]
LF+20%RMD	20.43±0.14 [efg]	29.11±0.19 [hj]	18.45±0.07 [a]	23.5±0.81 [ab]
LF+10%RS	23.87±0.62 [b]	34.65±0.62 [ab]	4.65±0.21 [e]	32.72±0.44 [hi]
LF+15%RS	22.13±1.27 [cd]	30.83±1.27 [efg]	6.78±0.04 [d]	39.02±0.33 [cd]
LF+20%RS	22.57±0.73 [bcd]	30.57±0.74 [fgh]	9.15±0.04 [c]	38.31±0.76 [d]
LF+1%CB	25.18±0.28 [a]	32.80±0.42 [cd]	-	32.50±0.15 [i]
LF+3%CB	25.06±0.46 [a]	31.84±0.46 [cdef]	-	34.06±0.29 [gh]
LF+5%CB	25.15±0.06 [a]	32.30±0.27 [cde]	-	34.40±0.98 [fg]
LF no carriers	25.52±0.11 [a]	35.75±0.35 [a]	-	29.96±0.73 [j]

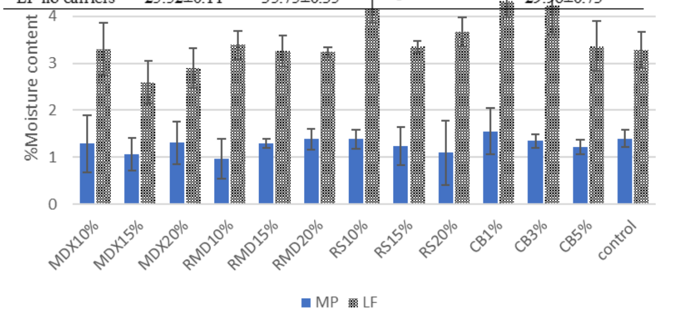

Fig. 4 Moisture content (%) variation in different powders and carriers.

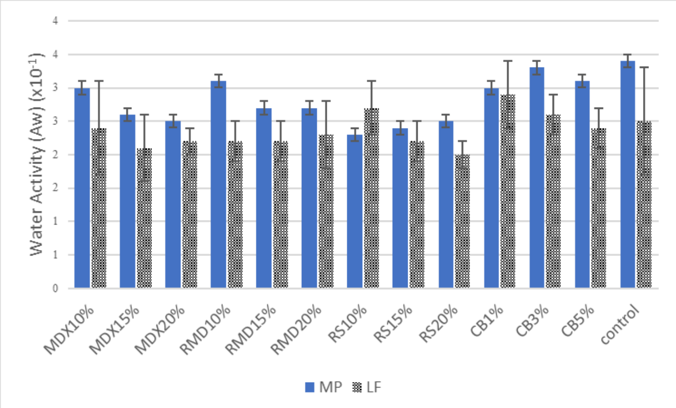

Fig. 5 Water activity (Aw) variation in different powders and

carriers.

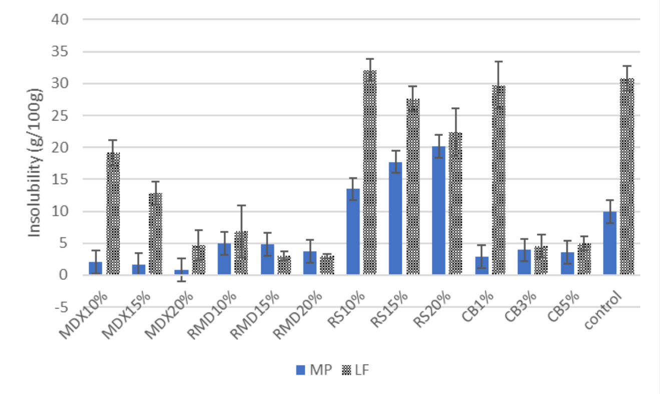

Fig. 6 Insolubility index (Isi) variation in different powders and carriers.

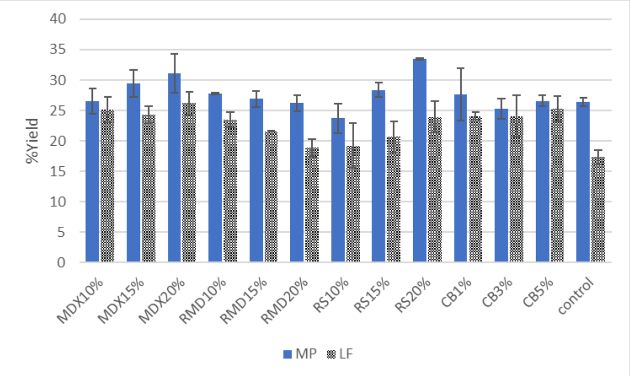

Fig. 7 Yield (%) variation in different powders and carriers.

Moisture and Aw

The carrier compound is a processing aid to improve powder yield and quality. Maltodextrin is a commonly used carrier due to its economic and demonstrated ability to increase powder yield, solubility, and bulk density, whereas, in terms of nutritional value, it is unsuitable for some consumers due to its high glycemic index. This research uses prebiotic carriers such as Resistant maltodextrin (RMD) and resistant starch (RS), ranging from 10%, 15%, and 20% of milk solids. Cellobiose (CB) is used only in a range of 1%, 3%, and 5%, unlike maltodextrin (MDX).

The results on drying plain milk powder (Fig.4-7) showed the highest water activity, and plain milk powder with 10% RS had similar moisture content but the lowest water activity. At the same time, plain milk powder with RS at 10, 15, and 20% showed the lowest water activity and was not different from other formulas except for the formula without the carrier. In addition, plain milk powder with no carrier is similar to plain milk powder with a CB trend. This result shows the complex relationship between carrier type and chemical structure-bound water, affecting moisture content and water activity (Aw). However, all samples' moisture content and water activity (Aw) were within the range specified in the product standard, at a moisture content of less than 5% and a critical water activity of less than 0.43. This behavior has also been reported in a previous study [15].

Insolubility Index

The insolubility index (Isi) is an indirect method that measures the inverse of solubility. This study was subjected to constant heating to compare the carrier properties of different types of milk powder. Isi of milk powder might be attributed to the unfolding of β-lactoglobulin, which binds with casein. Fouling could also be caused by the heating equipment utilized during the drying process and increase with the particle diameter and the air temperature [16]. The Isi of plain milk powder with 10-20% RS was high due to the insoluble properties of RS carriers to the no carrier. The Isi was even higher, which can be influenced by the carrier type and the binding between RS molecules and milk proteins, whereas adding other carriers such as MDX and RMD, the Isi of milk powder was less than 5 mg. The addition of 20 % MDX had the lowest Isi, not different from 10 % MDX and 20 % MDX, due to the carrier properties that improved the solubility of the powder milk quality. Further, a plain milk powder containing carriers, except RS, was found to have low Isi or good solubility within the standard. The Isi of plain milk powder generally ranged from 3.9 to 113.5 mg, also related to the degree of heat exposure to the sample and changes in the whey protein structure [16].

Powder Yield Rate

The type of carrier agent showed no significant effect on the process yield. However, the process yields of the powders containing 10-20 % RMD, 10-20% RS, 10-20%, 10-20% RS, 1-5% CB was slightly lower than that of the maltodextrin (MDX) and resistant starch (RS). The lower yield of cellobiose powder compared to maltodextrin powders is due to its lower glass transition temperature of 102°C. This causes the particles to stick together and clump within the spray dryer. On the other hand, maltodextrin DE12 with less than 5% moisture content has a glass transition temperature of around 160°C [18].

Predicted Glycemic Index (PGI)

All formulas with carriers increase carbohydrate content, affect starch and sugar digestion (Fig. 8-9), and decrease protein and fat, but plain and lactose-free milk powder with RMD and RS can increase unavailable carbohydrates or dietary fiber. Corresponding to the predicted glycemic index (PGI) of the plain and lactose-free milk powder with the prebiotic carrier has a PGI of 28-30 (Table 3) and 48-50 (Table 4), respectively that does not differ from milk powder without a carrier, and milk powder with MDX have PGI differs from other formulas and differ from no carrier by MDX20 have highest PGI at 36.04±1.05 and 60.44±1.29 respectively.

Other than PGI, Glycemic Load (GL) is one step to consider, taking into account the speed of glucose conversion and the amount of carbohydrates contained in a given food that impact blood sugar. It considers the speed and amount of carbohydrates converted to glucose, thus involving available carbohydrates. Both milk powders with MDX carriers have the highest value at MDX, at 20%. Therefore, using maltodextrin as a carrier in milk powder promoted the increase of milk powder's GL to high GL. MDX is an available carbohydrate; higher MDX also means higher GL. In contrast, milk powder with the prebiotic carrier (unavailable carbohydrate), such as RMD at 15%, is the lowest GL and does not significantly differ from RMD at 10% and RMD at 20%. Although the GL value of milk powder without a carrier and CB is higher than RMD, there was a moderate GL value range from 11-19 GL values. The results confirm the previous study [7].

The results of lactose-free milk powder drying using different maltodextrin-substituted prebiotic carriers, namely RMD and RS, at 10-20% and CB at 1-5% showed the physical and chemical composition such as moisture content (%MC), water activity (Aw), Powder yield (%Yield), Insolubility (Isi) and color in CIE Lab system. Adding MDX at 10-20% to the lactose-free milk powder formulation can enhance the quality of milk powder when used in larger quantities. This results in a decrease in %MC and Aw, higher solubility quality, increased yield percentage, and a colorvalue similar to a formula without carrier substances. Additionally, except CB, prebiotic carriers such as RMD and RS can be improved to a level comparable to MDX. Lactose-free milk powder with CB at 1% was the highest %MC and was not significantly different from CB at 3% and 5%. At the same time, MDX at 15% had the lowest %MC and was lower than the no-carrier lactose-free milk powder. In addition, the %MC of lactose-free milk powder with carriers such as RMD, RS, and without carriers were not significantly different. It is also possible that the structure absorbs moisture from the CB carrier, a disaccharide classified as reducing sugar. The %MC of lactose-free milk powder with RMD and RS was not significantly different from the formula without carrier added [11].

Meanwhile, lactose-free milk powder with RMD and RS at 10-20% tended to have a drying performance similar to MDX with Aw, which was not significantly different from MDX.

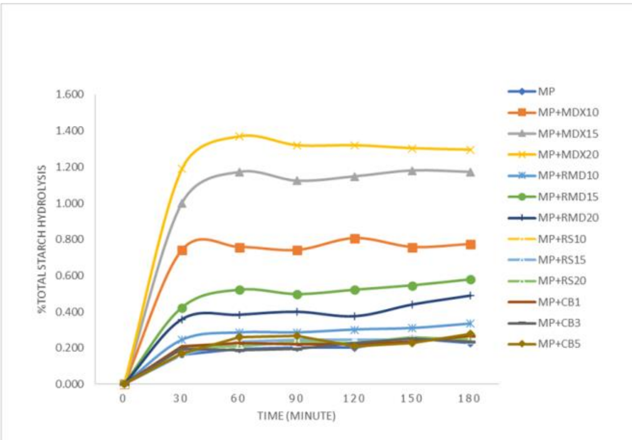

Fig. 8 Starch and sugar digestion in vitro at a period of 0-180 minutes compared to the reference sample (glucose), where MP is plain milk powder.

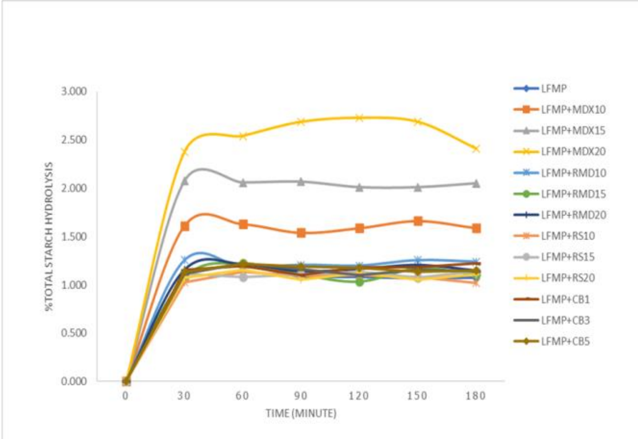

Fig. 9 Starch and sugar digestion in vitro at a period of 0-180 minutes compared to the reference sample (glucose), where LFMP is lactose-free milk powder.

However, from Fig.5, it was found that CB at 1-5% had the highest Aw and was not significantly different from the non-carrier added formulation, whereas RS and RMD at 10-15% had the lowest Aw and were close to MDX at 10-20% as a control formula. Based on the analysis of percentage yield, lactose-free milk powder with MDX at 10-20% demonstrates notable drying efficiency. It exhibits the highest percentage yield and is comparable to other drying agents, such as CB at 1-5%, RS at 20%, and RMD at 10%. However, it is important to note that the moisture content present may influence CB at 1-5% in the powder. Upon comparing carrier-added and non-carrier formulas in lactose-free milk powder, the former shows a significant increase in percentage yield. In particular, RS and MDX carriers exhibit higher yields with higher application percentages, whereas RMD displays decreased productivity with higher application percentages. These findings align with plain milk powder, indicating that RS and MDX possess a less hygroscopic structure than RMD. A carrier with lactose-free milk powder showed a significant decrease in lightness and a change to a more yellowish compared to

Table 3 Predicted Glycemic Index of plain milk powder.

Carriers	PGI	GL
MP+10%MDX	32.54±0.75 ^{b}	13.15±0.50 ^{c}
MP+15%MDX	34.84±0.67 ^{a}	14.98±0.67 ^{b}
MP+20%MDX	36.04±1.05 ^{a}	17.00±0.42 ^{a}
MP+10%RMD	29.80±1.14 ^{cde}	8.64±0.36 ^{gh}
MP+15%RMD	30.78±0.54 ^{cd}	8.44±0.13 ^{h}
MP+20%RMD	30.55±1.20 ^{cd}	8.33±0.27 ^{h}
MP+10%RS	28.53±0.13 ^{e}	10.30±0.13 ^{d}
MP+15%RS	28.90±0.43 ^{de}	10.00±0.12 ^{de}
MP+20%RS	29.10±0.64 ^{cde}	10.41±0.23 ^{d}
MP+1%CB	29.06±0.68 ^{cde}	9.45±0.18 ^{ef}
MP+3%CB	29.04±0.67 ^{cde}	10.46±0.21 ^{d}
MP+5%CB	29.07±0.59 ^{cde}	10.60±0.33 ^{d}
MP no carrier	28.38±0.18 ^{e}	9.52±0.07 ^{ef}

Data are expressed as mean ± S.D. (n = 3), and values followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test. (p >0.05)

Table 4 Predicted Glycemic Index of lactose-free milk powder.

Carriers	PGI	GL
LF+10%MDX	53.22±0.17 c	19.07±0.25 c
LF+15%MDX	57.54±0.36 b	21.22±0.21 b
LF+20%MDX	60.44±1.29 a	25.25±1.05 a
LF+10%RMD	50.59±0.65 d	12.72±0.29 g
LF+15%RMD	49.68±0.89 de	12.26±0.24 g
LF+20%RMD	49.91±0.61 de	12.50±0.28 g
LF+10%RS	49.05±0.46 de	14.27±0.30 f
LF+15%RS	49.09±0.29 de	15.82±0.09 de
LF+20%RS	49.29±0.69 de	14.38±0.56 f
LF+1%CB	48.77±0.67 e	15.85±0.14 de
LF+3%CB	48.64±1.11 e	16.56±0.24 d
LF+5%CB	48.89±0.81 de	16.81±0.21 d
LF no carriers	48.89±0.23 de	14.65±0.29 f

Data are expressed as mean ± S.D. (n = 3), and values followed by the same letters within a column are not significantly different according to Duncan's Multiple Range Test. (p >0.05)

The non-carrier mixture. Our research shows that even a 10-20% difference in the addition of the carrier can impact the color value. Furthermore, RMD observed a decrease in lightness and an increase in yellowness as more carriers were added. This involves a reduction in the percentage of production.

Lactose-free milk powder with MDX found that a 10-20% difference did not affect the color value. RMD had decreased lightness, and yellowness increased with increasing carrier added, corresponding to the decrease in the percentage of production. The carrier addition affects powder quality. At the same time, adding MDX and RS has increased brightness from more carriers. According to yield percentage, the CB color value was found to have the lowest lightness corresponding to the moisture content from the binding between sugar molecules when heated.

IV. CONCLUSION

The physicochemical properties of plain and lactose-free milk powder with prebiotic carriers tested in this study are within the internationally accepted specifications. The experiment showed that carrier type can improve the milk powders' physical properties due to their compositional and structural changes on different carrier and quality attributes. Furthermore, the use of prebiotic carriers for substituting maltodextrin in a lactose-free formula can improve the productivity and quality of lactose-free milk powder products and a source of soluble dietary fiber, increasing nutritional benefit.

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