Hardness of high protein nutrition bars based on milk protein concentrates: a review

Mohamed H. Abd El-Salam ¹, Safinaz El-Shibiny ¹
corresponding author e-mail address: no_salam38@yahoo.com (Scope ID 6603837589)

ABSTRACT

High protein nutrition (HPN) bars are gaining increased global popularity as convenient and high nutritious food products. Proteins of different origins have been used singly or in combinations in HPN but milk proteins (whey protein products, casein, and caseinates) remain the favorable proteins used in HPN formulations. Milk protein concentrates (MPC) of different protein contents are new milk protein ingredients of multifunctional properties for diversified food applications. They contain both casein and whey protein in their native form and ratio found in milk. The use of high protein MPCs in nutrition bars is one of the promising applications for these products. HPN based on different protein sources develops hardness during storage particularly at high temperatures but more pronounced hardness develops on the use of MPCs. Several approaches have been suggested to overcome this problem through modification of MPCs. This review presents an overview of the HPN bar hardness mechanisms and MPC modifications to combat this problem.

Keywords: High protein nutrition bars, milk protein concentrates, polyols, hardness.

1. INTRODUCTION

The high protein nutrition (HPN) bars, are bar-shaped dense nutrient products based on balanced combinations of proteins, carbohydrates, and fats. Vitamins minerals and/or fiber are usually added to enhance the nutritional value of HPN. They are regarded as intermediate moisture foods developed for sports nutrition, muscle building, health supplement, and weight reduction markets [1]. They provide healthy substitutes to conventional snacks because they contain 15% to 35% (wt/wt) of protein. HPN is formulated to have water activity (aw) less than 0.65 in order to inhibit the growth of spoilage microorganisms. Nutritional bars are generally classified as high-protein (HPN bars), balanced nutrition (40%/30%/30% carbohydrates/ non-trans fat/protein caloric-basis), carb conscious, and carbohydrate-rich. In USA, the number of commercial nutrition bars increased from 226 products in 2005 to 1012 product in 2015 whereas the high protein bars shows better marketability than other categories of nutrition bars [2].

High protein nutrition bars were first commercially released in 1986 under the name of “power bars”, as a new segment of energy supplements for athletes to provide them with a source of high level and quality proteins. Soon protein bars have been formulated to appeal to a wide range of health-conscious consumers and became a regular replacement of many protein diets. Globally, sales of protein and nutrition bars in 2016 exceeded 4 billion US $ and are expected to register a CAGR of 4.23%, during the forecast period (2019 – 2024) [3].

Single or mixed proteins of animal and plant sources have been used in the formulations of HPN bars. There is no official standard for the amount of protein to be added in HPN bars formulations but ratios that range between 15 and 35% are usually added [4]. Proteins are added in HPN bars formulations to provide texture, flavour, consumer acceptability and stability of the product. Milk proteins including whey protein products, casein, caseinates and milk protein concentrate vegetable proteins such as soy protein, rice proteins and pea proteins and protein hydrolysates have been used in the formulations of HPN bars. However, Casein, caseinates and whey protein products are heavily used in HPN due to their unique functional and nutritional properties.

With the advent of membrane processing and ion exchange technologies, several milk protein products of diversified functional products became available in the market [5]. Traditionally casein and caseinates have been the main industrially produced milk protein products but growth in the production of whey protein concentrates and milk protein concentrate became evident in recent years.

Ultrafiltration/diafiltration of skim milk followed by concentration and spray drying of the concentrate results in a total milk protein concentrate (MPC) with casein/whey protein ratio (80/20) similar to that of the original milk. MPCs are produced with different protein contents and identified by the number directly following MPC (i.e., MPC80 has almost 80% protein content). MPCs with protein content ≥ 90% are referred to as milk protein isolates (MPIs). The use of membrane filtration in the manufacture of MPCs allows the casein micelles to retain its structure offering emulsion and heat stability, opacity, flavour, and protein fortification for different food applications. Compared to other protein sources, MPC has the highest digestible indispensable amino acid score (DIAAS; 1.18) while the scores for soy protein isolate and whey protein concentrate are 0.91 and 1.10 respectively [6]. Also, MPC can be considered as a natural and rich source for calcium which adds to the nutritional quality of these products [7]. Also, MPCs have unique multifunctional properties such as water holding, gelling, emulsification, foaming and heat stability that diversify its potential uses as food ingredients [7]. Significant (P<0.05) differences in the sensory flavor profile between MPC, caseins and caseinates have been reported [8] whereas MPC showed better bland flavor. Lagrange et al. [9] stated that data on the production of MPC was only
available from USA where 50,000-55,000 metric tons (MT) from
MPC42 and MPC56 and 17,000-18,000 MT from MPC70,
MPC80 and MPI were produced in 2013. Nowadays several
MPCs of variable composition and functional properties are
available in the market.

Although MPCs contain the two protein fractions (casein
and whey proteins) commonly used in the formulation of HPN
bars, bars formulated with MPCs tend to develop hardness, to
become unpalatable, and to have reduced shelf-life. Also, HPN
bars containing high MPC content tend to lack cohesiveness and
are too crumbly [1]. During the last decades, studies have been
directed to investigate changes in the texture of HPN during
storage, the mechanism of hardening of high protein bars
particularly with the use of MPCs in formulation, ways to
overcome this problem through MPC modification and to design
suitable approaches to successful incorporation of MPC in HPN
bars. This paper presents a comprehensive overview of this
subject.

2. COMPOSITION AND INGREDIENTS OF HIGH PROTEIN NUTRITION BARS

High protein nutrition (HPN) bars are composed of blends
of proteins, sugar and /or polyol-based syrups and fats/oils as the
main ingredients. In addition, vitamins, minerals and/or fibers are
usually added to enhance the nutritional value of the products.
HPN bars have typically moisture content that range from 10% to
15% and a low water activity (< 0.65) to avoid microbial growth
and to ensure consumer safety as they are usually made with no
heat treatment applied. Low molecular weight humectants such as
glycerol and sorbitol are added to control the water activity of the
product.

3. HARDENING OF HIGH PROTEIN BARS

Hardening is the main defect of consumer acceptability of
HPN bars. Understanding the mechanism of hardening is a key
element for developing HPN bars of acceptable quality and
storage stability. The number and complexity of the ingredients
used, and the low moisture and low water activity of the different
formulations are the main difficulties in understanding and solving
the problem of hardening. Changes in proteins and their
interaction with small molecules polyol and sugars play the main
roles in hardening of HPN and they should be taken into
consideration. Hogan et al. [10] showed that the hardness of bars
was dependent on protein type, concentration and co-solvents and
that hardening arises from solvent-induced plasticisation and re-
conformation of protein secondary structures.

4. CHANGES IN MILK PROTEIN CONCENTRATES DURING STORAGE

Briefly, MPC is made by ultrafiltration (UF)/diafiltration
(DF) of skim milk where milk proteins, colloidal calcium
phosphate and residual fat are retained in the UF retentate while
the lactose and soluble minerals are removed in the permeate [11].
In order to produce MPC of protein content higher than 65% DF
must be used. The retentate is then spray dried directly or after
further concentration by evaporation under reduced pressure. The
American Dairy Products Institute set standard specification for
MPC and MPI of different protein contents (Table 1). Only a single
study [13] gave data on the mineral composition of commercial
MPC samples (Table 1) which shows marked differences between
MPC of different protein contents. This study [13] showed a high
negative correlation between solubility and Ca content of the
MPC.

MPCs of high protein content usually exhibit poor
dissolution, even after long rehydration time. This has been
explained by the difficulty for water to transport into powder
particles, and the particle surface activity which may decrease the
powder dispersion [14]. High-protein MPC powders (≥ 80% protein)
exhibited the poor wettability, which negatively affected
rehydration. This behavior was attributed to the combined effect
of the high calcium ion activity and poor solvent quality, which
promote the formation of aggregates between casein micelles [15].

The changes in the texture and structure of milk protein
concentrates (MPC) have been attributed to decreases in the
interparticle distances, their spatial correlations and diffusivity
between casein micelles during concentration [16]. Both solubility
and flavors of MPC change during storage but only solubility that
received much attention [8]. Solubility of MPC varies depending
on the method and conditions used for measurement [17]. For
example the differences in the solubility of aged MPC were more
pronounced in the presence of sugars than in water [18]. The
changes in the solubility of MPCs during storage are affected by
their protein contents whereas high protein MPCs can be severely
affected by storage at high temperature and humidity [13]. During
storage the percentage of the insoluble materials increased in MPC
which has been attributed to non-covalent interactions between α-
and β-casein [19]. Although, β-LG interact with k-casein and some κ-casein through disulphide bonds the formed aggregates have no significant role in the formation of the
insoluble materials [19]. Anema et al. [20] showed that the
solubility of MPC 85 decreased with time, the insoluble proteins
were caseinins and caseinsins underwent lactolysis. They [20]
postulated that the insolubility of MPC 85 arisen from cross-
linking of proteins at the MPC surfaces. Slight decrease in rigidity
of molecular domains in MPC during storage brought by the
plasticizing effect of moisture was observed by FTIR and NMR
analysis which could facilitate protein interaction and denaturation
[21, 22]. A crust was observed on the surface of the stored
powders by scanning electron microscopy [23]. This crust
consisted of a thin layer of fused casein micelles. Also, the
hydrophobicity at the surface of the particles increased as evident
by X-ray photoelectron spectroscopy analysis and atomic force
microscopy measurements [23]. Mimouniet al. [14, 24] attributed
the decreased solubility of MPC during storage to changed
rehydration kinetics. The release of casein micelles from MPC
particles was suggested to be the rate-limiting step of the
rehydration process which was inhibited with storage. Also,
interactions between and within casein micelles were increased
during storage of MPC leading to compaction of micelles and
formation of a tightly packed surface layer of casein micelles.
These changes may be also responsible for the slow solubilization

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of stored MPC powders [14]. The high calcium ion activity and its gradual transfer from the aqueous phase to the non-aqueous phase surrounding the casein micelles were considered to contribute to insolubility of MPC [25]. The effect of storage temperature on the moisture content of the HPN ingredients was particularly at high temperature, it was hypothesized that the moisture migrates from high αw components to low αw components in order to attain equilibrium [10]. Also, simple sugars in the formulations lose their ability to hold water on crystallization or glass transition and the released water migrates to the protein phase [1]. Consequently, changes in moisture distribution result in the development of hard texture. Also, the differences in the osmotic pressure between phases were considered to be responsible for the observed changes HPN microstructure as it results in segregation of proteins from small polyhydroxy compounds [38]. On the other hand, migration of water and small molecules (such as glycerol) into the protein phase was reported to be responsible to the protein phase [1]. Consequently, changes in moisture distribution result in the development of hard texture. Also, the differences in the osmotic pressure between phases were considered to be responsible for the observed changes HPN microstructure as it results in segregation of proteins from small polyhydroxy compounds [38].

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5. CHANGES IN WHEY PROTEIN PRODUCTS DURING STORAGE

The changes in the solubility of whey protein concentrate during storage were less pronounced compared to MPC. A slight decrease in the solubility of MPC (34% protein after storage at 37°C and 75% humidity for 42 days but pronounced losses in free lactose and available lysine and formation of large aggregates were evident [26]. Hsu & Fennema [27] reported that browning was the most important change in WPC during storage. The storage temperature and time were the most important factors in the developed changes in the WPC and αw were less important. High protein WPC (80% protein) exhibited less solubility than WPC of lower protein content (34%) and in both the solubility decreased slightly during storage at high temperature [28]. The loss in solubility was attributed to thiol-disulphide bonding and Maillard reaction.

6. POLYOLS/PROTEIN INTERACTIONS

Polyols have the capacity to protect proteins from thermal unfolding depending mainly on their molecular volume [29] but the mechanism of these effects still debateable. The stabilizing effect of a polyol originates mainly from its preferential exclusion effect from the protein surface whereas a thin hydration shell is formed on the protein surface and a cluster of many polyol molecules at a distance of 4 Å around the protein indicating no direct contact between the polyol and the protein. Vagenendeet et al. [30] gave evidence for significant electrostatic and hydrophobic interactions between glycerol and specific site chains on the surface of the protein. This formed an amphiphilic surface which prevented the protein from undergoing conformational changes and intermolecular aggregations. Also, electrodynamic force was suggested to have a role in the protein stability due to the polyol cosolvents including glycerol [31]. The type of polyol and protein determine the changes observed in the intermediate moisture high protein model system. Glycerol, sorbitol and maltitol stabilized the native structure of whey proteins, provided the desired texture, and slowed the hardening of the model systems but glycerol was the most effective in this respect [32]. Differences were observed in protein stability with the increase in glycerol concentration depending on the protein nature [33]. Thus the stability of β-LG increased with the increase of glyceral concentration but the stability of α-LA first increased and then decreased beyond 50% glyceral which may be attributed to penetration of glycerol to the protein hydration layer [34].

7. MECHANISM OF HPN BARS HARDENING

Several mechanisms based on moisture migration, phase separation, protein aggregation and Maillard reaction have been proposed to explain the developed hardening of HPN but no single mechanism has agreed upon. Table 2 summarizes the different proposed mechanisms for HPN hardening. More than one of these mechanisms may be responsible for the developed hardening of HPN.

Differences in the moisture content of the HPN ingredients were responsible for the hardening of HPN bars [10]. During storage, particularly at high temperature, it was hypothesized that the moisture migrates from high αw components to low αw components in order to attain equilibrium [10]. Also, simple sugars in the formulations lose their ability to hold water on crystallization or glass transition and the released water migrates to the protein phase [1]. Consequently, changes in moisture distribution result in the development of hard texture. Also, the differences in the osmotic pressure between phases were considered to be responsible for the observed changes HPN microstructure as it results in segregation of proteins from small polyhydroxy compounds [38]. On the other hand, migration of water and small molecules (such as glycerol) into the protein phase was reported to be responsible for the observed changes in the microstructure of HPN [35].

Table 1. Composition of milk protein concentrates

<table>
<thead>
<tr>
<th>Component</th>
<th>MPC-40</th>
<th>MPC-80</th>
<th>MPI</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein % min</td>
<td>39.5</td>
<td>79.5</td>
<td>89.5</td>
<td>[12]</td>
</tr>
<tr>
<td>Fat % max</td>
<td>1.25</td>
<td>2.5</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Lactose % max</td>
<td>52.0</td>
<td>9.0</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Ash % max</td>
<td>10.0</td>
<td>8.0</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>Moisture % max</td>
<td>5.0</td>
<td>6.0</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Ca mg/100 g</td>
<td>903-956</td>
<td>1423-1496</td>
<td>1436-1506</td>
<td>Modified from [13]</td>
</tr>
<tr>
<td>Mg mg/100 g</td>
<td>83-89</td>
<td>68-80</td>
<td>66-69</td>
<td></td>
</tr>
<tr>
<td>K mg/100 g</td>
<td>1134-1177</td>
<td>217-336</td>
<td>199-266</td>
<td></td>
</tr>
<tr>
<td>Na mg/100 g</td>
<td>284-303</td>
<td>45-100</td>
<td>52-64</td>
<td></td>
</tr>
<tr>
<td>P mg/100 g</td>
<td>816-882</td>
<td>375-1109</td>
<td>1083-1118</td>
<td></td>
</tr>
<tr>
<td>Cl mg/100 g</td>
<td>1049-1059</td>
<td>70-213</td>
<td>155-183</td>
<td></td>
</tr>
<tr>
<td>Total minerals</td>
<td>4279-4456</td>
<td>2614-3339</td>
<td>3022-3173</td>
<td></td>
</tr>
</tbody>
</table>
Aggregation of proteins during storage is another factor for the hardening of HPN. In a model system of HPN based on WPI, addition of cysteine and N-ethylmaleimide (NEM) reduced hardening [36]. Formation of thiol-disulphide bonds was suggested to dominate for the hardening at the early stages of storage while the non-covalent interactions were responsible for the hardening in later stages of storage.

Phase separation into protein-rich and carbohydrate-rich phases has been proposed as a mechanism for the hardening in HPN bars due to the preferential exclusion of sugar/polyols surrounding the protein molecules [37]. The decreased protective effect of polyols on protein structure and closer proximity of protein molecules would increase the protein-protein and protein-

moisture interaction resulting in protein aggregation. Hassan & McMahon [41] proposed that the hardening of HPN bars aroused from the interactions between the co-solvents and the protein surface and not because of phase separation. The orientation of glycerol on the protein surfaces whereas its carbon backbone masks the hydrophobic regions thus avoiding a decrease in entropy of water molecules.

Zhou et al. [40] showed that the early stages of the Maillard reaction caused little changes in the hardness of HPN. On further storage, dramatic modifications were developed in proteins with the formation of high-molecular-weight polymers and significant hardening of HPN bars.

Table 2. Proposed mechanisms for hardening of high milk protein bars.

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Basis</th>
<th>Supporting evidences</th>
<th>Suggested steps to control</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture migration</td>
<td>1-Non-equilibrium aw distribution between bar constituents leading to of moisture migration from high to low aw constituents 2- Loss of the ability of sugars to hold water either by crystallization or glass transition which results in migration of moisture to the component proteins. 3- Migration of small molecules into protein particles.</td>
<td>Changes in microstructure and conformation of proteins. Marked decrease in mobility of solid-like domains of water and low molecular weight polyhydroxy components, which may indicate glucose crystallization. Reduced mobility of small molecules and changes in microstructure.</td>
<td>1-Minimizing the osmotic differences between bar components 2-Selection of type and concentration of used protein concentrate.</td>
<td>[10] [1] [35]</td>
</tr>
<tr>
<td>Protein aggregation</td>
<td>Formation of intermolecular disulphide bonds and non-covalent interactions</td>
<td>Reduced aggregation of WPI via thiol-disulphide was positively correlated with bar softening</td>
<td>Minimizing protein aggregation</td>
<td>[36]</td>
</tr>
<tr>
<td>Phase separation</td>
<td>Separation of the protein from the sugars into two distinct phases High osmotic pressure of sugar/glycerol phase.</td>
<td>Phase separation between proteins and carbohydrates. Low molecular mobility of proteins.</td>
<td>Selection of polyol/sugars to be preferentially excluded from the salvation layer surrounding proteins.</td>
<td>[37] [38]</td>
</tr>
<tr>
<td>Maillard reaction</td>
<td>Glycation of proteins</td>
<td>Replacement of reducing sugars with non-reducing polyol minimized changes in texture</td>
<td>Use of non-reducing polyol in formulation</td>
<td>[39,40]</td>
</tr>
</tbody>
</table>

8. MODIFICATION OF MPCS IN ORDER TO REDUCE THE HARDNESS OF HPN BARS

Industrial production of MPCs utilizes basically ultrafiltration (UF) and diafiltration (DF) of skim milk without pH adjustments with or without further removal of water by evaporation under vacuum followed by spray drying for the obtained retentate [42]. The protein content of the obtained MPC can be manipulated by changing the number of DF stages. Solubility is considered as the most important functional properties of MPC that determine the expression of other MPC properties [17]. Reduction of solubility of the high protein MPC during storage particularly at high temperature is a major problem that limits its use in many food applications including HPN [17]. Therefore, modifications in MPC should target decreased hardening and improved cohesion being the two important quality attributes for HPN acceptability [43]. Specifically modified MPC (PowerProtein™ 4857 andPowerProtein™ 4861) produced by Fonterra™ have been reported suitable for inclusion in HPN formulation with minimal hardness development but increased crumbliness during storage [43]. Several approaches have been developed to modify the conformational structure, functional properties and storage stability of high protein MPCs (>80% protein).

8.1. Reducing calcium content of MPCs.

Partial removal of Ca was reported to improve the stability of MPCs during storage as apparent from its improved solubility. Acidification of skim milk before ultrafiltration, addition of monovalent cations or calcium chelators, and injection with CO2 have been used to reduce the Ca content of MPC. A decrease in the pH of skim milk during UF was reported to affect the integrity and supramolecular structure of casein micelles due to the partial removal of Ca [44, 45] and the internal structure of the non-dissociated micelles became more homogenous. Replacement ~ 30% of Ca with Na in MPC powder was carried by contacting a aqueous solution of MPC with a strong cation ion exchanger in the sodium form [46]. Partial removal of Ca (0-38.7%) using ion exchange treatment was accompanied by increased dissociation of casein from casein micelles and the size of casein micelles...
decreased markedly [47]. Injection of CO₂ in skim milk before and during UF significantly decreased the zeta-potential and increased casein micelle size and 28 and 34% decrease in ash and Ca contents respectively of the resultant MPC [48]. The modified MPC80 had significantly higher solubility after storage both at room temperature and at elevated temperatures. Adjusting the pH of skim milk to pH 5.9 before UF exhibited minimal effect on membrane performance and resulted in MPC of optimum emulsifying properties [49]. Addition of 150 mM NaCl or KCl during diafiltration reduced the Ca content and changed the partition of minerals and proteins between the colloidal and soluble phases of the resulting MPCs [50, 51]. The retained high solubility of NaCl or KCl treated MPCs during storage was attributed to the modification in powder hydrophobicity and sulphhydryl-disulphide interchange reactions and/or increased electrostatic repulsion between casein micelles. Addition of 20-30 mM calcium chelators (EDTA or citrate) to skim milk prior to UF resulted in MPC with enhanced solubility and heat stability [52]. The enhanced solubility was explained by the partial removal of Ca and modification of casein micelle structure. Reducing the Ca content of MPC altered its emulsifying properties [53]. Compared with emulsions formed with higher calcium MPCs emulsions formed with low calcium MPCs were finer with lower total surface protein concentration and altered protein composition [53].

8.2. Modifying the manufacturing steps of MPC.

Treatments of concentrate prior to spray drying affected the solubility of the obtained MPC. High shear treatment (high pressure homogenization, microfluidization and ultrasonication) increased the nitrogen solubility of MPC powders but microfluidization was most effective in improving the long term solubility of MPC during storage [54]. Application of combined high hydrostatic pressure (HHP) and heat (200 MPa and 40°C) for concentrate before spray drying improved the solubility of the obtained MPC [55]. This treatment increased the solubility of MPC from 66% to 85% and the powder retained the initial solubility for 6 weeks at 20°C and 85% of the initial solubility after 12 mo of storage. The HHP assisted improvement in MPC solubility was attributed to an increase in the non-micellar casein content. Preparation of concentrate by combined UF and evaporation steps resulted in MPC80 of higher ash, total calcium, and bound calcium contents compared to concentration with only membrane filtration but with no marked influence on powder solubility [56]. Hydrodynamic cavitation (HC), a process of vaporisation, bubble generation and bubble implosion which occurs in a flowing liquid as a result of a decrease and subsequent increase in local pressure, decreased markedly the viscosity of UF skim milk retentate and improved the performance of the spray dryer [57]. The HC treatment improved the bulk density and tapped density of the obtained MPC powder indicating smaller particle size but had no effect on the solubility of the product. The effect of HC treatment on the changes in the solubility of the stored MPC was not studied. Spray drying conditions affect the morphological properties and distribution of constituents within the MPC particles and intern the solubility of the powder. The lipids and proteins were reported to be preferentially located at the particle surface whereas lactose was found in the core irrespective of the drying temperature. However, surface enrichment with lipids and proteins increased in powders spray dried at low outlet pressure [58]. At low inlet air temperature MPC particles had spherical shape while those obtained at high inlet air temperature appeared deflated and exhibited low solubility due to protein denaturation [59]. Increasing the solids in the retentate reduced the shrinkage, increase the rate of temperature rise during drying and slowdown the rehydration of the obtained MPC [60]. Protein cross linking was carried out by treatment of concentrate with trasglutaminase (0.3 unit/g protein) before spray drying but small textural differences were found between the cross linked MPC and the control [61].

8.3. Mechanical treatments of MPC powder.

Extrusion of MPC induces the formation of disulphide bonds and may create non-reducible protein association in the texturized product and in turn modifying its functional properties [62]. The extruded MPC80 had reduced solubility, surface hydrophobicity and water holding capacity suggesting its suitability for use in HPN bars [62]. This has been proved by incorporating extruded MPC80 in HPN formulation as the obtained product was less prone to phase separation and low textural changes during storage but these changes were not related to disulphide bonds formation [63]. MPC powder (85% protein) of fine (22 μm) and coarse (49 μm) particle sizes were prepared using jet-milling of control (86 μm). Reducing the particle size improved the ability of MPC to plasticize within HPN and in turn the cohesiveness and textural stability of the HPN bar [64]. Extrusion-porosification increased the number and size of pores in powder particles and improved significantly the rehydration properties of MPC [65].

8.4. Enzymatic hydrolysis.

Limited hydrolysis of MPC 80 with chymotrypsin, trypsin, pepsin and papain improved its solubility within the pH range of 4.7-7.0, reduced its surface hydrophobicity and gel strength [66]. Also, the emulsifying properties of MPC were improved by hydrolysis with trypsin and chymotrypsin. However, these hydrolysates were not tested in the formulation of HPN bars.

9. EFFECT OF USING MODIFIED MPC ON THE HARDNESS OF HPN BARS

Few studies have been done on the effect of using modified MPC on the textural properties of HPN bars. Using MPC as the only protein source to provide 30% protein in the formulations [61, 67].TGas cross linked, calcium reduced, toasted and texturized MPCs were tested for their effects on HPN textural properties (Table 3). These results concluded the TGase cross linking and calcium reduction and toasting did not improve the storage stability of HPN bars compared to the unmodified MPC. However, the use of extruded MPC improved the storage stability of HPN and MPC modified by extrusion can be considered as promising candidates in the formulation of HPN bars.
10. CONCLUSION

High protein nutrition bars produced with MPC are prone to develop textural changes during storage, particularly at high storage temperatures. Modification of MPC by reducing its calcium content, cross linking using and toasting had no practical advantage over the unmodified MPC with respect to textural changes in HPN bars during storage while extrusion gave promising results. Blending MPC with WPC was reported to improve the texture of HPN bars during storage [43]. This trend needs further studies using other protein sources. Formulation and the ratio of the used ingredient have received much less attention in the studies on the use of MPC in HPN bars. These factors were reported to be of notable impact on the rheological properties of HPN bars [68]. Several additives can reduce the hardness of HPN bars during storage and needs to be investigated in HPN based on the use of MPC. Addition of a low concentration of xanthan gum was reported to soften the high protein intermediate-moisture model system containing sodium caseinate [69]. Also, the addition of SiO2 and Ca3(PO4)2 as anticaking agents slowed down the increase in hardness and inhibited the Millard reaction in HPN based on whey protein concentrate [70].

5. REFERENCES


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