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Review Article

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Comprehensive Reviews on Effect of Water Activity on the Shelf-life Extension of Indian Traditional Dairy Products

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Abstract

India is the largest milk producer in the world. For safe processing, distribution, and storage dairy industries require a mechanized system with modern technologies. Therefore, a major part of the fluid milk production is converted into traditional Indian dairy products. Approximately, 50% of total milk production is converted into dairy products where traditional dairy products share around 90% of the total milk products consumed in India. However, the shelf-life of traditional dairy products is the major concern due to their short shelf-life under ambient conditions. Several studies reported that by maintaining the optimum water activity, the shelf-life of traditional dairy products can be extended significantly. Most of the indigenous dairy products comes under the intermediate moisture range (a_w > 6). The moisture sorption isotherm (MSI) of most indigenous dairy products showed a sigmoid type II pattern. The negative temperature coefficient of equilibrium moisture content (EMC) shows that water activity above 0.5 exerts an increasing interactive effect in most dairy products during storage at a temperature above 20 °C. The aim of current review was to study the effect of storage temperature on water activity and MSI as well as shelf-life of indigenous dairy products.

Keywords

Water activity, Dairy, Moisture sorption isotherm, Milk, Sweets

Introduction

Traditional Indian dairy products are liked by many consumers, but their reach is limited only to the local market due to various constraints (i.e., temperature, moisture content, packaging material, storage conditions, etc.) which affects their physical, biochemical, and microbiological quality. India is the largest milk producer with an annual production of 221.1 million tons in 2021 - 22 [1] and accounts a major share of total milk production in the world. Production of milk in India is surplus mainly in rural areas where the people are habitual to consume milk mainly in its liquid form and the remaining milk gets converted into different traditional products, such as curd, lassi, paneer, khoya, etc. Manufacturing of traditional dairy products has a great social, cultural, religious, medicinal, and economic aspect in India. But variation in people's habits and habitat, as well as religion widely affects their milk consumption and utilization trends. In India, 50 - 55% of total milk production is converted into a variety of traditional dairy sweets such as khoa, peda, barfi, dudhchurpy, rabri, paneer, chana, kheer, basundi, makkhan, ghee, etc. Small scale sweet makers and halwaies, by culinary skill, practicing different production processes such as heat desiccation, heat acid coagulation, and fermentation to produce various traditional dairy products. It was reported that approximately 50% of total milk production

is converted into dairy products where traditional dairy products share approx. 90% of the total milk products consumed in India [2], therefore, having a great commercial and economic significance. According to United States Department of Agriculture, 50% of total milk production of India is consumed as such in liquid form while 35% of it is converted into the traditional dairy products whereas 18% of it is consumed in the form of butter, ghee, milk powder and other processed dairy products [3]. In traditional Indian dairy products khoa is used as a base material for various relish sweets (i.e., peda, barfi, kalakand, etc.,) and contributes a major share (5.5%) of total milk products [4, 5]. The preservation of milk solids for a long time can provide considerable employment opportunities with a handsome remuneration mainly in rural areas through value addition to raw milk [6]. Owing to surplus production and commercialization of milk, the extension of shelf-life is the key factor that allows its safe storage and convenient distribution. Unlike other food products, commercial production of traditional dairy products requires a mechanized system of modern technologies. In general, the shelf-life of traditional dairy products commercially ranges from few days (at 25 ˚C) to few weeks (at 4 ˚C), which restricts their large-scale manufacturing and transportation [7]. Over the last few decades, researchers have paid considerable attention to the application of some well-known technical concepts such as water activity, crystallization, glass transition, etc., and developed innovative techniques for manufacturing, packaging, storage, and marketing for dairy products. There are various physico-chemical and microbiological factors limiting the shelf-life of milk products. Studies suggest that water content is one of the major factors that highly influence the quality and stability of traditional dairy products. Water activity and moisture sorption behavior of traditional dairy products differ under different storage conditions. An increase in temperature during storage influences equilibrium relative humidity of food and thereby increases water activity and deterioration of product quality. Therefore, understanding the effect of water activity could be the simplest way of assessing the possible changes in quality attributes during storage of dairy products. In this review, the role of water activity and moisture sorption behavior on quality, stability of food in general and in Indian traditional dairy products are discussed comprehensively.

Water activity

Usually, water is the major component of almost all foods including milk and milk products. The stability of traditional dairy products strongly depends on the mode of water binding to their components (particularly protein and lactose). The evaluation of quality as well as shelf-life requires a precise and prudent interpretation of the water content of the food. Quality characteristics of food extremely influence their water sorption properties (i.e., adsorption or desorption of water), chemical potential, and bond energy for water interaction. In food, water is present in various forms, i.e., bound form, adsorbed or less tightly bound form, and unbound/active form or free form. Water that is absorbed by the specific binding sites of food molecules (i.e., carbohydrate, protein, and minerals) known as bound water or un freezable water. This bound form of water is un freezable (even at -40 ˚C), but it is unavailable

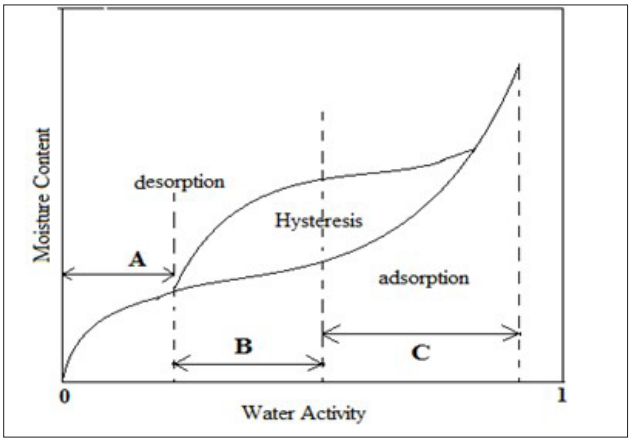


Figure 1: Sorption isotherm for a typical food product.

for the chemical reactions and acts as a plasticizer in food. The bound form of water has an important role in producing desirable physico-chemical properties including texture in dairy products [8]. However, most dairy products also contain some amount of less tightly bound water which works as a solvent for water-soluble molecules, but unavailable for deteriorative reactions. The major cause of physiological, biochemical, and biological changes in dairy products is the presence of a free, unbound, or active form of water which is highly responsible for the short shelf-life [9-12]. The measurement of these various forms of water in dairy products is closely related to their water activity and can also be illustrated through sorption isotherm (Figure 1).

Sorption isotherms

Food scientists and technologists envisaged MSI as an extremely valuable tool for predicting the potential changes in food quality and process development such as a selection of packaging material and determination of storage conditions [13, 14]. MSI of an ideal food highly influences by the surface area and number of specific moisture-binding sites which is also associated with product physical characteristics including porosity and microstructure. Whereas, the storage temperature of food influences the monolayer moisture content, number of adsorbed waters, density of sorbed water, surface area of adsorbent and percent bound water. Like other hygroscopic foods, dairy products also sorb moisture eventually from their surrounding atmosphere till equilibrium reaches among them [15-19].

Therefore, sorption isotherm can be used to understand the thermodynamic relationship between water activity and EMC of dairy products when surrounding conditions (i.e., temperature and pressure) are constant. Indeed, EMC cannot be recognized only through the adsorption phenomenon but also needs to be considered desorption process at different temperatures. A static gravimetric method is the most widely used technique to determine the sorption behavior of dairy products where saturated salt solutions are used to fix the relative humidity of the surrounding environment (Table 1). It was also perceived that excess partial molar enthalpy is the resultant of water activity coefficient which also depends on temperature and can be expressed as [20-22].

Table 1: Salt solutions and their corresponding relative humidity at 5, 20, 25, 30 and 45 °C.

Salt solution	Relative humidity (%) at different temperature (°C)				
	5	20	25	30	45
Lithium chloride	11.30	11.40	11.30	11.20	11.10
Potassium acetate	23.50	23.10	22.50	21.60	20.60
Potassium carbonate	43.10	43.20	43.20	43.20	43.50
Magnesium nitrate	58.90	54.10	52.90	51.40	46.90
Potassium iodide	73.30	69.90	68.90	67.90	65.40
Sodium chloride	75.70	75.50	75.30	75.10	74.50
Ammonium sulphate	82.40	81.30	81.00	80.60	79.50
Potassium chloride	87.70	-	84.30	-	81.70
Potassium sulphate	-	97.20	-	96.60	-

$$\left[\frac{d\ln\gamma_i}{dT}\right]_P = -\frac{h_i^E}{RT^2} \quad (1)$$

Clausius-Clapeyron equation of classical thermodynamics is a consequence of integration between two different temperatures that can be also used to determine sorption isotherm of dairy products at different temperature [23].

$$\frac{d\left(\ln a_w\right)}{d\left(\frac{1}{T}\right)} = \frac{\Delta H}{R} \quad (2)$$

Where, a_w is the water activity, T is the absolute temperature, ΔH is the heat of sorption and R is the gas constant.

Despite this, some empirical equations have also been proposed to express the temperature dependence of water activity. It was reported that the stability of dairy products depends on the mode of water interaction with product molecules and their surrounding conditions. The knowledge of sorption isotherm deals with defining the interaction between the product solids and the moisture content [8, 24, 25].

Fundamental concept of sorption isotherm

A typical shape of sorption isotherm (Figure 1) can be used to illustrate how water molecules interact with food components.

Water sorption characteristics of food differ even at identical temperature and pressure; therefore, each product has its specific sorption curve. A typical shape of sorption isotherm is sigmoid, identical in most foods. The sorption curve comprises both adsorption and desorption, which could be obtained by a consequence of adsorption of moisture to food molecules or by desorption of moisture from food molecules. Often, in a sorption isotherm, the curve obtained by the adsorption process is not the same as desorption even in the same food [26]. Adsorption and desorption phenomena are used to predict the physical properties of food and their thermodynamic relationship with water. Both curves differ with each other due to the occurrence of conformational and structural changes in food molecules as well as changes in their water-binding potential. Sorption isotherm also assimilates the phenomenon of hysteresis, the area between adsorption and desorption isotherm of a sorption curve. The phenomenon of hysteresis still needs

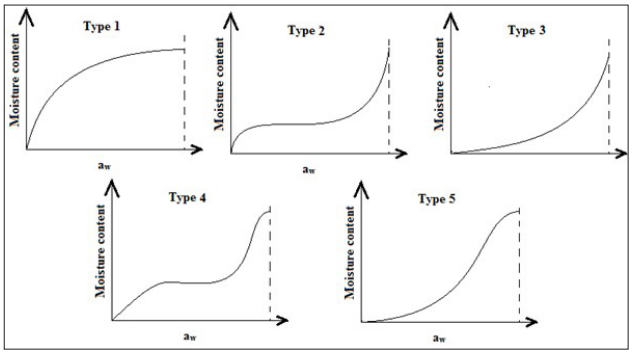


Figure 2: Types of isotherms described by Brunauer et al. [30].

to be explained for understanding the relationship between adsorption and desorption phenomenon. In the recent past, various hypotheses were suggested by researchers to explain hysteresis, however, they were unable to explain it completely. Often, open-pore theory, molecular shrinkage theory, swelling fatigue, and capillary condensation theory as well as a wetting theory of the Ink bottleneck are used to explain the phenomenon of hysteresis. All these hypotheses suggest that the phenomenon of hysteresis, owing to high a_w, is only limited to the region of capillary condensation. However, practically it has been also observed that hysteresis extends to a maximum range of isotherm [27, 28].

Figure 1 illustrates the low water activity of food where water adsorbs only at the surface sites. The dissolution of soluble components, mainly carbohydrates and proteins of food become more prone to their surrounding moisture content which leads to an increase in water activity during adsorption and for desorption vice-versa. A report illustrated the phenomenon of hysteresis on mint leaves by dividing the adsorbed moisture content into that of desorbed moisture [20]. Their study shows that the phenomenon of hysteresis increased gradually up to a water activity level of 0.75 at 25 °C after which the difference was decreased gradually. Classification of the five different types of sorption curves based on their shape was done [29], as illustrated in figure 2.

Type 1 curve is designated as Langmuir or similar isotherms bearing a gradual increase in water activity with increasing moisture content. This derivative of sorption isotherm exemplifies that the curve obtained during the adsorption phenomenon becomes convex upward with increasing moisture content. Tentatively, it has also been observed that this type of sorption isotherm elaborates on the interaction of the water monomolecular layer at the internal surface of a material.

Type 2 sorption isotherm is sigmoid, and the curve becomes concave upward with increasing moisture content. It describes that the product is multilayered in the internal surface.

Type 3 plot is known as Flory-Huggin's isotherm. It shows changes in the properties of a solvent or plasticizer (glycerol) above the glass transition temperature.

Type 4 plot recognizes the adsorption behavior of a swellable hydrophilic solid till a maximum of site hydration is reached.

Type 5 plot is known as the Brunauer-Emmett-Teller (BET) multilayer adsorption isotherm generally it can be obtained by the adsorption of water vapor on charcoal. This plot is closely related to sorption isotherm type 2 and type 3.

Among different types of sorption curves, type 2 and 4 are the two most frequently observed sorption curves in food [30, 31]. Based on these isotherms there are several mathematical models and equations being developed to describe and predict the water activity as well as sorption behavior of any food containing solid phase, including traditional Indian dairy products [32, 33].

Application of sorption models

The vapor-liquid equilibrium of an osmotic solution or food can be perceived by most thermodynamic models that are based on a relation allied with Gibbs's free energy of a system [34]. It is a well-known phenomenon that a product reciprocates to its surrounding environment by a continuous exchange of moisture which is also an attribute of change in free energy (the energy required to transfer water molecules from one state to another i.e., from solid to vapor state and vice versa). This shift in free energy is allied with the measurement of work done by the system to complete the sorption process effectively. A study reported that the free energy gradient across the interface becomes zero when the equilibrium reaches [35]. The degree to which food combines with water molecules can be measured as binding energy which is a consequence of the difference between the heat of adsorption of moisture by the food and heat of condensation of water at identical temperature table 1 [36]. These consequences can be studied by implementing principles of thermodynamics to moisture sorption concepts [37]. The surface potential of water sorbed in food can be determined by the concept of monolayer moisture content which is a crucial parameter that specifies the lower limit of dehydrated food. A study insisted that the physical and chemical behavior such as structural characteristics, lipid oxidation, enzymatic, and non-enzymatic browning is reciprocated to monolayer moisture content of dehydrated foods [38, 39]. Based on food composition monolayer moisture content varies from 2 to 15% (wb) [40], whereas water activity for this range of monolayer varies from 0.07-0.35. Formerly, it is controversial that products are most stable at their monolayer moisture content, i.e., a water activity value of about 0.1 - 0.3 [41]. Monolayer moisture content is often accomplished using the BET, Guggenheim, Anderson, and de Boer (GAB) and Caurie isotherm equation [42]. The prediction of monolayer moisture has a significant importance because it is expected that deterioration of food including indigenous dairy products will be less when it contains moisture content below the monolayer values, which is also a consequence of high-water binding energy. Subsequently, it has also been envisaged that the water-binding energy of a food with different moisture content can be determined by combining the BET and Clausius-Clapeyron equations. A study reported a long list of available isotherm models [43]. Commonly, sorption isotherm is presented by using mathematical models based on several empirical, semi-empirical, and theoretical criteria. Among these models, the theoretical BET model has a wide application in the water sorption phenomenon of foods. The application of the BET model is limited to a range of water activity (0.3 - 0.4). Although, BET model of adsorption analysis has some theoretical limitations, the concept of BET monolayer is found to be crux concerning various aspects of dried foods [33, 44]. The equation for the BET model is presented in table 2.

The modified form of BET equation is known as GAB equation. GAB equation is accepted as one of the most effective models for sorption isotherms of food which has great accuracy and validity over a wide range of water activity (0.1 to 0.9) (Table 2) [45].

The GAB equation has also been recommended as a fundamental equation for physical properties and characterization of water sorption of food by the European Project Group COST 90 [46]. Except for these, there are several empirical relations, such as Hasley, Henderson, Chung Pfost, Oswin, Langmuir, Smith, and Caurie's model, that are proposed to describe the sorption behavior of food including indigenous dairy products (Table 2). The goodness of fit can be compared

Table 2: MSI models fitted moisture sorption data.

S. No.	Model	Expression
1	Bradley	In $\ln\left(\frac{1}{a_w}\right)=k_2k_1^M$
2	BET	$\frac{a_w}{(1-a_w)M}=\frac{1}{M_mC_b}+\frac{(C_b-1)}{M_mC_b}a_w$
3	Oswin	$M=a\left\{\frac{a_w}{1-a_w}\right\}^b$
4	Smith	$M=a-b\ln(1-a_w)$
5	Halsey	$a_w=e^{\left[\frac{-a}{M^b}\right]}$
6	Henderson	$1-a_w=\exp(-cTM^n)$
7	Kuhn	$M=\left(\frac{a}{\ln a_w}\right)+b$
8	Chung and Pfost	In $\ln a_w=\frac{-c_1}{RT}\exp(-c_2M)$
9	Iglesias and Chirife	$\ln\left[M+\left(M^2+M_{0.5}\right)^{1/2}\right]=ba_w+p$
10	Caurie	$\ln\frac{1}{M}=\ln\frac{1}{CM_o}+\frac{2C}{M_o}\ln\frac{1-a_w}{a_w}$
11	GAB	$M=M_o\frac{Gka_w}{(1-ka_w)[1-ka_w+Gka_w]}$
12	Modified Mizrahi	$M=\frac{a+a_w(ca_w+b)}{a_w-1}$

Note: a_w is water activity (decimal), M is EMC (decimal, db), M_o is Monolayer moisture content, and a, b, c, C, G and k are model constants.

for each equation and can be evaluated in terms of percent root mean square (RMS) by the equation given as follows:

$$\%RMS=\sqrt{\frac{1}{n}\sum_{1}^{n}\left(\frac{M_{exp}-M_{cal}}{M_{exp}}\right)^{2}}\times 100 \quad (3)$$

Where M_{exp} is the experimental value of moisture content, M_{cal} is the calculated value of moisture content and n is the number of observations (experimental value).

Role of water activity and MSI in storage stability of traditional dairy products

Indian traditional dairy products can be divided based on the method of manufacturing and additives added into three main subgroups: (1). Concentrated dairy products; (2). Cereal based dairy products; and (3). Acid coagulated dairy products.

Concentrated traditional dairy products

Concentrated milk products account highest share of total milk-based products in India. Production of concentrated milk products is limited to regional markets due to their short shelf-life, which varies from a few days to a few weeks. One of the major reasons for their short shelf-life is high moisture content and thus high-water activity. To enhance the shelf-life and storage stability it is essential to determine the MSI of concentrated milk products (i.e., khoa, peda, barfi, rabri, etc.) [4, 5]. Almost all milk products relish by the Indian population is produced through evaporation of moisture from milk which increases the solid concentration in the rest mass. MSI determines the adsorption and desorption properties as well as the influence of surrounding environmental conditions of dairy products (configuration and structure changes). Owing to the large-scale production of concentrated indigenous dairy products, it is essential to determine appropriate packaging materials and storage conditions which directly associated to their shelf life and quality. Prediction of moisture sorption requires fitting various isotherm models to the experimental moisture sorption data. The moisture sorption behavior of various concentrated milk products has been reviewed systematically, i.e., khoa [47], peda [48], dudhchurpy [49], kheer [50], ready-to-use basundi mix [51], sandesh [52], lal peda [53], and rabri [54] for their suitability of large-scale manufacturing and marketing.

Khoa

Khoa is a product obtained by the rapid drying of cow or buffalo milk (goat or sheep) or their combination, containing not less than 30% milk-fat in the final product [55, 56]. It is a heat coagulated and partially dehydrated milk product obtained by the heat desiccation of whole milk up to 65% to 75% milk solids without the addition of any foreign ingredients. It is also known as khoya, khawa, khava, kava, plgho, or mawa. It can be stored for two to three days under ambient conditions and 15 to 16 days under refrigerated conditions [57]. Rancidity was found to be one of the major reasons for deterioration of the quality in khoa, which is mainly influenced by the moisture content. A study analyzed the MSI of khoa at storage temperature of 15, 25, 35 and 45 ˚C and over a water activity range 0.11 - 0.97. The curves obtained were sigmoid (type II) where the GAB equation was suitably fitted to the sorption data. The water activity of freshly prepared khoa was found to be 0.96, which decreased up to 0.9 due to the influence of temperature [58].

The use of humectants plays a major role in reducing the a_w of dairy products. A report suggested that maltodextrin could be a potential humectant for enhancing the shelf life of khoa [59]. They found that the addition of Maltodextrin (2 - 10%) significantly increased the monolayer moisture (from 2.91 to 3.81) content and reduced the a_w of khoa. Another study reported the effect of five selected humectants (polydextrose, maltodextrin, mannitol, sorbitol, and corn syrup) in a_w of reconstituted khoa. They found that the a_w reduction potential of sorbitol was higher at 20% level of concentration among all analyzed humectants. The a_w of reconstituted khoa was reduced from 0.956 to 0.931 by the addition of 20% sorbitol [60].

Peda

Peda is a heat desiccated milk (khoa) based confection having highly cooked flavor but susceptible to microbial spoilage due to its intermediate moisture content and non-acidic nature [61]. Generally, it is expected that peda has a long shelf-life as compared to other khoa-based sweets which may be due to its comparatively low moisture content, high sugar, and application of sever heat treatments during preparation. There are several studies reported to extend the shelf-life of peda such as plain peda and malai peda [48, 62-65]. Brown peda and lal peda are the two very popular varieties of peda known with different names in different states of the Indian subcontinent (such as in Uttar Pradesh as Mathura peda, in Karnataka as Dharwad peda, and in Maharashtra as Mishra peda). These varieties vary based on their intensity of characteristic caramelized color, highly cooked flavor, and long shelf-life [66]. A study reported 10-12% (wb) moisture in brown peda that have a soft body and grainy texture [67]. Yet another study determined the MSI of lal peda at temperature 10, 25 and 37 ˚C over a water activity range 0.113 to 0.868. The MSI obtained were sigmoid shape (type II) at all temperatures [54]. The controlled humid environment was created in a closed chamber to a range of water activity (a_w) values 0.113 - 0.868 over three temperatures. GAB model was found best among five models fitted to the moisture sorption data of lal peda due to its suitability at all storage temperatures and to a wide range of a_w [68]. Sigmoid pattern (type II) in MSI of lal peda was found [54]. The pattern showed low EMC during high-temperature storage as compared to storage under low temperature. The monolayer moisture content of lal peda was found to be in the range of 3.852% to 5.253% (db) using the GAB model at temperatures 10, 25 and 37 ˚C.

Rabri

Rabri is a concentrated, sweetened whole-milk delicacy, containing several layers of clotted cream skimmed off from slowly evaporating milk. It has 2 - 4 days shelf-life at room temperature due to its high fat and moisture content. Knowledge of MSI could be an important aspect of the packaging

and storage of rabri [69, 70]. The studies on MSI of dietetic rabri were carried out for extending the shelf-life and standardizing its proper packaging and distribution. Keeping storage stability in view, The MSI of dietetic rabri was studied [55] at temperatures 10, 25, and 37 ˚C to find out the model best fitted to describe the sorption data. Samples of dietetic rabri having final moisture content 61.7% (wb) were prepared using the standard procedure as described in the outlines of diary technology [71]. Control humid environment was created during storage at a_w range 0.113 - 0.868 for rabri and changes in moisture sorption behavior were analyzed by fitting Halsey, Owsin, Caurie, modified Mizrahi, and GAB models to the moisture sorption data (Table 2). The results suggested that sorption isotherms obtained at 37 ˚C were sigmoid in shape (type II), while the curve obtained at 10 ˚C was type V and at 25 ˚C resulted as type I for all the samples (Figure 2). There were three models out of five best fitted to the experimental moisture sorption data. Halsey's model for 10 ˚C, Caurie's model for 25 ˚C and modified Mizrahi's model for 37 ˚C were found to be good to predict the experimental moisture sorption data of rabri. The results clearly show an increasing effect of hysteresis on the sorption behavior of rabri at low temperatures (10 ˚C), whereas the effect decreased gradually with increasing temperature (37 ˚C).

Dudhchurpy

Modification of the moisture sorption apparatus was done for the equilibrium studies of dudhchurpy at temperature 15, 25, 35, and 45 ˚C [46]. The static gravimetric method was used to create a controlled atmospheric condition at a range of 0.113 to 0.979. The moisture content of a freshly prepared sample of dudhchurpy was 15.41% (w/w) where EMC increased rapidly at low a_w (0 - 0.15), then slowly between a_w 0.15 and 0.78 followed by a steep rise above a_w 0.78. The curve obtained was a typical type II sigmoid according to the BET classification. To predict a_w of dudhchurpy nine equations were fitted to the sorption data out of which Caurie's equation was found best to predict the EMC. The adsorption isotherm of dudhchurpy showed three regions of a typical isotherm as reported for milk protein [72, 73]. Region I showed high water uptake (represented by monolayer moisture which strongly binds with protein) which decreased slowly in region II (it includes multilayer moisture content) and again accelerated in region III (free water content). Caurie's equation (influenced by temperature) was found best to describe the sorption behavior of dudhchurpy in a complete range of water activity [74, 75]. It was also observed that in low water activity region water-binding capacity of dudhchurpy decreased with increasing temperature whereas, at low temperature it resulted in high water-binding capacity. The report suggests that an increase in temperature from 24 ˚C to 35 ˚C resulted in a decrease in water-binding property of protein and carbohydrate concentrate of dudhchurpy [76].

Basundi mix

It is a traditional heat desiccated, sweetened, concentrated milk product having relatively thick creamy consistency, sweetish white to a light caramel color, and aroma where soft textured flakes were uniformly distributed throughout the product [2]. It is a very popular milk product in the western part of India. The shelf-life of the basundi mix is low, limited to a few days at refrigerated temperature. Therefore, several studies were conducted to enhance the shelf-life of the basundi mix. Ready to reconstitute dry basundi mix developed by the application of osmo-air drying and spray drying processes which could remain stable for several weeks at room temperature [52]. The relevant sorption parameters were derived for experimental data of MSI using thermodynamic functions for ready to use basundi mix. Controlled atmospheric conditions were created using static gravimetric method at temperature 5, 25 and 45 ˚C to a water activity range 0.113 - 0.877. The moisture content equivalent to monolayer (Wo) was estimated using GAB and BET equations for basundi mix at definite temperatures (5, 25 and 45 ˚C). The monolayer moisture content of the basundi mix was within the range of 2.1 - 3.6 g water/100 g solids (db) [77]. The result suggests that desorption isotherm of basundi mix is sigmoid type II. An increase in EMC was noticeable with an increasing rate of water activity (above 0.5). However, the temperature played a significant role in influencing the equilibrium between EMC and water activity. The increase in temperature of sorption resulted in a reduction of EMC. The negative effect of temperature on EMC was similar as defined earlier for protein-rich foods whereas, it was also due to an increase in solubility of sugar [7, 78-80]. It reported that an increase in storage temperature speeds up the activation of water molecules which breaks water binding sites of food and lowers the EMC [81].

Cereals based traditional dairy products

Kheer

A partial heat concentrated rice-based sweetened milk dessert called kheer. High water content generally 60 g/100 g of kheer limits its shelf-life from few hours to few days (3 - 4 days under refrigeration) depending on storage conditions. The short shelf-life of kheer is the major constraint for its large-scale manufacturing and organized marketing. The MSI of kheer was studied at different experimental temperatures [7]. They analyzed various recommended models (BET, Halsey, Oswin, Caurie, modified Mizrahi, and GAB models) for making shelf-stable kheer. The desorption isotherm obtained at temperature10, 25 and 40 ˚C was sigmoid type II. GAB model was fitted best to the sorption data at all three temperatures (10, 25 and 40 ˚C). GAB equation predicts the influence on a_w of kheer at different moisture levels which changes due to storage temperature.

Acid coagulated traditional dairy products

Sandesh

A heat-acid coagulated milk product channa is used as a base material for the preparation of sandesh. The moisture content of sandesh generally varies between 12 - 14% (wb) [82]. Sandesh contains less moisture and high sugar content which enables it to be less susceptible to microbial spoilage but prolong storage under ambient conditions adversely affects consumer's acceptability. The moisture sorption behavior of sandesh was determined under a control humid environment at 20 and 30 ˚C using saturated salt solutions (Table 1). There

were various sorption models (BET, Caurie, and GAB model) fitted to the moisture desorption data of sandesh, where the BET model was fitted best at high temperature, however, the GAB model was found adequate to fit desorption data. The sorption isotherm obtained was sigmoid type II at both temperatures. The curve divided into three zones showed similar results as earlier in high protein-containing food. The increase in temperature significantly affected the EMC of sandesh by influencing water activity especially up to 0.6. The monolayer moisture content of sandesh was found to be 5.892% and 5.235% (db) at 20 and 30 ˚C, respectively.

Chhana podo

A traditional heat acid coagulated milk product of the eastern region of India, well known as chhana based delicacies. The product contains a top brown crust and light brown body which is compact to a grainy cake-like texture with internal pores and sweet taste. The moisture sorption behavior of chhana podo was determined at 5 and 35 ˚C using a Rotronic hygroscope water activity meter (Rotronic, Switzerland). The sorption data of the chana podo obtained at temperature 5 and 35 ˚C was evaluated for twelve mathematical models. The acceptability of the BET model for the MSI of chhana podo was limited due to its effectiveness for the narrow water activity range. Iglesias and Chirife and Handerson equations were fitted adequately to the sorption data at a specific range of water activity (0.97 - 0.98). The moisture sorption of the product increased steeply above a_w 0.85. EMC of chhana podo was found to be high at low temperatures, whereas it was decreased with increasing temperature [83].

Conclusion

In most dairy products the phenomenon of sorption accelerated at high water activity which may be due to increased solubilization of solid. Sorption data of most dairy products showed good agreement with popular sorption models. Products like kheer, basundi mix, lal peda, shows agreement with the GAB model, while chhana podo, dudhchurpy, and sandesh with the Caurie's model. Moisture sorption data of rabri was fitted well in Halsey model at 10 ˚C, Caurie's model at 25 and at 37 ˚C it was suitably fitted to the modified Mizrahi model. The reduction in moisture sorption and increase in water binding capacity was observed with increasing temperature in most indigenous dairy products. The monolayer moisture content of dairy products was decreased with increasing temperature. The isosteric heat of sorption is also known as differential heat of sorption that can be used as an indicator of binding energy between sorbed water and food constituents. The isosteric heat of sorption higher than the latent heat of vaporizing pure water vapor indicates high binding energy between sorption sites and water molecules that hold water molecules together in a liquid state. In general, adsorption of moisture initially occurs with high interaction energies on the most active sites. After initial interaction, the less active site was occupied with low binding energies. However, the value of isosteric heat was observed high in some indigenous dairy products like sandesh, khoa, and chhana podo.

Future Recommendation

Water activity is a crucial aspect in shelf-life extension of traditional dairy products. Apart from product basic ingredients such as sugar and product solid contents itself, storage temperature and additives play an important role in regulating a_w of traditional dairy products. The increase in temperature leads to a rise in a_w of traditional dairy products whereas a_w remains low at cold storage conditions. Therefore, maintaining the cold condition throughout the supply chain along with application of additives is the promising technique of maintaining even extending the shelf-life of traditional dairy products. Till date measurement of a_w content as well as sorption behavior of food products including traditional dairy products requires a sophisticated system and a laboratory. Therefore, there is an ample scope of developing an efficient kit/system for on-spot measurement of a_w so that the product a_w can be controlled more efficiently throughout processing and supply chain.

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Conflict of Interest

None.

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