Chapter

Active and Intelligent Packaging of Cheese: Developments and Future Scope

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Abstract

Technological advances and changes in consumer preferences for safer food with better shelf life have led to packaging innovations like smart packaging. Smart packaging systems involve the blend of active and intelligent packaging properties. Most of the smart packaging systems in food sector are mainly focused on fish, sea, food, meat, poultry, fruits and vegetables. With cheese being the major dairy product and its market expanding exponentially, smart packaging systems for cheese are exhaustively addressed in this book chapter. Some of the smart packaging systems pertaining to cheese like antioxidant releasers, antimicrobial packaging, ripening indicator and self-cleaning rinds can hasten commercial acceptance and reliability of cheese products. This book chapter also tabulates the recent data related to production, and consumption of cheese, permitted additives, types of active and intelligent packaging systems explored for cheese and commercial suppliers of smart packaging systems. Along with, future research directions for smart packaging of cheese are also presented.

Keywords: active packaging, intelligent packaging, cheese, dairy products

1. Introduction

Packaging industry stands at third position globally, next to food and petroleum industries contributing nearly 2% of Gross National Product in developed nations [1]. Approximately 51% of all packaging applications are dedicated to food sector [2]. Consumer inclination towards safe and healthy food have led to the development of state-of-the-art and unique approaches in food processing and packaging. One such development is the introduction of smart packaging technologies. Smart packaging although interchangeably used for intelligent packaging at times, refers to combination of active and intelligent packaging [3]. The Framework Regulation on Food Contact Materials (1935/2004) defines "*active materials and articles*" as materials intended to extended the shelf-life or to maintain or improve the condition of packaged food; they are designed to deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food. Similarly, according to Framework Regulation (EC) No. 1935/2004 materials and articles which monitors the condition of packaged food or the environment surrounding the food are defined as "*intelligent materials and articles*" [2]. Most of the smart packaging interventions in food sector

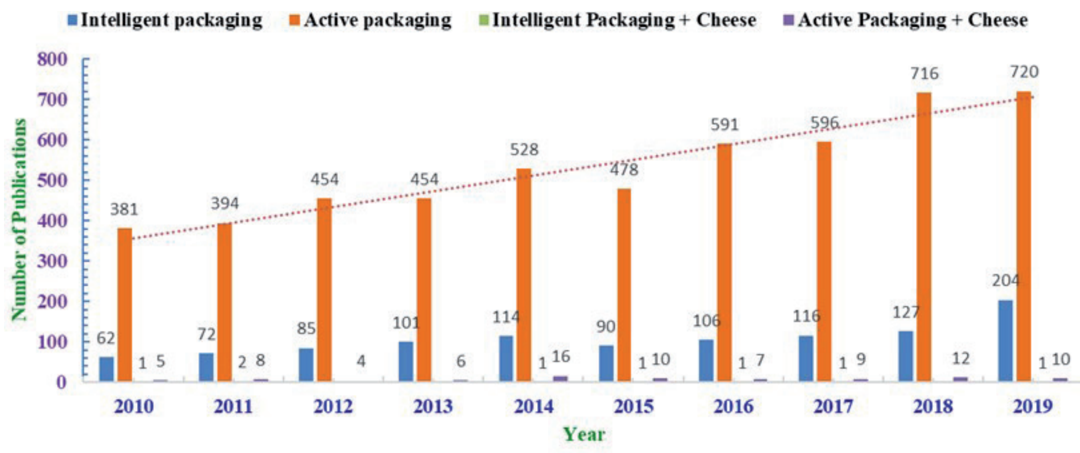

Figure 1.
Graph illustrating the number of publications on active packaging, intelligent packaging and cheese during the year 2010–2019 (Source: compiled from SCOPUS using document search with title, abstract, keywords).

are limited to fruits and vegetables, fish products, meat and seafood [4] indicating huge scope and potential to be explored for dairy products.

Active and intelligent packaging market was estimated at 17.50 billion US $ in 2019 and expected to reach at 25.16 billion US $ by 2025 witnessing a CAGR of 6.78%. Asia Pacific region was identified as the fastest growing market including China, Japan, India and South Korea and North America as the largest market with WestRock®, Honeywell®, BASF® and Amcor Ltd. as the major market players. Oxygen and moisture scavengers are the utmost commercialized forms of active packaging. Gas scavengers for food was the most marketed active packaging technique in USA during 2018–2019 [5]. During past ten years, the research interestedness in active and intelligent packaging has increased steadily as indicated by the trend of peer-reviewed publications in **Figure 1** during 2010–2019. As per a survey conducted by O'Callaghan and Kerry (2016) [6] for applicability of smart packaging to cheese, the future is highly optimistic with consumers willing to pay more on receiving the information provided by these advanced technologies. However, to the best of our knowledge, not a single article has reviewed the application and future research directions of smart packaging technologies in cheese. Therefore, the present review offers insight to active and intelligent packaging systems for cheese and future research aspects.

2. Status of cheese market

World cheese production has shown significant increase from 5.43 million tonnes in 1961, 14.58 million tonnes in 1995 to 22.65 million tonnes in 2015 [7]. About 3000 varieties of cheeses are produced throughout the world and the annual total cheese consumption during 2015–2028 is expected to grow at a CAGR of 1.4% [8]. EU 28 (European Union consisting of 28 countries) stood at first position in cheese export by exporting 841.8 thousand tonnes of cheese. The USA accounted for almost 20% of the world's cheese production and exported 348.5 thousand tonnes of cheese contributing 13.8% of the total export share during 2018 while Japan and Russia were the top export destination [8]. Approximately 40% of world's milk is converted to cheese with France, USA, Iceland, Finland and other developed nations being the major players in cheese production and consumption [7]. The total cheese production in USA was 5,908 million kg, with an import of 176 million kg [8]. Mozzarella is the highest produced cheese variety in USA and several other major cheese

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Country	Production	Consumption	Imports	Exports	Retail Price		
					Cheese type	Currency	Price/kg
EU28	9376	9652	59 (H)	842 (H)			
Germany	2339	2002	32	130	Gouda	EUR	5.98
France	1725 (A)	1721	—	117	Emmental	EUR	8.43
Italy	1101 (A)	1320	10	100	Mozzarella	EUR	4.46
Netherlands	880 (A)	420	—	140	Gouda	EUR	10.98
Poland	825	723	—	53	Gouda	PLN	20.69
Denmark	452	166	—	73			
United Kingdom	426	795	—		Cheddar	GBP	7.28
Ireland	224	31	—	49	NS	EUR	9.60
Austria	200	200	—	—			
Spain	179 (A)	416	—	—	NS	EUR	8.60
Czech Republic	135	201	—	—	Edam	CZK	144.73
Belgium	109	164	—	—	NS	EUR	9.65
Lithuania	102	58		—	Tilsit	EUR	7.34
Finland	87	142	—	—	Edam	EUR	9.08
Hungary	84	129	—	—	Trappist	HUF	1700.00
Sweden	82	201	—	—	Herrgardsost	SEK	90
Latvia	47	39	—	—	Hard cheese	EUR	7.89
Estonia	45	32	—	—	Gouda	EUR	8.24
Slovakia	38 (A)	74	—	—	Edam	EUR	6.55
Cyprus	3 (A)	22	—	—	—	—	—
Luxemburg	3	16	—	—	—	—	—

Country	Production	Consumption	Imports	Exports	Retail Price		
					Cheese type	Currency	Price/kg
Other EU	—	—	17	179	—	—	—
North and Central America							
USA	5908	5668	176	348	Cheddar	USD	11.87
Canada	443	538	31	—	NS	CAD	14.70
Mexico	419	539	123	—	—	—	—
El Salvador	—	—	39	—	—	—	—
Nicaragua	—	—	—	41	—	—	—
South America							
Brazil	755	781	—	—	Mozzarella	BRL	30.49
Argentina	579	574	—	49	Quartirolo-type	ARS	184.24
Chile	101 (B)	198	—	—	Gouda	CLP	6396.00
Colombia	97	100	—	—	—	—	—
Uruguay	45	33	—	—	NS	UYU	143.22
Other Europe							
Russia	473	811	263	—	NS	RUB	412.60
Belarus	332	128	—	210	—	—	—
Switzerland	190 (A)	186	62	68	NS	CHF	13.32
Ukraine	168	198	—	—	Russian (50% fat)	UAH	172.00
Norway	82 (C)	101	—	—	—	—	—
Iceland	11	9	—	—	—	—	—
Asia							
Turkey	753 (D)	714	—	—	—	—	—
Israel	146 (A)	160	—	51	Edam	ILS	41.30

Country	Production	Consumption	Imports	Exports	Retail Price		
					Cheese type	**Currency**	**Price/kg**
India	48 (E)	—	—	—	Mozzarella	INR	380.00
Japan	45 (F)	321	297	—	Processed	JPY	1890.00
China	41 (G)	149	124	—	—	—	—
Kazakhstan	28	47	—	—	—	—	—
Republic of Korea	4	156	124	—	NS	KRW	16,225.0
Saudi Arabia	—	—	172	—	—	—	—
Indonesia	—	—	30	—	—	—	—
Philippines	—	—	38	—	—	—	—
Oceania							
New Zealand	385 (G)	48		323	Cheddar	NZD	8.84
Australia	344	350	98	176	Cheddar	AUD	13.25
Africa							
Egypt	395	482	—	61	NS	EGP	59.41
South Africa	108	109	—	—	NS	ZAR	117.19
Zimbabwe	3	9	—	—	NS	USD	4.00
Total selected countries	21,277						
Rest of world	—	—	865	381	—	—	—
World	—	—	2550	2550	—	—	—

(A) Cow's milk cheese only; (B) Based on production of big dairies; (C) 2018: Cow's milk cheese- 72,600 tonnes; (D) 2018: Cow's milk cheese- 658,500 tonnes; (E) Refers to co-operative dairies only; (F) Natural cheese production; (G) Including processed cheese; (H) Excluding Intra-EU trade; NS- Not specified (Source: compiled from Bulletin of the International Dairy Federation 501/2019).

Table 1.
Cheese production, consumption, imports, exports (in '000 tonnes) and retail price during 2018–2019.

producing nations [9]. Additionally, the retail prices of cheese in almost all the countries had shown an upsurge during last ten years [8]. The detailed information about cheese production, consumption, import, export quantity of several countries and retail price of selected cheeses are presented in **Table 1**. The total whole cow milk cheese in India was 2250 tonnes in 2014 [7]. It is true that India is not a traditionally structured 'cheese nation' but it is gaining pace with increased domestic consumption and exports. India offers only 40 varieties of cheese of which about 60 per cent of the market is dominated by processed cheeses, 30 per cent by cheese spreads and the remaining 10 per cent by flavored and Mozzarella cheese [10].

3. Presently used cheese packaging systems

In order to simplify the cheese packaging requirements, its mandatory to classify them in several categories depending on their moisture content (hard, semi-hard, soft, very-soft), shapes (wheels or half-wheel cheese, cheese slabs also known as portioned cheese, sliced cheese, cheese squares, soft and creamy cheese, grated, diced and processed cheese) and preservation techniques (cheese preserved in brine, wax coated, modified atmosphere or vacuum packaged). The very hard, extra hard, hard to semi-hard category of cheese possess moisture content in the range of 36–52% and includes Edam, Gouda, Swiss, Parmesan, Cheshire and Romano [11]. Rindless types of cheese are ripened in their packaging material alike to cheeses having their surface covered with molds, bacteria or yeasts producing enzymes responsible for ripening [12]. The important factors for selecting packaging materials of very hard to hard varieties of cheese are ripening time, temperature, cheese surface area to volume ratio, gas production (if any), cheese product form (sliced, grated, portions) and permeability of packaging materials [13]. The packaging systems for rindless cheeses includes laminates of polyethylene terephthalate- low density polyethylene (PET-LDPE) (300/50 μm thickness), cover film of oriented (O)PET-LDPE (23/75 μm thickness), tubular bags of oriented polyamide (OPA)-LDPE (15/40 μm thickness) and trough film of PET-HMLDPE (high molecular weight LDPE) (200/25/25 μm thickness). Wax coatings (mineral, paraffin and microcrystalline wax) are used to prevent mold growth, moisture evaporation and high gas barrier properties [11]. Modified atmosphere packaging (MAP) with high barrier materials (PA/EVOH (ethylene vinyl alcohol), LLDPE/EVA (ethylene vinyl acetate)/Ionomers) is generally used for portioned or sliced hard cheese owing to their large surface area exposure to light and oxygen. Vacuum packaging is not preferred for cheese with eyes (Swiss, Gouda, Edam) as it rupture the eyes structure [14].

The semi-soft and soft varieties of cheese contain 52–80% moisture and can be further categorized broadly in three groups (i) ripened by bacteria e.g. Brick, Munster; (ii) ripened by surface mold e.g. Limburger, Brie, Camembert and (iii) internally mold ripened e.g. Gorgonzola, Roquefort, Stilton [15]. Packaging requirements of bacteria ripened cheeses is affected by presence of light, humidity, pH and gases. Internally mold ripened cheese should be packed in O_2, CO_2 and water permeable packages e.g. polystyrene, polyvinyl chloride or thermoformed packages etc., for optimum mold growth [3]. For externally ripened cheese, packaging should not take place until mold had grown to certain extent and packaging material with certain permeability to O_2 and H_2O are prerequisite to avoid growth of anaerobic proteolytic bacteria and moisture condensation inside cheese pack, respectively. *Penicillium camemberti* converts lactate to CO_2 and H_2O, hence perforated OPP (oriented polypropylene) is the suitable material for gas and water passage [16].

Name of the additive (&INS No.)	Recommended maximum levels			
	Unripened cheese	#Ripened cheese	Plain processed cheese/ processed cheese, processed cheese spread	Note
Aspartame (951)	1000 mg/kg	—	—	If used in combination with aspartame-acesulfame salt (INS 962), combined maximum use level, expressed as aspartame, should not exceed this level.
Carotenoids	100 mg/kg	—	100 mg/kg	
Chlorophylls and Chlorophyllin, copper complexes	50 mg/kg	—	100 mg/kg (Chlorophyll- INS No.-140)	
Canthaxanthin (161 g)	15 mg/kg	15 mg/kg	—	For use in flavored products only
Caramel III - ammonia caramel (150c)	15000 mg/kg	—	—	
Caramel IV-sulfite ammonia caramel (150d)	50000 mg/kg	—	—	
Indigotine (Indigo carmine) (132)	200 mg/kg	—	—	For use in surface treatment only
*Lauric arginate ethyl ester (243)	200 mg/kg	—	—	Equivalent to 2 mg/dm2 surface application to a maximum depth of 5 mm, For use in surface treatment only
Natamycin (Pimaricin) (235)	40 mg/kg	40 mg/kg	40 mg/kg	
Phosphates	4400 mg/kg	—	9000 mg/kg	As phosphorus
Polysorbates	80 mg/kg	—	—	On the creaming mixture basis
Ponceau 4R (124)	100 mg/kg	—	—	For use in surface treatment only
Riboflavins	300 mg/kg	300 mg/kg	300 mg/kg	
*Sorbates	2000 mg/kg	3000 mg/kg	3000 mg/kg	As sorbic acid, For Chhana and paneer only)
Nisin (234)	12.5 mg/kg	12 mg/kg	12.5 mg/kg	For Chhana and paneer only
Propionic acid, sodium propionate, calcium propionate (singly or in combination, expressed as propionic acid) (280, 281, 282, 283)	3000 mg/kg	3000 mg/kg	—	
Glucono delta lactone (575)	GMP	—	—	

Name of the additive ([&]INS No.)	Recommended maximum levels			
	Unripened cheese	**[#]Ripened cheese**	**Plain processed cheese/ processed cheese, processed cheese spread**	**Note**
Sunset yellow FCF (110)	100 mg/kg	—	100 mg/kg	For use in surface treatment only
Calcium chloride (509)	200 mg/kg	200 mg/kg		Except cream cheese
Beta-carotenes, vegetable (160a(ii))	600 mg/kg	100 mg/kg	1000 mg/kg	Except Coulommiers
Carrageenan (407)	5000 mg/kg	—		For cream cheese only
Alginate of sodium/potassium/ calcium (410, 402, 404)	5000 mg/kg	—	—	For cream cheese only
Propylene glycol alginate (405)	5000 mg/kg	—	—	
Paprika extract (160c)	GMP	GMP	—	
Curcumin (100)	GMP	100 mg/kg	100 mg/kg	
Annatto (160b (i) and (ii))	GMP	[$]100 mg/kg [@]50 mg/kg	50 mg/kg	[$](Norbixin based) [@](Bixin based)
Lysozyme (1105)	—	GMP	—	
Sodium salts of mono/di/poly phosphoric acid (339, 450 (i, ii, iii), 451 (i), 452 (i))	—	9000 mg/ kg	—	Total salt content should not exceed 9000 mg/kg calculated as phosphorous/carbonates /citrate/ chloride
Potassium salts of mono/di/poly phosphoric acid (340, 450 (iv, v), 451 (ii), 452 (ii))	—	9000 mg/ kg	—	
Allura red AC (129)	—	—	100 mg/kg	
Diacetyltartaric and fatty acid esters of glycerol (472e)	—	—	10000 mg/kg	
Hydroxybenzoates, para	—	—	300 mg/kg	As para-hydroxybenzoic acid
Iron oxides	—	—	50 mg/kg	
Sodium aluminum phosphates	—	—	1600 mg/kg	For use in processed cheese only As aluminum

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Name of the additive ([&]INS No.)	Recommended maximum levels			
	Unripened cheese	**[#]Ripened cheese**	**Plain processed cheese/ processed cheese, processed cheese spread**	**Note**
Pimaricin (Natamicin) (235)	—	2 mg/dm^2 surface.	—	For surface/rind treatment only Not present in depth below 5 mm

[#]Ripened cheese- Cheddar, Danbo, Edam, Gouda, Havarti, Tilisiter, Camembert, Brie, Saint Paulin, Samsoe, Emmentaler, Provolone, extra hard grating/sliced/cut/shredded cheese.
**Ingredients permitted in whey cheese includes Lauric arginate ethyl ester (INS No.-243) - 200 mg/kg and Sorbates (1000 mg/kg).*
[&]INS- International Numbering System for food additives.
[$]Indicates the amount of annatto if it is norbixin based.
[@]It indicates the amount of annatto if it is bixin based.
Source: Compiled from Manual of Food Safety and Standards Authority of India

Table 2.
Additives permitted in different varieties of cheese as per FSSAI (Food Safety and Standards Authority of India).

Figure 2.
Commercially available active and intelligent packaging systems for cheese (A) biodegradable active antifungal film Antipack™ AF, Handary, Brussels, Belgium (B) antimicrobial films with natamycin, VGP SL®, Barcelona, Spain (C) edible plastic films developed from casein by Lactips, France (D) pull timer™, time temperature indicator for indicating temperature abuse developed by Macfarlane labels and insignia technologies, Scotland. (Source: compiled from internet).

Fresh or unripened cheeses (e.g. cottage, quark, cream etc.) have moisture content greater than 80% and are exposed to lactic acid fermentation. Such cheeses have very high chances of dehydration or whey expulsion owing to their high-water activity. Some of the suitable packaging material for fresh cheeses are injection molded HDPE or PP packages with side slits for whey drainage, paraffin or PVDC (polyvinylidene chloride) coated paper and LDPE or PP laminated aluminum (Al) foil (7–20 μm) [14]. Processed cheese is hot filled into pouches, polymer coated or lacquered Al foils (12–15 μm). Processed cheese slices are packed in laminates of PET-HDPE, PET-PVDC and OPP-EVOH-LDPE and processed cheese spreads in tubes of LDPE/EVOH/PET or metal tubes, PP or PET-LDPE cups heat sealed with Al foil, tin plate or enameled Al cans and glass cups closed with Al foil plastic laminate or lidded with an easy opening tin plate [17]. A comprehensive list of permitted additives and their recommended usage level is presented in **Table 2**, which could be utilized for the development of legally permitted smart packaging materials. Also, a few commercially available smart packaging systems used for cheese are listed in **Figure 2**.

4. Active packaging of cheese: concepts and applications

"Active packaging" term was coined by food scientist Dr. Theodore Labuza [3], which includes oxygen absorbers, carbon dioxide absorbers/emitters, moisture absorbers, self-heating and self-cooling containers, antimicrobial packaging, ethanol emitters, flavor absorbers/releasers and microwave assisted containers [18]. The following section discusses different active packaging systems applicable to cheese and brief studies on active packaging materials for cheese and its products are also presented in **Table 3**.

Type of active packaging	Variety of cheese	Description
Antimicrobial packaging	Cottage cheese [19]	Sachets of allyl isothiocyanate were effective against yeast and mold
	Mozzarella cheese [13]	Lysozyme and ethylenediaminetetraacetic disodium salt (Na_2-EDTA) inhibited the growth of coliform and *Pseudomonadaceae* without affecting the lactic acid bacteria
	Kashar Cheese [20]	Zein and zein-wax coating with lysozyme, catechin and gallic acid. Lysozyme based film prevented the growth of *Listeria monocytogens*
	Mozzarella cheese [21]	Packages containing calcium lactate and lactic acid-based brine enhanced the shelf-life by 50%
	Surface ripened cheese [22]	Polyethylene films coated with polyvinyldichloride and containing natamycin/nisin possessed inhibitory effect against *Penicillium expansum* in surface ripened cheese i.e. *Blatacke zlato* and *Olomoucke tvaruzky*
	Zamorano sheep cheese [23]	Poly propylene and polyethylene terephthalate films with *Origanum vulgare* and ethyl lauroyl arginate essential oils inhibited *E.coli* O157:H7
	Saloio cheese [24]	Whey protein isolate coating containing natamycin reduced water loss, color changes and microbial growth throughout the storage period of 60 days
Oxygen absorbers	Low fat cheese (5% fat in dry matter) [25]	Microbial oxygen absorber; Contains microorganisms which utilizes oxygen e.g. *Lactococcus lactis* strain; Flavor and odor improved
	High fat cheese (60% fat in dry matter) [25]	Microbial oxygen absorber containing *Lactococcus lactis* strain; Flavor improved and no explicit difference on odor
	Cheddar cheese [26]	Microbial oxygen absorber containing *Lactococcus lactis* strain; Positive influence on shelf-life
	Delite 5% sliced cheese [26]	Microbial oxygen absorber containing *Lactococcus lactis* strain; Positive influence on product characteristics
Moisture absorbers	Saloio cheese [27]	*Humidipak*®, Moisture controlling sachets with sodium propionate impregnated over it to control mold growth. Extended the shelf significantly by decreasing the water loss
	Camembert cheese [28]	3-layered film with absorber/desorber film. 10% concentration of water absorbent, maintained attractive white appearance of cheese while 25% caused damage of the varnish layer due to swelling.
UV light absorbers	Cheese puffs [29]	Tricalcium phosphate-based UV light inhibitor could be incorporated directly into dry mix flavor powder of cheese puffs cooked in hot oil to prevent light induced rancidity and spoilage.

Table 3.
Types of active packaging materials/systems explored for cheese and cheese-based products.

4.1 Moisture absorbers

The presence of moisture not only affects the package appearance but also leads to poor texture and quality of cheese both microbiologically and chemically. Moisture control in the cheese package reduces the water activity thus preventing microbial growth and leaching of soluble nutrients [17]. Moisture scavengers include desiccants like silica gel, molecular sieves, natural clays like calcium oxide, calcium chloride and modified starch in the form of pads, sheets, sachets and blankets [4]. Moisture control in cheese packages could also be attained by incorporating humectant between different layers of packaging material, while keeping the inside layer water permeable. A two layered packaging material for moisture sensitive products like soft cheese was developed by [30] Marbler & Parmentier, (1999). The packaging material consisted of first functional layer (coated paper) for storing and releasing moisture and second layer (plastic laminate) for controlling gas permeability as a function of moisture content. These types of packaging material find their utility for cheese matured inside the package. Pantaleao, Pintado, & Pocas (2007) [27] successfully demonstrated humidity controller (Humidipak®) with Saloio cheese for shelf-life extension. A dual compartment vacuum packaging system (Tenderpac®) developed by SEALPAC® (Germany) for neatly collecting the drip loss from meat products, could be optimized for fresh unripened cheeses like mozzarella, quarg and cottage [31].

4.2 Oxygen scavengers

Oxygen scavengers market size was 1.80 billion USD in 2016 which is estimated to reach 2.41 billion USD in 2022 at a compound annual growth rate (CAGR) of 5.1%. North America (USA, Canada and Mexico) is the leading market while Asia Pacific region (China, India, Japan and South Korea) is the fastest growing market [5]. Oxygen is majorly responsible for cheese spoilage as its presence facilitates the growth of aerobic microorganisms, oxidation of cheese components, nutritional value decline, off-flavors generation, unacceptable color changes, shelf-life reduction and decrease in food safety [32]. Therefore, control of oxygen content inside cheese package is of prime importance. Modified atmosphere packaging (MAP), vacuum packaging and oxygen absorbers are the alternatives available to reduce or completely remove oxygen from the package [25]. However, MAP and vacuum packaging require costly equipment for packing cheese and still do not remove the oxygen completely (residual oxygen could be up to 1% in the headspace). Vacuum packaging can affect the appearance and structure of soft cheeses adversely and oxygen can also permeate through the packaging film during later stages of storage or distribution [33]. Oxygen scavengers provide the best alternative to remove the oxygen permeating through the packaging film and also to overcome the challenges of MAP and vacuum packaging [34].

The shelf-life of cheese tarts increased to 48 days when packaged with an iron-oxide based oxygen scavenger as compared to 7 days for control samples [35]. An oxygen scavenging film containing a blend of ethylene, methyl acrylate and cyclohexene methyl acrylate copolymer as oxygen scavenger resin was developed to overcome the oxidative rancidity in cheeses, dried milk and meat products [36]. A study on the effectiveness of various packaging methods for Gouda cheese revealed that oxygen scavengers (ATCO FT 210) were as effective as vacuum packaging and MAP (40% CO_2 and 60% N_2) in prolonging its shelf-life [34]. Microbiological oxygen scavenging material consisting of *Lactococcus lactis* strain was reported to consume oxygen in cheese packs with limited production of acetoin and diacetyl [25]. Graviera cheese when packed using a combination of oxygen scavenger and ethanol emitter showed lower microbial growth as compared to 100% nitrogen modified atmosphere packages. An increase in sensory shelf-life for oxygen scavenger and ethanol emitter combined packages was also observed [33]. Negamold®, an ethanol vapor sachet was developed by Nippon Kayalan firm (Japan) for meat products. Later, Freund corporation (Japan) combined oxygen absorber with Negamold® and used it for cheese packaging [37].

Ozdemir & Sadikoglu (1998) [38] had also suggested the replacement of ethanol emitters in cheese packages with UV-excimer-laser-treatment of polymer films to generate bactericidal properties. BIOPACK is a polylactic acid-based packaging system consisting of oxygen scavengers and preservatives encapsulated in cyclodextrin with an objective to extend the best before date of cheeses from 2 to 3 months to 9 months with minimum effect on cost of package [39].

4.3 Free radical scavenger or antioxidant incorporated films

Cheeses like Cheddar, Swiss, Blue, Colby etc. are highly prone to lipid oxidation owing to their high fat content. Antioxidants are extensively used to prevent oxidation by scavenging free radical but due to augmented customer trend for additives free food products, incorporation into packaging material is the best option [40]. Antioxidants incorporation into packaging material not only prevents quality deterioration of the product but also stabilizes the polymer [41]. Synthetic antioxidants like butylated hydroxytoluene (BHT) and butylated hydroxy anisole (BHA) are conventionally used in cheese packing. As per Code of Federal Regulation (CFR 21/172.115), the maximum rate of BHT addition to cheese is 200 mg/kg of fat and specific migration limit of BHA is 30 mg/kg of food product as per EU 10/2011 regulations. Asadero cheese was vacuum packed in LDPE co-extruded film containing 8 and 14 mg/g of BHT. Cheese packed in LDPE film incorporated with 8 mg/g of BHT had oxidized flavor while film with 14 mg/g of BHT surpassed the legal limit of BHT addition [42]. Therefore, similar to natural counterparts of other additives the recent focus is on natural antioxidants. Pomegranate peel extract (PPE) incorporated into zein films for packaging of Himalayan Kalari cheese retarded the oxidation of fat and protein due to the presence of polyphenols in PPE [43]. Sliced cheese packed in red algae films incorporated with 1% grape fruit seed extract (GFSE) showed decreased peroxide and thiobarbituric acid value indicating the antioxidant capability of GFSE [44]. Gelatin-chitosan edible film with Boldo herb extract possessed antioxidant and antimicrobial activity and had preservative effect on sliced Prato cheese by preventing psychrotrophs [41]. Similarly, other natural antioxidants like green tea extract [45], catechins [46] and rosemary extract [40] had been explored for their antioxidant potential in cheese packaging but the major challenge with antioxidant incorporated films in cheese packaging is synchronization of antioxidant diffusion rate according to cheese requirement. Also, for natural antioxidant incorporation in continuous film production by extrusion, their stability or thermal degradation is the major concern [46].

4.4 Carbon dioxide absorbers

Cheeses packed with higher CO_2 may suffer from sensory related issues as its dissolution leads to formation of carbonic acid [14]. Taleggio cheese produced excessive 2.5 mmol kg-1 day-1 CO_2 when stored in nitrogen flushed packages at 6°C causing quality degradation [47]. However, carbon dioxide production is essential in some cheeses to achieve desired texture, eye formation in Emmental and Swiss cheese, and inhibition of microorganisms but excessive production could lead to puffed pouches or package burst [48]. When cheeses are preserved and sold at ambient temperature or when desired shelf life is high, the adverse effects of higher CO_2 concentration aggravates many folds [47]. In such circumstances, carbon dioxide absorbers could be used to remove the excess CO_2 and create a balanced internal cheese package atmosphere [2]. The only noticeable progress in segment of CO_2 absorbers for cheese is by Fellows (2009) [49], who developed a mechanism for CO_2 release from mold ripened cheese (e.g. Camembert) package using one-way valve while disallowing other gases to infiltrate. Crump (2012) [50] developed a CO_2 absorber pouch using polyethylene that contained 1.1 g of calcium hydroxide (200 mesh) and silica gel each in 2:1 mixture of water for shrink wrapped Swiss cheese (114 g) and reported that the product remained in good color with acceptable taste without any expansion due to CO_2 release during storage at 5°C for 4 months. The gas composition and volume of modified atmosphere packed semi-hard cheese (Kadett®, Arla Foods) packages were optimized using mathematical modeling based on gas solubility coefficients, initial carbon dioxide content in cheese and packaging material, thus avoiding consumer rejection due to volume changes [48].

4.5 Light stabilizers

Light, and principally UV light, may cause or accelerate various undesirable reactions like lipid oxidation in cheese. Also, riboflavin, an efficient photosensitizer, present in cheeses at levels of 0.30–0.60 mg/100 g, quickly captivates energy owing to its conjugated double bond and generates either free radicals or reactive oxygen species (ROS). These free radicals and ROS are the major causes of lipid oxidation, off-flavors, color bleaching and nutrient losses especially vitamin A in cheeses [51]. Light stabilizers are divided into five major categories namely: light absorbers, light screeners, excited-state quenchers, peroxide decomposers and free radical scavengers based on their mode of action [52]. Kristoffersen, Stussi, & Gould (1964) [53] reported reduced flavor deterioration in consumer packs of cheddar cheese using Uvinul D 49® as a UV light screening material. Uvinul® S-Pack is a novel FDA approved UV absorber for PET packaging films, which prevented the UV degradation of vitamins and β-carotene, thus highlighting its potential of preventing light degradation changes in cheeses kept in refrigerated illuminated cabinet of supermarkets [54]. Recently, flavonoids had been reported to facilitate the dissipation of photon energy to heat thus deterring photodegradation [22]. Thus, flavonoids incorporated packaging material as natural active element for UV light absorption may be explored for cheese.

4.6 Antimicrobial releasers

Antimicrobial packaging is the most researched forms of cheese active packaging. Antimicrobial agent at certain minimum concentration (known as minimum inhibitory concentration (MIC)) diminishes or impedes microbial growth [9]. Antimicrobial effect in cheeses is most commonly obtained by organic acids and its salt derivatives (sorbic acid, citric acid and their anhydrides), bacteriocins (nisin, lacticin and pediocin), fungicides (imazalil and natamycin), enzymes (lysozyme and lactoferrin), essential oils (basil leaf, thyme, oregano and cinnamon) and miscellaneous compounds like potassium metabisulphite, allyl isothiocyanate, EDTA (ethylenediaminetetraacetic acid) or a combination of these agents [22, 55, 56]. Antimicrobial agents which are sensitive to higher polymer processing temperature are usually applied as coatings. Gliadin based bioplastic films prepared by casting, and containing cinnamaldehyde as active ingredient inhibited fungal growth in cheese spreads [57]. Immobilization of antimicrobial agents like nisin on the surface of cheese packaging material is a convenient technique, however immobilization is appropriate for fluids because of direct contact between antimicrobial surface and entire liquid food [58]. Active polyethylene terephthalate film immobilized with silver nanoparticles extended the shelf-life of white fresh cheese up to 30 days [59]. Labels containing antimicrobial agents can also be used for enhancing cheese shelf life. Labels containing allyl isothiocyanate enhanced the shelf-life of Danish Danbo cheese to 28 weeks when used in combination with MAP as compared to 18 weeks with MAP alone [60].

Chitosan, a natural polysaccharide had been utilized for antimicrobial cheese packaging owing to its biodegradable, antimicrobial, filmogenic and metal complexation attributes [61]. Cellulose polymer based antimicrobial films incorporated with nisin and natamycin showed the potential for preservation of sliced Mozzarella cheese [62]. Electrospinning technique was utilized for incorporation of nisin (at the rate of 5 mg/mL) in polyethylene oxide nanofibers to inhibit *Listeria monocytogens* contamination in cheddar cheeses without affecting its sensory attributes [63]. A novel antimicrobial film based on hybrid organic–inorganic material commonly called as "anionic clays", consisting of layered double hydroxide intercalated with salicylate and carbonate anions increased the storage life of Mozzarella to three weeks at a storage temperature of 18°C [64]. DSM™ has developed Pack-Age® as a solution for ripening of cheese in a vapor pervious foil united with yeast and mold blockers [65].

4.7 Color and flavor releasers

Flavor emitters are mainly used to impart flavor to any packed product or scalp/downgrade any undesirable flavor due to harsher processing conditions, thereby improving sensorial attributes and chances of modifying product formulation [66]. It may be used for masking off-flavors but food processors may unfairly market their expired, unsafe or low-quality foods without letting the consumers know. ScentSational Technologies® is global leader in developing food packages with controlled release of legally permitted flavor into headspace of a pack at varying intervals and provision for adjustment of flavor intensity [31]. Recently, they have also ventured into developing customized and patented injection molded scented and/or flavored parts of any pack. Kraft foods had developed a system for controlled and prolonged release of volatile flavor upon opening and reopening of the package [67]. Such type of packaging innovation could also be used for cheese products like chiplets, slices, processed cheese etc. which are usually contained in multi-use packages.

Color releasing multilayered film is the novel technique for incorporating permitted food grade colors (**Table 2**) such as annatto over cheese surface. Such films generally find their application when low intensity shade of color is desired or color is adversely affected during any processing step, storage or distribution. Mohan, Ravishankar, & Gopal, (2010) [4] suggested the migration of edible food permitted red color from the wrapper of surimi to provide it a more desirable and acceptable color. Similarly, α, β-citral migrated from the cellulose acetate films and improved the yellowness of Coalho cheese without affecting its texture during 25 days of storage [68].

4.8 Miscellaneous active packaging systems for cheese

4.8.1 Self-cleaning rinds

Rindless cheeses are cooked or uncooked hard varieties of cheese that are ripened in plastic film which allows little or no gas or moisture movement e.g. Cheddar, Edam, Gouda and Swiss. Natural rind is the outer crust of cheese formed either during cheese making or storage under controlled humidity and temperature [3]. These rinds are highly susceptible to undesirable fungal growth and becomes slimy at times. Gerber, Koehler, Grass, & Stark (2012) [69] developed a three layered, self-cleaning and porous rind inoculated with *Penicillium roqueforti*. The base layer consisted of polyvinyl chloride (90 μm), living layer of agar (300 μm) with inoculum and porous cover layer of polycarbonate (10 μm) for diffusion of gases and nutrient supply. There is immense future potential for the development of antibacterial self-cleaning rinds using penicillin producing molds (*Penicillium jensenii*) for cheese varieties [69].

4.8.2 Microwave assisting films

Microwave susceptors are the substances which absorb microwave energy and convert it into heat energy. It consists of Al foil layer deposited on paperboard or polyester film for uniform heating treatment [18]. Emmi®, a USA based cheese manufacturing firm, provides different variants of fondue recipes (melted Swiss cheese) in microwaveable containers which are ready-to-(h)eat, convenient and recyclable [70]. These types of microwave assisted heating packs could be used for melted cheese recipes. The major concern with microwave assisted heating cheese containers is duration of microwave heating. Some pop-up sound mechanism could be attached with package which blows up and makes a noise on complete even heating of the package content [3].

4.8.3 Pesticide control agents

Pesticide control agents are generally used with secondary packaging systems to prevent insects, or for fungicidal control, during import and export of food products over distant horizons. Packaging material with pesticide control could also be used to prevent detrimental effects of pests and insects for cheeses like Cheddar, Parmesan etc. which require longer ripening period. The major concerns with these types of pesticide control agents containing packaging is their permissible limit and regulatory issues for use with cheeses. Natamycin is a GRAS status (as per FDA) fungicide which is produced during fermentation by *Streptomyces natalensis*. Romero et al. (2016) [71] showed positive effect of natamycin incorporated biodegradable triticale flour films on mold inhibition when used for wrapping soft cheese.

5. Intelligent packaging of cheese: concepts and applications

Intelligent packaging has not been researched extensively for cheese as reflected by very few publications in **Figure 1**. A few intelligent packaging systems investigated for cheese are presented in this section. However, large size of cheese market including import and export offers attractive opportunities. A list of different suppliers of commercially available smart packaging materials along with their head office, website and contact point are detailed in **Table 4**.

5.1 Gas indicators

Gas indicators or package integrity or leak indicators generally indicate the presence or absence of any gas (majorly oxygen) on the basis of certain chemical or enzymatic reactions. Cheeses are packed under modified atmospheres usually devoid of oxygen to enhance their shelf life. However, the gas composition of cheese package may change relying on the microbial growth inside the package, barrier properties of the packaging material, efficiency of packaging system, or physical damage, if any, that causes leakage [72]. So, knowing the level of oxygen is important to ensure cheese quality and safety in the entire supply chain and throughout its shelf-life. Redox dye-based oxygen indicators have been reported to indicate the

Type of smart packaging	Company (Head Office)	Brand name	Website	Distributor/Contact point in Asia
Oxygen scavenger	Clariant® Chemicals (Switzerland)	OXY-GUARD™, O-Buster®	www.clariant.com	Clariant Chemical, Vadodara
	Mitsubishi Gas Chemical (Japan)	Ageless	www.mgc.co.jp	Information & Advanced Materials Company, Oxygen Absorbers Division, Japan
	Toppan Printing (Japan)	Freshilizer	www.toppan.com	Max Speciality Films Limited, Punjab, India
	Multisorb Filtration Group® (New York, USA)	StabilOx®, Freshmax	www.multisorb.com	—
	Southcorp Packaging (Acquired by Visy®) (Australia)	$Zero_2$	www.visy.com.au	No facility in India. Available in Thailand.
	AGM Containers (USA)	ActiSorb®O		Clariant India, Maharashtra India
Time temperature indicator	Avery Dennison (California, USA)	TT Sensor™	www.averydennison.com	Bangalore, Karnataka
	IntroTech (Netherlands)	Monitor Mark®	www.introtech.eu	—
	Vitsab® (Limhamn, Sweden)	CheckPoint®	www.vitsab.com	—
	TempTime® Corporation (USA)	Fresh-Check®	www.temptimecorp.com	Lisaline Lifescience Technologies Pvt. Ltd., Thane, India
Antimicrobial packaging	Life Materials Technology Limited (Hong Kong)	Agion®	www.life-materials.com	—
	Addmaster Limited (UK)	Biomaster®	www.addmaster.co.uk	Jebsen & Jessen, Indonesia (Contact point in Asia)
	VGP (Barcelona, Spain)	Natamycin	info@pimaricina.com	—
Ethylene scavenger	Evert-Fresh Corporation (USA)	Evert-Fresh	www.evertfresh.com	—
	Sekisui Jushi (Japan)	Neupalon	www.sjc-strapping.com	—
	Peakfresh Products Ltd. (Australia)	Peakfresh	www.peakfresh.com	—
Moisture absorbers	Sealed Air® Corporation (USA)	Dri-Loc®	www.sealedair.com	—
	SEALPAC® (Germany)	Tenderpac®	www.sealpacinternational.com	Synerchem Sdn. Bhd., Selangor, Malaysia (Contact point in Asia)

Type of smart packaging	Company (Head Office)	Brand name	Website	Distributor/Contact point in Asia
Integrity Indicator	Freshpoint Lab (Australia)	O_2 Sense	www.freshpoint.com	—
	Timestrip Ltd.	Timestrip	—	—
	Mitsubishi Gas Chemical (Japan)	Ageless Eye	www.mgc.co.jp	Information & Advanced Materials Company, Oxygen Absorbers Division, Japan
	Insignia Technologies Ltd. (Scotland)	Novas	www.insigniatechnologies.com	—
RFID	Temptrip LLC (USA)	Temptrip	www.temptrip.com	—
	Mondi Plc (Austria)	Intelligent Box	www.mondigroup.com	—
Freshness Indicator	COX Technologies (USA)	Fresh Tag	www.cox-tec.com	—
	Timestrip (UK)	Timestrip®	www.timestrip.com	—
	Ripesense Ltd. (New Zealand)	ripeSense®	www.ripesense.co.nz	—
Microwave susceptors	Sirane Food Packaging Limited (UK)	Sira-Crisp™	www.sirane.com	Sirane East, Vostok, Russia
	VacPac Inc. (USA)	SmartPouch	www.vacpacinc.com	—

Source: compiled from internet using website of the companies.

Table 4.
Suppliers and Asian contact point of commercially available smart packaging systems.

package integrity and status of MAP in food non-destructively [73]. A schematic illustration of Mozzarella cheese package equipped with an oxygen indicator and oxygen scavenger with dye-based oxygen sensor is presented in **Figures 3** and **4**, respectively.

A single use fluorescent-based oxygen sensor prepared using platinum octaethylporphyrin-ketone (PtOEPK), a phosphorescent oxygen-sensitive dye, sensed oxygen concentration changes in MAP cheddar cheese over a period of 4 months. The sensor was reported to possess sensitivity in the range between 0.02% and 100% oxygen. Correlation between oxygen concentration and microbial growth presented an opportunity for assessment of cheese quality using colorimetric oxygen sensor [74]. Similarly, dye based ultraviolet light activated oxygen sensor was successfully developed and characterized for its oxygen sensitivity, oxygen dependent color change and mechanical properties by Deshwal et al. (2018) [75]. The developed indicator was integrated with MAP Mozzarella cheese as an integrity/oxygen indicator, which could be helpful for stakeholders in the entire supply chain [15]. Hempel, Gillanders, Papkovsky, & Kerry, (2012) [76] successfully exploited optical oxygen sensors for detecting integrity (ingress of oxygen) of vacuum packaged cheddar cheese samples during its storage.

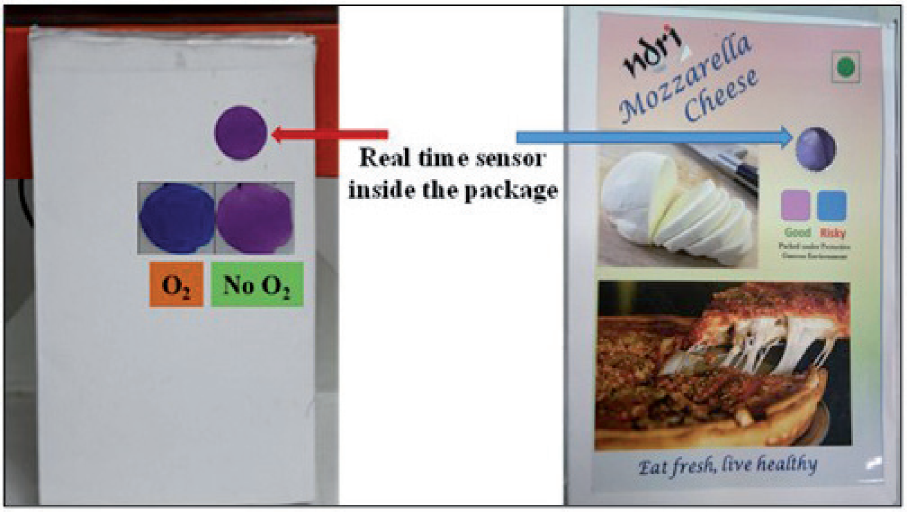

Figure 3.
A schematic illustration of intelligent packaging system using an oxygen indicator applied to mozzarella cheese package (Source: [15]).

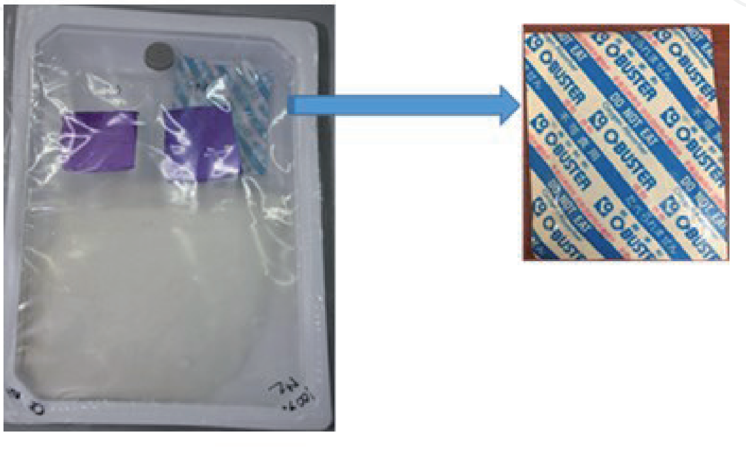

Figure 4.
A schematic illustration of smart (active + intelligent) packaging system for mozzarella cheese package with oxygen indicator (shown in pink color) and oxygen scavenger (O-buster® oxygen scavenger) (Source: [15]).

5.2 Freshness indicators

Freshness indicators, mostly colorimetric in nature, determine the safety, quality or freshness of product based on microbial growth or chemical change. They trigger a visual indication mechanism by detecting the metabolites of microbial or chemical change [77]. Possibilities of freshness detection of packaged milk, cream and cottage cheese using polymer-based labels was proposed by Chen & Zall (1987) [78]. Major approach for characterizing the deterioration of any cheese is by identifying the volatile organic compounds liberated during its storage (or ripening) using solid phase microextraction-gas chromatography/mass spectroscopy (SPME-GC–MS). Octane, hexanal and 2-pentyl-furan were the indicators for light exposure as obtained during the volatile profile of processed cheese [79]. Fourier Transform Infrared Spectroscopy (FTIR) and near infrared spectroscopy (NIR) have also been used to rapidly identify the chemical groups involved in the Crescenza cheese spoilage for possible development of freshness indicator [80]. Most recently, a biodegradable chitosan film containing pomegranate peels/Melissa officinalis essential oil demonstrated not only antimicrobial potential but also anthocyanins functionality as a spoilage indicator changing its color from blue to red due to pH change of cream cheese during spoilage [77]. A diverse blue cheese classification or identification indicator based on chromogenic array pattern of several pH dyes differentiated five cheeses i.e. Roquefort, Blue Stilton, blue cheese with leaves, blue cheese spread and Cheddar with 100% accuracy [81]. Such type of indicators can be used as freshness indicators of blue cheese where the changes in pH and color could be correlated with cheese spoilage. An attempt for the development of red cabbage extract-based pH indicator for monitoring Ricotta cheese spoilage was reported by Bento, Pereira, Chaves, & Stefani, (2015) [82]. Biogenic amines like histamine, tyramine, tryptamine and phenylethylamine are produced in cheese during ripening. Several reports of histamine poisoning in the past for Gouda, Swiss, Cheddar, Cheshire etc. cheeses indicate the potential of biogenic amines as freshness or spoilage indicators for cheese [83]. Freshness indicators for poultry, fish and seafood are commercially available, but a very few "biological use by date" or "chemical best before date" indicators for dairy products had been reported to the best of our knowledge indicating research possibilities in this area.

5.3 Ripening indicators

Cheese ripening indicator could be defined as the use of any technique/process/sensor for spotting metabolites (majorly volatiles) or chemical breakdown by-products of glycolysis, proteolysis and lipolysis to quantify the maturity or age of any cheese variety. The earliest attempt in cheese segment included the use of amido black dye for detecting the age of Cheddar and lactose-hydrolyzed cheddar cheese. Dye binding values were correlated with the free amino acid content [84]. Electric nose (or e-nose) had been used for headspace fingerprinting of packaged ripened cheese (Crescenza) volatiles and the data obtained was found to be helpful for its shelf-life measurement [85]. Tavaria, Ferreira, & Malcata, (2004) [86] quantified major ripening descriptors like free fatty acids, acetic, isobutyric and isovaleric acid concentration during 180 days ripening period of Serra da Estrela cheese. These volatile fatty acids furnished information about the optimal consumption time of cheese which could also be successfully used as ripening indicator. Industrially successful models based on infrared reflectance spectra, attributed to the changes in absorbance patterns of alcohol and amide groups have been used to predict the ripening stages and sensory characteristics of Cheddar [87] and Camembert cheese [88] with a minute error of one day.

5.4 Time temperature indicators (TTIs)

The shelf-life of any food commodity as mentioned on the package in terms of "biological use by date" or "chemical best before date" is subject to its temperature exposure history owing to temperature dependence of microbial growth, enzyme activity and chemical reactions. Time temperature indicators (TTIs) convey information about the temperature exposure of the food commodity over a period of time [89]. TTIs mainly finds their applications in temperature sensitive food products that are stored or distributed in chilled conditions like milk, cheese, ice-cream, yoghurt, meat, fish etc. Shellhammer & Singh (1991) [90] used enzyme-based full history TTI (I-POINT®) on cottage cheese to correlate temperature variation with cheese quality parameters and reported that the TTIs response was significantly affected by pH, titratable acidity and standard plate count of cheese samples. However, attempts of TTI usage in cheese are few and include shelf-life evaluation of Taleggio cheese [91] and Caprino type cheese [92] using TTIs. Potential of diacetylenic monomers as active ingredient in TTIs based on polymerization reaction for monitoring cheese maturity had also been suggested [93]. A study on evolution of proteolytic activity products in Azeitao cheese with fluctuating temperature revealed prominent presence of two free amino acids (valine and leucine) and two biogenic amines (tyramine and putrescine), which may serve as temperature change indicators for the development of microbial TTI for ripened cheese [94].

5.5 Radio frequency identification devices (RFID)

Cheese traceability at batch level is maintained using self-adhesive casein labels, written records, and in advanced cases information is stored in a local database. However, such systems are inefficient considering food safety, counterfeiting risks, voluminous cheese production, warehouse optimization and cost involved in production [95]. So, application of RFID tags at 'farm to fork' levels of cheese industry could provide reliable solutions as it stores more information and assess at longer distances [12]. Regattieri, Gamberi, & Manzini (2007) [96] developed a RFID based traceability systems for hard cheese (Parmigiano Reggiano) which detects the history of the product over entire supply chain. Every minute information starting from feed input, production details to detailed pedigree of a cheese piece is available, thus even facilitating consumers to authorize cheese origin and prevent cheese imitation. The final cost of such RFID tags on customer was calculated to be 0.5%. Similarly, improved traceability of long-ripened cheeses (Bra Tenero, Bra Duro, Raschera and Toma Piemontese) with automatic movement recording during production, handling in ripening room and warehouse, delivery, packing and selling was achieved using tags operating at low (125 kHz), high (13.56 MHz) and ultra-high (865 MHz) frequency [12]. RFID tags with an ability to store data related to 200 variables of cheese production not only improved the quality and yield control of the production plant but also possessed robustness against different temperature, humidity, acid and frictional forces [97]. Papetti et al. (2012) [98] designed a web based "infotracing system" for Italian cheese (*Caciottina massaggiata di Amaseno*) using RFID tags. On linking maturity level of cheeses with quality information (chemical, sensory and spectrophotometric data), RFID system was found to be reliable and compatible with production process. An additional application is "Smart Shelf" which consists of network of RFID antennae for identifying a product's location. It had been successfully validated for tracking expiry dates of processed cheese [99].

5.6 Physical shock indicators

Physical shock indicators are of prime importance for status quo of any fragile product during its rough handling or carriage. Cheeses are often exported across the globe with highest probability of mishandling by personnel during any step of distribution channels or improper selection of transportation channel. Physical shock indicators could be developed using diffusion mechanism, where a fluid leaks and collects irreversibly in another impermeable package, thus indicating the force or pressure to which package content had been exposed. To the best of our knowledge and literature mining no physical shock indicator for cheese and food packaging had been reported. Convex-concave type of metallic structure could also be used to identify the forces to which any cheese packages are exposed over long distances.

6. Development trends and research directions for smart packaging of cheese

6.1 Active packaging systems

Packaging could also be used for facilitating the reduction of cholesterol and lactose in cheeses using cholesterol reductase and lactase enzymes. Cholesterol reductase enzyme converts cholesterol to undigested form (coprosterol), reducing its absorption in intestine. An innovative ethylene-vinyl alcohol copolymer (EVOH) plastic encompassing 30% beta-cyclodextrins reduced the cholesterol concentration by 23% in UHT milk [100]. Such type of active plastic films could be incorporated with β-galactosidase enzyme (lactase) and explored for the development of lactose free whey cheeses due to increased incidences of lactose intolerance across the globe [101].

Citric acid, ferrous salt/ascorbic acid, cellulose triacetate and activated carbon/clays/zeolites are most commonly used off-odor absorbers finding their use in fish, cereals, fruits and poultry products [3]. Off-flavor and odor scavengers prevent cross contamination of pungent odor and aids in improving the overall acceptance of cheeses. However, it is imperative that the constituents scavenged should not be spoilage indicators or essential for flavor development. Some ketones, aldehydes and esters are associated with fruity flavor of cheeses which may be undesirable for some customers [102]. Aldehyde and ester scavengers in cheese packaging can be helpful in improving its sensorial quality. The identified volatile compounds from the headspace of cheese packages revealed the possibilities for development of absorption system and stabilization of sensory qualities of semi-soft ripened cheese [103].

The earliest documented and patented step to achieve the tack ability of a multilayered polyester film over cheese surface was the electrical discharge or flame treatment of the inner surface [104]. Such films were temporarily adherent and easily peel able while opening cheese package. Presently, these anti-stick films can find their vast application for packaging individual slices of processed cheese or Mozzarella cheese spheres thus, reducing sticking losses.

Carbon dioxide and ethanol not only inhibit bacteria, yeasts, molds but also reduces oxidation and could be used individually or in combination for cheese packaging systems to inhibit microbial growth and pack shrinkage [105]. Cheese is most commonly packed with higher CO_2 concentration using MAP technique but CO_2 dissolves in the product leading to package collapse [6]. Package collapse could be overcome by inserting CO_2 emitters in standard MAP cheese trays with perforated false bottom. The controlled release of ethanol in cheese packs could be obtained by encapsulating in a carrier material [65]. Ethicap®, a commercialized ethanol emitter absorbed in silica pads and embedded in sachets made from ethylene vinyl acetate copolymer prevented the growth of molds and yeast, thereby enhancing the shelf-life of soft cheeses [106]. However, objectionable off-flavors involved with higher concentration of CO_2 and ethanol are concerning and supplementary flavor mixtures may be required.

An innovative single use package having the ability to absorb oxygen, carbon dioxide and water vapor, comprising of calcium hydroxide which emits water due to CO_2 absorption, thus activating transition metal (iron oxide) based oxygen scavenger has been developed. Such containers would be suitable for hard cheeses like Taleggio, which emits large amount of CO_2 during ripening and require slight oxygen for maintaining the growth of live cultures [107].

Self-cooling packaging technique is based on an endothermic chemical reaction involving the dissolution of ammonium chloride or ammonium nitrate in water and heat pump technology using water as the heat transmission medium. Such type of packaging systems may remunerate the cold chain conditions, especially where supply channel is inefficient [3]. Initially, thermal sensitive cheese varieties may be shipped using secondary or tertiary thermal management system. Greenbox Thermal Management Systems™ utilizes organic phase change nanomaterial labeled as PureTemp®, to provide specifically designed distribution carriage systems with an ability to maintain temperature precisely for longer durations of supply [108]. It consists of a reusable, recyclable and completely biodegradable boxes in box arrangement with exterior layer of corrugated plastic. Such type of self-cooling containers may be really helpful for exporting cheeses over longer distances without any thermal abuse and quality deterioration.

6.2 Intelligent packaging systems

Emmental and Gouda cheese possess typical and desired regular round holes (eyes) owing to the production of large amount of carbon dioxide during lactate metabolism [109]. Dye based CO_2 indicators based on color intensity that is correlated with amount of CO_2 released could be used to monitor advances in ripening and signpost the accomplishment of optimal ripening. Recently, a novel consumable adhesive CO_2 indicator strip consisting of phenol red dye and tetrabutylammonium hydroxide coated onto silica nanoparticles was developed by Wang, Yusufu, & Mills, (2019) [110]. The color response was dependent on temperature and thickness of polymer barrier films. Such type of indicators could be explored for the development of CO_2 indicator or freshness indicator for modified atmosphere packaged cheese and cheese-based products.

Temperature sensitive networks based on chitosan-poly-(N-isopropylacrylamide) for controlled release were developed by Alvarez-Lorenzo et al. (2005) [111], which can be used in active cheese packaging materials for precise emission of any active component. Films changing their gas permeability in response to degree of temperature and exposure duration may be frequently used during storage and distribution of respiring cheeses like Camembert and Gouda. BreatheWay® membrane technology (Apio Inc., California), based on side chain crystallizable (SCC) polymers provides the solution for gas permeability control according to change in temperature. The change in polymer properties like chain length and side chains can be used for attaining required oxygen and carbon dioxide permeabilities in cheese packages [3].

7. Conclusion

With the focal point being shifted to consumer convenience, quality and safety, active and intelligent packaging tools may help customers with informed choice.

As the world is witnessing increased consumption of cheese, these packaging tools have potential market growth. The expansion of smart packaging technologies in cheese industry remains at a nascent stage. Recent research publications on smart packaging of meat, fish, fruits and vegetables suggest innovative ideas which could be conceptualized for cheese in near future. Smart packaging tools need to be of low cost and multiple benefits. The partnership of active and intelligent packaging can be used to complement each other's actions. Existing challenges could be overcome by multidisciplinary approaches for the development of smaller, more powerful and cost-effective smart packaging systems. Biotechnology, nanotechnology, food science, sensor technology and information technology could be combined for overcoming the shortcomings. Biosensor and hybrid devices for cheese packaging remains untouched in terms of its development and commercialization. It could be expected that with the continuous advances in intelligent packaging and growing modified atmosphere packaged dairy products market, the demand for such type of intelligent packaging systems is expected to rise.

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Conflict of interest

The authors declare no conflict of interest that might be perceived as affecting the neutrality of the article.

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