Available online at www.elixirpublishers.com (Elixir International Journal)

Food Science

Elixir Food Science 131 (2019) 53231-53237

ISSN: 2229-712X

Alteration of Quality Attributes in Yogurts as a Function of Natural Fibers Incorporation

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ARTICLE INFO
Article history:
Received: 15April 2019;
Received in revised form: 24 May 2019;
Accepted: 4 June 2019;

Keywords
Yoghurt,
Dietary Fiber,
Quality Attributes,
Natural Fibers.

ABSTRACT
Fortification of yogurt by dietary fibers from different natural sources has been used to improve its health benefits. However, this could lead to change the other quality parameters of the yogurt. Hence, it is necessary to have an idea about the effect of dietary fiber incorporation from different natural sources on the quality attributes of yogurt. This paper reviews the effect of dietary fiber incorporation to yogurt from different natural sources to its quality attributes.

1. Introduction

Yogurt is the most popular dairy product worldwide (El Samh et al., 2013), produced through lactic acid fermentation of milk base, the foremost ingredient of yogurt. There is currently a massive interest in reducing fat and calorie content while enhancing the nutritional and therapeutic benefits of yogurts due to the high health consciousness. Fortification of physiochemical active ingredients such as dietary fibers (DFs), phytosterols, omega 3 and 6 fatty acids, whey-based ingredients, antioxidant vitamins, and iso-flavones can use as important tools in this endeavor (Reeta, 2015).

Yogurt is a good source of essential amino acids, vitamins, and minerals but no fibers. However, fibers can accomplish multitude functionalities when added into yogurts as stabilizers, fat replacers, prebiotic agents, functional ingredients and nutraceuticals (El-Said et al., 2014; Guggisberg et al., 2009; Ozcan and Kurtuldu, 2014). Hence, numerous researches exploring the possibilities of fortifying DFs from different sources into yogurts. For example, incorporation of natural fibers from fruits like citrus, apple, grapes, guava and dates (Espirito Santo et al., 2012b; Hashim et al., 2009; Maurya, 2016; Staffolo et al., 2004; Tseng and Sheo, 2013); vegetables like carrot, pumpkin, asparagus and yam bean (Bakirci et al., 2017; Puvanenthiran et al., 2014; McCann et al., 2011; Ramirez-Santiago et al., 2010; Sanz et al., 2008); yams like sweet potato, purple yam, modified yam and Chinese yam (Lin, 2013; Liu and Mu, 2013; Ramirez-Santiago et al., 2010); grains or legumes like wheat, soybeans, mungbeans and brown rice (Bilgicli et al., 2006; Munasinghe et al., 2013) and non-edible plants like bamboo (Staffolo et al., 2004) into yogurts were reported.

Enrichment of DFs leads to modify the basic quality parameters of yogurts such as physiochemical, textural, microbiological, nutritional, functional, and sensorial attributes. Since the changes occur in both favorable and unfavorable manner, selection of an appropriate fiber in a precise level is a must. This paper reviewed and summarized the recent findings on the alteration of quality attributes of yogurts as a function of DFs incorporation.

2. Dietary fibers (DFs)

DFs are carbohydrate polymers which opposed to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine (American Association of Cereal Chemists (AACC), 2000). They are either plant or animal origin or else synthetic. Cellulose, β-glucan, hemicelluloses, gums, mucilage, pectin, inulin, resistant starch, and oligosaccharides are typical examples for plant-based DFs. There are two types of DFs as water-insoluble/less fermented fibers (WIF) and water-soluble/well-fermented fibers (WSF). Cereals are the chief source of WIF (e.g. cellulose, lignin, and hemicelluloses) whereas fruits and vegetables are the key sources of WSF (pectin, gums, and mucilage).

Consumption of products containing high fiber may prevent or decrease risk for developing noncommunicable diseases (NCDs) and certain gastrointestinal disorders (Anderson et al., 2009).

3. Functions of dietary fibers in yogurts

DFs are non-caloric bulking agents that can replace high-calorie sweeteners (e.g. sucrose). Similarly, fibers can favorably utilize as fat replacers due to their lubrication, thickening, emulsion, opacity and gel texture stimulation effects (Cho, 2001). Moreover, fibrous nature leads to stabilize or modify the physical structure while minimizing shrinkage and improve density. Water holding capacity (WHC) of fibers largely depends on their particle size, composition, chemical structure and extraction method (Sendra et al., 2010). High WHC of fibers promotes the reduction of moisture migration, ice crystal formation, and syneresis. Further, WHC and gel-forming capabilities (GFC) enhance the viscosity and mouthfeel of yogurts (Cho, 2001).

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In addition, fibers can perform as prebiotic agents in yogurts, encourage probiotic bacteria to produce exopolysaccharides which are possible texture modifiers (Kailasapathy, 2006, Ozcan and Kurtuldu, 2014). Beside all, yogurts become more nutritious and healthier with fiber incorporation.

4. Influence of dietary fiber addition on Quality attributes of yogurts

Yogurt quality is a combination of desirable physiochemical, textural, microbiological, nutritional, functional and sensorial properties. It is largely diversified in reference to the milk source (e.g. bovine, ovine, Buffalo, Goat's, mare's, Camel's, soy, corn, coconut and peanut milk), variation in production steps (e.g. milk standardization, time-temperature combination of pasteurization and incubation, homogenization time and pressure), Ingredients and additives (e.g. type of yoghurt culture, stabilizers, sweeteners, bulking agents and other fortifications) and plant design. Numerous yogurt types found globally, based on a processing method (e.g. set, stirred, drinking, frozen and concentrated yogurts), fat content (e.g. full cream, low fat and no fat yogurts) and ingredients (e.g. fruit, fiber, probiotics, and organic yogurts). However, the basic biochemical changes are similar to all these yogurts as part of lactose in milk convert into lactic acid by starter culture and casein protein in milk tend to coagulate with elevated acidity (pH = 4.6 or isoelectric point of cow's milk).

4.1 Influence on physiochemical attributes

pH, titrable acidity (TA), solid nonfat (SNF) and total soluble solids (TSS) contents are evaluated under physiochemical properties. According to the Australia, New Zealand Food Standard Code (1991) maximum recommended pH of yogurt should be 4.5. Despite, the value fluctuates with the addition of fruit purees. According to the FAO/WHO (2011) code and principles, the minimum recommended TA and SNF contents of yogurt are 0.6% and 8.25%, respectively. TSS content is not bound by such standards. However, commercial yogurts are fall within the range of 14%-16%. Moreover, if the TSS content is in excess of 25%, it will adversely affect the microbial strains by reducing the moisture availability (Tamime and Robinson, 2007).

The acidity of yogurt mainly exerts due to the fermentation action of bacteria. However, numerous researches pointed out the fluctuations in TA and pH values after fiber addition. For example, pea and passion fruit fiber (PFF) added yogurts showed significantly high acidity values (Damian and Olteanu, 2014, Damian, 2013). Garcia-Perez et al. (2005) studied the reduction of pH about 0.2 units in orange fiber fortified yogurt, after 14 days of storage. Authors suggested that fiber fortification originates additional mechanisms to uplift the acidity, hence reduction of pH of yogurts. Some fiber sources are rich in substances with a buffering capacity which can influence the acidity, for instance, organic acids and phenolic compounds.

In contrast, apple, wheat, bamboo, and inulin fibers do not influence the pH of yogurts (Staffolo et al., 2004). Fibers from grape pomace (GP) also had no effect on yogurt pH and acidity according to Mohamed et al. (2014), whereas GP was reduced the pH according to Marchiani et al. (2016).

The maximum rate of acidification (Vmax) and time to reach the maximum acidification rate (Tmax) were reduced with the addition of PFFs. It also accelerated the fermentation kinetics in all skim yogurts (Espirito Santo et al., 2012a). According to McCann et al. (2011), carrot cell wall (CCW) addition reduced 1 h of the fermentation time of yogurt. TSS content ultimately increased by the fiber addition thus SNF values also uplifted.

pH and TA are the most affected physiochemical attributes in yogurt as a function of fiber addition. pH of the yogurt mix has a direct influence on flavor, texture and shelf life of the final product. Hence, care must be taken to select fiber sources that will not adversely interfere with the fermentation process or else acidity regulators can use to alter and control the excess acidity.

4.2 Influence on nutritional and functional attributes

Yogurt is an excellent source of protein, comprising all essential amino acids. Calcium, phosphorus, riboflavin (vitamin B2), thiamin (vitamin B1) and vitamin B12, are the abundant micronutrients in yogurts. In addition, folate, niacin, magnesium, and zinc also present in bioavailable forms (Mckinley, 2005). According to the FAO/ WHO code and principles minimum recommended protein content of yogurt is 2.7% and the fat content vary as 3.25% to 15% for full cream, 0.5% to 2% for low fat and less than 0.5% for no fat yogurts (FAO/WHO, 2011). Yogurt fortified with vitamin A, C, and D, minerals Fe, Ca, Mg and Zn unsaturated fatty acids and phytosterols from seed oil as well as fibers from outsources augmented the nutrition value (Gahruie et al., 2015).

Bioactive peptides such as casein and albumins are present in milk in their inactive form. Fermentation and proteolysis of milk by various microorganisms tend to release these peptides into the medium. Yogurt is such a product which has a large number of bioactive peptides with beneficial biological activities such as antioxidant activity and inhibition of the angiotensin-converting enzyme (Gjorgievski et al., 2014). Antioxidant activity of yogurt starter cultures is an upcoming topic in dairy innovations (Kim et al., 2005, Zhang et al., 2011). Fortification of yogurt with plant sources such as fruits, vegetables, cereals, and legumes also facilitate with phytochemical antioxidants such as carotenoids, flavonoids, and phenols, as well as protein bound polysaccharides which increase serum insulin, hence helps to reduce blood glucose levels (El Samh et al., 2013). Combined effects of these mechanisms create yogurt the best remedy with hypoallergenic, immune boosting and anticarcinogenic effects as well as enhanced bioavailability of nutrients, control of gastrointestinal infections, growth stimulation, reduction of serum cholesterol and longevity (Kim et al., 2005). Yogurt is the best dairy option for lactose intolerance people because lactose converts to lactic acid during the fermentation step of yogurt manufacturing.

Nutrition benefits of yogurt are eventually upgraded after the addition of fibers. It has also an indirect influence on the fatty acid profile of yogurt. Espírito Santo et al. (2012a) published that short chain and polyunsaturated fatty acid contents of yogurts were enhanced with compared to their respective controls by incorporating Apple, Banana, and PFF. Moreover, α-linolenic acid contents augmented after addition of banana fibers. Differently, volatile fatty acidity levels were diminished by inulin addition.

Fibers acts as a good matrix for the growth and function of yogurt microflora hence improved the proteolytic activity to produce amino acids (AA). Tyrosine is such AA, levels were augmented with inulin content (Guven et al., 2005).

Reduction of mineral bioavailability was identified as a drawback in fiber fortification. Staffolo et al. (2012) revealed that different plant fibers were decreased the availability of glucose, calcium, and iron in yogurt, whereas the effect of chitosan (fiber from animal source) was more pronounced.

Scanty of in vivo and in vitro experiments are available to prove the therapeutic benefits of fiber-fortified yogurts. Wine grape pomace added yogurts demonstrated high polyphenolic content and delayed lipid oxidation during refrigeration storage (Tseng and Sheo, 2013). Further, added soluble fibers improved the satiation power of low energy density yogurts can assist against additional weight gain (Perrigue et al., 2009).

Yogurt can use as an excellent food model to check the bioavailability of nutrients as influenced by dietary fibers. Further, there is a huge room, particularly for in vitro studies to prove the therapeutic benefits of fiber-fortified yogurt.

4.3 Influence on microbial attributes

Streptococcus thermophilus and *Lactobacillus delbrueckii* ssp. *bulgaricus* are the key or traditional bacterial involve in lactic acid fermentation of yogurts. Less traditional microorganisms, such as *Lactobacillus helveticus* and *Lactobacillus delbrueckii* ssp. lactis, is sometimes mixed with the starter culture to exert desirable new characteristics. In addition, yogurt can act as an excellent vehicle to deliver probiotics such as *Bifidobacterium, Lactobacillus rhamnosus, Lactobacillus brevis*, and *Lactobacillus acidophilus*. According to the FAO/WHO (2011) standards and principles, the minimum sum of microorganisms constituting the starter culture is 10^7 CFU/g and from that specific probiotic is minimum 10^6 CFU/g. Sri Lanka Standards (1989) stated that both E-coli and mold count should be less than 1/g while maximum yeast count is 1000/g.

Fibers from different sources having prebiotic activities, proven by various findings. Conferring to the outcomes of Ozcan and Kurtuldu (2014), survival of probiotic bacteria (*Bifidobacterium bifidum*) was within biotherapeutic level (> 7 logs CFU/g) as a result of the prebiotic effect of barley and oat based β-glucan. Findings of Rosburg (2009) was demonstrated that β -glucan impart a protective effect on *bifidobacterium* strains in yogurts when stressed by prolonged cold storage. Fermented milk supplement with PFF showed no effect on *Lactobacillus acidophilus* L10 probiotic strains' count. However, some fiber sources contain compounds such as phenols, fatty acid esters, thiols, terpenes and alcohols which can disturb the growth of probiotics (Espirito Santo et al., 2012a).

Addition of fiber sources has a possible prebiotic effect which accelerates the growth of probiotic microflora in yogurts (Sendra et al., 2008). However, it is better to add only the fiber particles extracted from the main fiber source to prevent growth disturbance.

4.4 Influence on sensorial attributes

Sensory attributes are a key component for consumer acceptability. Carbon dioxide, acetic acid, diacetyl, acetaldehyde, and several other substances are formed as byproducts of lactic acid fermentation which are then responsible for the characteristic taste and aroma of the yogurt. Appearance, color, odor, taste, mouthfeel/consistency and overall acceptability are the common sensory attributes evaluated in yogurt. The attributes can be measured by exploiting a sensory panel (trained/semi-trained or untrained) or else instrumental methods. For instance, hunter color quest spectrophotometer is the instrument used to measure L (lightness), a (red/greenness) and b (yellow/blueness) (Bilgicli et al., 2006). Hardness, gumminess, adhesiveness, cohesiveness, and springiness are the sensory attributes which can evaluate using texture profile analyzer (Ozcan, 2013).

Sensory attributes have large diversifications depend on fiber source, particle size, and extraction method. For instance, yogurts with water-extracted asparagus fibers being more colorful than ethanol extraction (Sanz et al., 2008). Hardness, gumminess, and springiness increased and adhesiveness and cohesiveness decreased significantly after addition of 3%, 4% and 5% of dried grape skin, whereas 1% and 2% doses had not to influence (Mohamed et al., 2014). Contrarily, firmness, cohesiveness, and consistency enhanced with the addition of PFFs in skim yogurts (Espírito Santo et al., 2012a). Garcia-Perez et al. (2005) had different finding as addition of orange fiber below 1% concentration reduce the firmness of skim yogurt.

Consumer test results indicated that the appearance, color, and flavor ratings were significantly affected by fiber fortification (Hashim et al., 2009). In most cases, the intensity of particular fruit flavor is considered as a weakness in fruit fiber enriched yogurts (Damian, 2013; Espirito Santo et al., 2013c). Fibers such as inulin, bamboo, and wheat fibers are neutral in taste and colorless, thereby only minimally influences the organoleptic characteristics of yogurts (Garcia-Perez et al., 2005; Kalyani Nair et al., 2010). Differently, slightly bitter taste also reported in inulin added yogurts due to elevated proteolysis (Guven et al., 2005).

Yogurt fortified with up to 3% date fiber (DAF) had similar sourness, sweetness, firmness, smoothness, and overall acceptance ratings as the control yogurt. Sensory ratings and acceptability of yogurt decreased significantly when increasing DAF to 4.5% (Hashim et al., 2009).

Fiber addition exerts a predominant effect on sensory attributes of yogurts. In most cases, the effects are favorable for texture modifications whereas unfavorable for taste, color and appearance. The influence varies depending on fiber source, particle size, fiber dosage, and extraction methods. Fiber sources can contribute to food colorants, to be further investigated.

4.5 Influence on textural attributes

The International Organization for Standards (Marchiani et al., 2016) has defined food texture as 'all the rheological and structure (geometrical and surface) attributes of a food product perceptible by means of mechanical, tactile, visual and auditory receptors'(Lund, 2002). Texture profile analyzer is the common instrument used to evaluate textural parameters.

4.5.1 Rheological attributes

Yogurt is a non-Newtonian fluid, showing a shear-thinning, yield stress, viscoelasticity, and thixotropic (time-dependency) flow behavior (Afonso and Maia, 1999). Rheological properties indicate the flow behaviors and deformation of yogurts, which are essential in designing flow processors, processing and storage, and predicting texture of yogurt.

Numerous researches revealed the effect of yogurt starter culture (Purwandari et al., 2007; Rawson and Marshall, 1997), incubation temperature (Lee and Lucey, 2003, Shaker et al., 2002), composition of milk (Staffolo et al., 2004), processing conditions (Harte et al., 2003; Vercet et al., 2002) and storage time (Abu-Jdayil and Mohameed, 2002; Beal et al., 1999) on rheological properties. Fundamental parameters of yogurt rheology include syneresis and water holding capacity (WHC), gel firmness, viscosity, flow characteristics, viscoelastic properties, and determination of the apparent particle size and zeta potential (Tamime, 2008a).

Textural attributes consist of both rheological and structural properties. Findings restricted to study the deformation of a few fundamental parameters of rheology as a function of fiber addition. There is a huge room to reveal the structural deformations of yogurt after fiber supplementation.

Syneresis and WHC: Syneresis is whey protein separation from yogurt gel network, determined by high-speed centrifugation or the drainage of whey from stirred yogurt through a mesh. It is determined as a major quality defect in yogurts. WHC is an indirect measurement of yogurt gel homogeneity, measured by centrifugation method (Harwalkar and Kalab, 1983).

In most cases, diminish of syneresis was reported due to the ability of fibers to hold more water than casein micelles (Garcia-Perez et al., 2005; Puwanentiran et al., 2014). The supplementation of β-glucan and pea significantly decreased whey separation or syneresis in yogurt samples (Damian and Olteanu, 2014; Ozcan and Kurtuldu, 2014). However, researches further exposed that fiber in small particle size as <0.4 g/100 ml had a disruptive effect on yogurt gels, although rheological parameters tend to increase over 0.6 g/100 ml (Sendra et al., 2010).

Fiber dosage also motives for altered the yogurt texture. A number of citrus fiber particles had a positive influence on the disrupting effect of yogurts. In contrast, dried grape pomace had not to impact to syneresis values up to 2% concentration, though 4% to 5% had a tendency to decline the syneresis (Mohamed et al., 2014). Staffolo et al. (2004) described that no syneresis has occurred when yogurt incorporated with 1.3% of wheat, inulin and apple fibers during 21 days of storage.

Fibers can be incorporated into yogurts before and after pasteurization. However, addition before pasteurization is worthier to avoid the texture disruption since it improves fiber integration in the gel matrix (Sendra et al., 2010).

Gel firmness: Penetrometer is an instrument with a cylindrical probe used to measure gel firmness. In addition to that penetration measurements of a texture analyzer (compression and creep test) can be utilized (Benezech and Maingonnat, 1994). Research data are scanty on the effect on gel firmness due to fiber addition.

Viscosity: Viscosity (η) is internal friction of a flow, measured by the viscometer. Yogurt viscosity is an indication of a network of casein-particle aggregation.

The rheological analysis revealed that viscosity augmented with the addition of apple and inulin fibers in skim yogurts. Further, 1% inulin added yogurts showed the nearest viscosity as full-fat yogurt, maybe due to the rearrangement of casein micelles (Garcia-Perez et al., 2005). Yogurts with pea fibers expressed similar trends (Damian and Olteanu, 2014, Damian, 2013).

The viscosity of yogurts directly proportional to the size of orange fiber partials (Espirito Santo et al., 2013c). The increment of thixotropy and apparent viscosity (η) of skim yogurts were observed after addition of PFFs (Damian, 2013; Espirito Santo et al., 2012b; Espirito Santo et al., 2013c). In contrast, apparent viscosity diminish with the augmentation of shear rate (γ) in apple fiber added yogurts (Garcia-Perez et al., 2005).

Flow characteristics: Different models are described to calculate flow characteristics as Power law, Herschel-Bulkley and Casson models. Shear stress (σ), yield stress (σ_0), shear rate (γ), limiting viscosity (η_∞), consistency index (K) and flow behavior index (n) are the parameters which used to calculate the flow behaviors. The equations for the models are as follow (Equation 1, 2 and 3) (Behnia et al., 2013).

Power law model: $\sigma = K(\gamma)^n$ (1)

Herschel-Bulkley model: $\sigma = \sigma_0 + K(\gamma)^n$ (2)

Casson model: $\sigma^{1/2} = \sigma_0^{1/2} + \eta_\infty^{1/2}\gamma^{1/2}$ (3)

In here, low σ value implies that the yogurt gel has a weak network, while a low value of γ implies that it is a brittle or short textured gel. The strength of protein-protein bonds, the number of bonds per cross-section of a strand, relaxation times for the network bonds, and the orientation of strands in the matrix all contribute to the σ, σ°, γ, K and n values of yogurt gels (Ozcan, 2013). Yam fiber enriched stirred yogurts showed lower flow index, higher consistency index, and higher yield stress (Ramirez-Santiago et al., 2010).

Determination of the apparent particle size and zeta potential: Dynamic light scattering (DLS) is used to determine particle size while zeta potential is tested using Zetasizer Nano Series and Pals Zeta Potential Analyzer. The relationship of electro-osmotic flow (EM) and zeta potential (ξ) can be expressed as follow (Equation 4).

$EM=(2\,\varepsilon\,\xi/3\,\mu)^*\,f(k\,\alpha)$

In here, ε is the permittivity of the liquid; μ is the viscosity coefficient of liquid; α is the particle radius; k the Debye-Huckel parameters and f (k α) is correction factor (Abdelmoneim et al., 2016). Clearly revealed research data on the effect of fiber added to the apparent particle size and zeta potential is not available.

Viscoelastic properties: Viscoelastic foods like yogurts have both liquid (viscous) and solid (elastic) behaviors. Controlled stress/small amplitude oscillatory rheometer (SAOR) is the instrument used to measure viscoelastic parameters as G′, G″, and tan δ. G′ (Storage/elastic modulus) relates to the elastic character of the material, while G″ (loss/viscous modulus) related to the vicious character of the material. The ratio of these two shear moduli is called the loss tangent, LT (G″/G′ = tan δ), give the information of overall structure. When the material behaves more like a solid, the G′ exceeds the G″, and consequently, tan delta is < 1.0. On the other hand, when the material is more like a liquid, then the G″ dominates and tan delta is > 1.0. In typical yogurts elastic character, G′ is predominant (Tamime, 2008b). These properties can measure during the gel formation process because SAOR does not disturb to the gel.

Sendra et al. (2010) demonstrated that fiber dose, particle size and addition time (prior or after pasteurization) have influence in viscoelastic properties of yogurts. Textural properties also depend on the method of asparagus fiber extraction (water or ethanol) and drying (oven or lyophilization). Higher η, G′, G″ values observed after addition of asparagus fiber while viscoelastic behavior (tan δ) was not expressed significant difference (Sanz et al., 2008).

Carrot cell wall particles (CWP) formed a network after 2% incorporation into yogurt which hindered the casein micelles to form a connected colloidal network, thereby reducing the complex modulus (G*) and alter the rheology and microstructure of yogurts (Puwanentiran et al., 2014).

4.5.2 Structural attributes

Structure of the yogurt has a distinct impact on its texture and rheology. Hence, the microstructure of yogurt has been evaluated using an electron microscope (EM) and confocal scanning laser microscope (CSLM). CSLM is the best since it has less sample preparation steps and no disturbance to yogurt gel while testing. This microstructure demonstrated a coarse particulate network of casein particles link with clusters, chains, and strands. Void spaces or pores in this network were confined the aqueous space. Fat globules and starter microorganisms were also visible (Tamime, 2008a).

Confocal images of CWPs added yogurt discovered CWPs are independently embedded in the casein micelle network, provide a ‘filler' effect (Puwanentiran et al., 2014). Inulin added yogurts showed less cohesive protein structure with fewer pores with compare to the controller (Guggisberg et al., 2009). That means the aqueous part was reduced and WHC was augmented after addition of inulin.

Fibers having high water holding capacities which assist in diminishing whey separation and augment viscosity in yogurt. Hence, fibers can be satisfactorily utilized in skim yogurt to avoid texture deformations and as a fat mimics. Research gaps are existing to evaluate the changes in yogurt microstructure as a function of fiber addition.

5. Conclusion

DFs incorporation to foods is vital with regard to nutritional and technological aspects as well as a way of utilizing food wastes and by-products. This review demonstrated that fiber source, particle size, extraction method and addition time (before/ after pasteurization) also influence in yogurt quality parameters. The deformations directed to act DFs as a nutraceutical, functional ingredient, stabilizer, bulking agent, fat replacer, colorant, prebiotic agent and so on in yogurts. Most appropriate fiber type in precious level should be the best selection to avoid unfavorable quality degradations. In spite of recent findings on DFs incorporated yogurts still, there are plenty of gaps in the research area.

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