Journal of Food Engineering 194 (2017) 46–57

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Drying characteristics and some properties of spouted bed dried semi-refined carrageenan

M. Serowik [a], A. Figiel [a,*], M. Nejman [a], A. Pudlo [b], D. Chorazyk [b], W. Kopec [b]

[a] Institute of Agricultural Engineering, Wrocław University of Environmental and Life Sciences, Chelmonskiego 37a, Wroclaw 51-630, Poland
[b] Department of Animal Products Technology and Quality Management, Wroclaw University of Environmental and Life Science, Chelmonskiego 37, Wroclaw 51-630, Poland

ARTICLE INFO

Article history:
Received 30 April 2016
Received in revised form
28 August 2016
Accepted 3 September 2016
Available online 6 September 2016

Keywords:
Carrageenan gels
Drying models
Density
Color
Solubility
Rheological properties

ABSTRACT

The study was focused on the evaluation of spouted bed drying as a method for achieving dried carrageenan gels suitable for grinding, in order to obtain a final product in the form of a powder. Cubes formed from semi-refined carrageenan gels K12, K73, and their blends with carrageenan 92S (iota) were dried in a spouted bed at three temperatures: 60, 100, and 150 °C. Functional properties of the dried product were assessed in terms of density (bulk, apparent, and true), water activity, color parameters, rheological properties, and solubility. The results revealed that the decrease in the moisture ratio with time during spouted bed drying of carrageenan gels can be described by the Page model, which was characterized by satisfactorily fitting parameters such as R^2, RMSE, and Ve. On the other hand, the decrease in the spouted bed volume ratio versus moisture content had linear characteristics, and depended significantly only on the kind of material. The increase in hot air temperature from 60 to 150 °C decreased the drying time for all types of carrageenan gels by ca 50%, contributing to lower equilibrium moisture content and water activity, as well as a lighter color of the dried product, apart from K73 + iota. However, drying at 100 °C provided product with the best solubility and high gelling ability. The differences in the final values of the bulk and apparent densities of dried carrageenan samples were explained, taking into account the effect of temperature and the materials' properties on the behavior of shrinkage.

1. Introduction

Most ready-to-eat products require modification of consistency by the incorporation of additives having appropriate functional properties. Carrageenans are some of the key stabilizing, emulsifying, and texture-forming additives used in the food industry.

Carrageenans are linear sulfated galactons (consisting of D-galactose and 3,6-anhydro-D-galactose units) extracted from red seaweeds (Rhodophyceae class) (Campo et al., 2009). These hydrocolloids, as well as their modifications, are widely used because they allow the production of food with established rheological and functional properties. The main fractions of carrageenans utilized in food products are: kappa, which creates strong and rigid gels; iota, which forms soft and elastic gels; and lambda, which is a non-gelling fraction used as thickener.

Carrageenans are extracted from seaweeds using the alkali method (semi-refined product), and can be further refined using an alcoholic or press method. In recent years, human food-grade semi-refined carrageenan (PES) has increased its global market share. In particular, sales of semi-refined carrageenans intended for meat products are growing. Their main segment of the market is their use as hydrocolloid food additives (Bixler and Porse, 2011). Their dried form has many advantages, taking into account their microbiological safety, storage, transport, mixing with other ingredients, and dosage.

Semi-refined carrageenans are usually dehydrated by sun-drying, which is a lengthy process and has low drying efficiency. Convective air system (Sarbatly et al., 2010) or spray drying (Anisuzzaman et al., 2014) are suggested as more efficient and faster methods. The drying kinetics of semi-refined carrageenans at 40, 60, and 90 °C in a convective dryer was studied by Faria et al. (2014). The best levels of some functional properties (such as gel strength) were observed after drying at 60 °C, but another property (low syneresis from gels) showed its optimum level at 90 °C.

* Corresponding author.
E-mail address: adam.figiel@up.wroc.pl (A. Figiel).

http://dx.doi.org/10.1016/j.jfoodeng.2016.09.007

Nomenclature

A	correction coefficient
a	constant term
b	parameter
a^*	degree of redness
a_w	water activity
b^*	degree of yellowness
db	dry basis
D_{eff}	effective diffusion coefficient (m^2 s^{-1})
G'	storage modulus (Pa)
G''	loss modulus (Pa)
k	drying constant (min^{-1})
L	cube length (m)
L^*	degree of lightness
m	mass of sample (kg)
M	moisture content (kg H_2O kg^{-1} db)
M_0	initial moisture content (kg H_2O kg^{-1} db)
M_e	equilibrium moisture content (kg H_2O kg^{-1} db)
MR	moisture ratio
M_τ	moisture content after time τ (kg H_2O kg^{-1} db)
n	functions parameters
PES	Processed Eucheuma Seaweed
R^2	coefficient of determination
RMSE	root mean square error
SBD	spouted bed dryer
T	temperature (°C)
$T1$	beginning of the sol-gel transition (°C)
$T2$	end of the sol-gel transition (°C)
V_0	initial volume of the bed (m^3)
V_c	volume of container (m^3)
Ve	residual coefficient (%)
V_p	volume of cubes with pores (m^3)
V_q	equilibrium volume of the bed (m^3)
V_u	volume of the bed at current moisture content (m^3)
V_{wp}	volume of cubes without pores (m^3)
VR	volume ratio
T	time (min)
ρ_{app}	apparent density (kg m^{-3})
ρ_{bulk}	bulk density (kg m^{-3})
ρ_{true}	true density (kg m^{-3})

The main problem in the drying process of carrageenans is the very high viscosity of the hydrocolloid suspensions (even at temperatures close to 70 °C), and the formation of gels which inhibits the diffusion of water to the surface. One possible solution could be foam-mat drying (with egg albumin as a foaming agent) to create a porous structure to increase the surface area for water transfer (Djaeni et al., 2015). Another solution could be drying gelled carrageenan that has been divided into pieces.

Taking into account the requirements concerning product quality and favorable technical and economic indicators, attention should be paid to spouted bed drying. In addition, studies on the spouted bed drying process indicate that this method can be used for the drying of cohesive particulate materials (Okoronkwo et al., 2013). During spouted bed drying, fluidizing particles can be subjected to so-called total circulation, promoting good mixing and a large contact area between dried particles and the drying agent, which provides a high heat transfer coefficient and isothermal conditions within the spouted bed (Izadifar and Mowla, 2003; Pusapati and Rao, 2014). The drying air temperature at the outlet of the drying chamber may be very close to the dew point temperature, which ensures high heat efficiency. Spouted bed drying is commonly used for dehydration of agri-food materials (Kaleta et al., 2013; Markowski et al., 2010; Spreutels et al., 2014). It is also a convenient way of drying heat-sensitive food materials, because overheating is prevented by continuous mixing (Harekrushna and Abanti, 2011) and intense heat exchange (Białobrzewski et al., 2008).

In the literature, only a few examples of spouted bed drying of carrageenans for pharmaceutical applications have been described. Ciro-Velásquez et al. (2012) applied two dimensional spouted fluidized bed equipment for the drying of λ-carrageenan suspensions at a temperature range from 43 to 77 °C. Thommes et al. (2007) dried pellets (special particles up to 2 mm in diameter), based on κ-carrageenan and used as carriers for drugs, with the fluid bed technique at 60 °C. The fluid bed method was used as a first stage of the drying process, followed by air or vacuum oven treatment. The cited studies did not exceed a drying temperature of 80 °C using the spouted fluid method, pointing to a possible deterioration of the quality of carrageenan. There is a lack of information concerning the application of the spouted bed technique, especially at a wide range of drying temperatures, in terms of process kinetics and the quality of the dried carrageenan.

Therefore, the aim of the work was to determine the effect of drying conditions, with particular emphasis on a wide range of temperatures, on the drying kinetics and quality attributes of carrageen gels dehydrated in a spouted bed dryer.

2. Materials and methods

2.1. Materials

The materials employed in this study were powders of two kappa type semi-refined carrageenans K12 and K73, and one iota type K92S, all obtained from Regis Ltd (Krakow, Poland). These materials, being the mixture of three production batches, were delivered in aluminum foil laminated polyethylene packages and stored not longer than two weeks before preparation of carrageenan gels. Temperature during transportation and storage did not exceed 20 °C.

2.2. Preparation of carrageenan cubes

Semi-refined carrageenan powders or their blends were mixed with distilled water and homogenized, and then heated in a water bath up to 70 °C. As soon as this temperature was achieved, the mixture was thermostated for 30 min while stirring using a CAT R50 mechanical stirrer (Ballrechten-Dottingen, Germany). The resulting gel was poured onto a stainless steel tray, heated to 70–80 °C in a convection oven, and allowed to cool at ambient temperature (20–22 °C). Cubes of 5 mm size were cut out from the solidified gel using a using a tool comprising two parallel knife blades with a distance of 5 mm. The drying process was carried out for cubes of carrageenan gel containing the ingredients presented in Table 1.

2.3. Drying process

The drying of the carrageen gels was performed using a spouted bed dryer (SBD), designed and made in the Institute of Agricultural Engineering in Wroclaw (Fig. 1). Air at ambient temperature, after