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READY-TO-EAT CHICKPEA PURÉE POWDER BY DRUM DRYING; PHYSICOCHEMICAL AND RHEOLOGICAL PROPERTIES OF POWDER PRODUCT

Esin Selçuk, Özgül Altay, Rabia Akçay Salık, Özgün Köprüalan Aydın, Figen Kaymak Ertekin*
Department of Food Engineering, Ege University, Izmir, Turkey

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ABSTRACT
This study aims to convert raw chickpea (*Cicer arietinum L.*) into dried chickpea puree powder form using a drum dryer having a high rehydration ratio and for ready-to-use consumption form maintaining its healthy properties. The effects of the drying conditions on the physical, chemical, and rheological properties of chickpea puree powders were investigated. Before drying, raw chickpeas were soaked in water at 25°C for 12 hours and boiled at 100°C for 55 minutes. In the drying process, saturated steam pressures (2, 3, and 4 bar) and drum rotation speeds (2.0, 3.0, 4.0, and 5.0 rpm) were chosen as process variables. The most appropriate process conditions were determined as 3 bar of steam pressure and 2 rpm of drum rotation speed targeting the maximum protein content (30.35±0.18%), maximum rehydration ratio (515±0.01%), and as low as possible browning index (BI)(59.28±4.90) values. It was determined that chickpea puree had the appropriate rheological characteristics when the shear stress and shear rate values for chickpea puree powders with various dry matter contents (%25, %26, %27.5, %30) produced under suitable process parameters were examined.
Keywords: Chickpea puree powder, drum drying, healthy food, rehydration ratio, rheology

VALSLI KURUTMA ILE TÜKETİME HAZIR NOHUT PÜRESİ TOZU; TOZ ÜRÜNÜN FİZİKOKİMYASAL VE REOLOJİK ÖZELLİKLERİ

ÖZ
Bu çalışmada, çiğ nohutun (*Cicer arietinum L.*) yüksek rehidrasyon oranına sahip valsli bir kurutucu kullanılarak kurutulmuş nohut püresi tozu formuna dönüştürülmesi ve sağlıklı özelliklerini koruyarak kullanıma hazır tüketim formuna getirilmesi amaçlanmıştır. Kurutma koşullarının nohut püresi

* Corresponding author/ Yazışmalardan sorumlu yazar
✉: figen.ertekin@ege.edu.tr ☏: (90) 232 311 3006 🖷: (90) 232 342 7592

Esin Selçuk; ORCID no: 0000-0002-3745-1791
Özgül Altay; ORCID no: 0000-0003-0067-9319
Rabia Akçay Salık; ORCID no: 0000-0002-9031-3160
Özgün Köprüalan Aydın; ORCID no: 0000-0001-8800-7714
Figen Kaymak-Ertekin; ORCID no: 0000-0001-5042-3659

tozlarının fiziksel, kimyasal ve reolojik özellikleri üzerindeki etkileri araştırılmıştır. Kurutmadan önce, çiğ nohutlar 25°C'de 12 saat suda bekletilmiş ve 100°C'de 55 dakika kaynatılmıştır. Kurutma işleminde, doygun buhar basınçları (2, 3 ve 4 bar) ve vals dönüş hızları (2.0, 3.0, 4.0 ve 5.0 rpm) işlem değişkenleri olarak seçilmiş ve valsler arasındaki 1 mm'lik boşluk sabit tutulmuştur. Maksimum protein içeriği (%30.35±0.18), maksimum rehidrasyon oranı (%515±0.01) ve mümkün olduğunca düşük esmerleşme indeksi (BI) (59.28±4.90) değerlerini hedefleyen en uygun proses koşulları 3 bar buhar basıncı ve 2 rpm vals dönüş hızı olarak belirlenmiştir. Uygun proses parametrelerinde üretilen çeşitli kuru madde içeriklerine (%25, %26, %27,5, %30) sahip nohut püresi tozlarının kayma gerilmesi ve kayma hızı değerleri incelendiğinde, nohut püresinin uygun reolojik özelliklere sahip olduğu belirlenmiştir.

Anahtar kelimeler: Nohut püresi tozu, valsli kurutma, sağlıklı gıda, rehidrasyon oranı, reoloji

INTRODUCTION

The chickpea (*Cicer arietinum L.*) is a significant grain legume source that is produced and consumed all throughout the world. It is a good source of protein and carbohydrates, and its protein content is considered to be higher than that of other legumes (Summo et al., 2019). Moreover, lysine, an essential amino acid, and linoleic acid, an important fatty acid, are two additional nutrients found in abundance in chickpeas (Malunga et al., 2014). By positively influencing the gastrointestinal system, chickpeas' high soluble and insoluble fiber content lowers the risk of colon cancer. It also lowers the risk of cardiovascular illnesses by contributing to the decrease of bad cholesterol (Pekşen and Artık, 2005). Moreover, some minerals including calcium, magnesium, salt, potassium, phosphorus, copper, iron, manganese, and zinc are prevalent in chickpeas. Nevertheless, it has been claimed that the phytic acid found in the chickpea structure inhibits and lowers the digestion of nutrients and minerals including protein and carbohydrates. While chickpeas should not be consumed raw, some procedures are used to minimize or eliminate their negative effects. Many pre-treatments such as soaking in water, peeling, grinding and germination are applied to increase the nutritional value of chickpeas, to produce consumable products with the right textural quality, and to save time and energy (Kaur and Prasad, 2021). In today's increasing pace of life, chickpeas are marketed as canned to provide ease of consumption for human nutrition and canned chickpeas are used in daily nutrition, as an ingredient in meals, and often in purees such as hummus. In addition to these potential uses, chickpeas can be used to create new, innovative, and healthy food products using a variety of processing techniques (Mustafa et al., 2018).

Drying, which is the most common food preservation technique, extends the shelf life of a wide variety of foods (Köprüalan et al., 2021), including fruit and vegetable purees, baby meals, mashed potatoes, dry soup mixes, and pre-gelatinized starches. The quality of the final product is directly affected by the drying method and drying process conditions. Therefore, it is very important to choose a food-grade drying technique to ensure the quality of the final product (Qiu et al., 2019). Drum drying is considered a relatively economical approach, especially for pureed foods, in terms of both rapid drying and imparting a cooked flavor to the dried product. On the heated surface, the latent and sensible heat required for evaporation during tumble drying is provided by conduction (Jangam, 2011). Drum drying process variables that affect the quality of the final product include feed rate, film thickness, drum speed and area, and drum surface temperature (Kaveh et al., 2020). In studies reported in the literature, mashed forms of various foods such as sweet potato (Soison et al., 2014), potatoes (Ruttarattanamongkol et al., 2016), mango (Germer et al., 2018), apple (Topuz and Pazir, 2019), and olive pomace (Baysan et al., 2022) were dried using a drum dryer. As a result of all these studies, it was found that products with low moisture content have high solubility in water, high wettability and easy tissue recovery. In these studies, it was reported that the evaluation of the rheological and viscoelastic properties of the mashed samples is also required.

Foods in puree and viscous forms require careful consideration of rheological properties which are evaluated using rheometers and viscometers (Tabilo-Munizaga and Barbosa-Cánovas, 2005). The viscosity (μ) parameter is important to determine the rheological properties of foods. Two types of rheological analysis are used in food products. These include static (measured by μ, mass tension, thixotropy and mixing under the influence of normal force, pumping, etc.) and dynamic (measured by observing product stability/stagnation and viscoelastic structure under the influence of modulus) storage (G'), loss modulus (G") and μ analysis.

The aim of this research is to examine the usability of the drum drying method in the production of ready-to-use chickpea puree powder and evaluate the quality characteristics of obtained products. After the chickpea is brought into puree form with different pre-treatments like soaking, boiling and mashing, the obtained puree was dried by using a drum dryer with different parameters such as steam pressure and drum rotation speed. The effects of drum dryer parameters on various physical, chemical and rheological properties of chickpea puree powder were investigated. This study reports the potential to produce a ready-to-eat edible chickpea puree powder with high nutritional content, good rheological characteristics, and having added value that is obtained by drum drying. Additionally, it is crucial to provide details regarding the nutritional content and health benefits of the product, as well as to offer advantages in terms of storage and transportation, by delivering chickpea puree in a powder form with a longer shelf life. Additionally, determining the rheological characteristics of chickpea puree is crucial for the product's manufacturing, packaging, and consumption.

MATERIALS AND METHODS

Materials

The same variety of chickpeas (*C. arietinum L ssp.* arieticeps) was purchased from the local market in İzmir. Determined to specify the initial quality of chickpeas to be used as raw material were moisture content, water activity (a_w), and composition (protein, total fat, total carbohydrate, and ash content).

Method

Pre-treatments

Chickpeas were washed using water to remove any impurities before being soaked in water at 25°C for 12 hours at a ratio of 1:2 chickpea: water (w/w) to soften the texture and decrease the boiling time. The drained chickpeas were boiled in water at 100°C for 55 minutes, with a 1:3 chickpea: water (w/w) ratio following the soaking process (Segev et al., 2011; Milán-Noris et al., 2023). The boiled chickpeas were then mashed in a blender for 3 minutes.

Experimental design

The drying process of the chickpea puree was carried out in a twin drum dryer with different saturated steam pressures (2, 3 and 4 bar) and drum rotation speeds (2, 3, 4 and 5 rpm) at a constant gap (1mm) between two drums (Baysan et al., 2021). Drying experiments were replicated two times. Moisture content, a_w, compositional analysis (protein content, total fat content, and total ash), and color properties (L*, a* b*, Chroma, BI, Hue, and ΔE) were determined for the raw chickpea and boiled chickpea puree. Besides, bulk density and tapped density, rehydration ratio, and rheological properties were analyzed for the dried chickpea powder. The rehydration ratio and rheological properties were determined to understand whether the final powder product is a ready-to-use chickpea puree when mixed with water. The most appropriate process parameters were determined by considering maximum protein content (%), maximum rehydration rate and as low as possible BI value.

Analysis

Physicochemical characterization

The moisture contents of the chickpea samples were evaluated using the gravimetric principle at 105°C until they attained an invariable weight, as described by AOAC (2005). The a_w value of the chickpea samples was determined using a_w testing equipment at room temperature (25°C) (Testo-AG 400, Germany). The protein content of the chickpea samples was determined with the Kjeldahl method (AOAC, 2005) and the findings were presented on a % dry basis. The total fat content of the samples was determined according to the method specified by Axelsson and Gentili, (2014), with some modifications, and the findings were presented on a % dry basis. Ash content was measured using the gravimetric method (AOAC, 2005), based on the burning of the samples at 550°C in a furnace. Triplicates of each measurement were performed.

Color properties

Minolta CR-400 Colorimeter (Japan) was utilized to measure the color attributes of chickpea samples, which included L*, a*, and b*. For every sample, the average values of five samples were utilized. Hue, Chroma, ΔE, and BI values of the samples were calculated using the Equations given below, taking the color values of the samples before drying as a reference (Köprüalan et al., 2021). Each analysis were carried out five times.

Chroma: $\sqrt{a*^2 + b*^2}$ (1)

Hue: $\arctan\frac{b*}{a*}$ (2)

ΔE: $\sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$ (3)

BI: $\frac{100*(\frac{at+1.75Lt}{5.645Lt-3.012bt})}{0.17}$ (4)

Bulk density and tapped density

The bulk density was calculated by dividing the mass of the powder by the volume occupied in the cylinder. For the tapped density (ϱ_t), the cylinder was tapped steadily and continuously on the surface by hand until there was no further change in volume (Köprüalan et al., 2021). Each analysis was carried out three times. Bulk and tapped density values were calculated with Equations 5 and 6.

ϱ: M/V (5)

ϱ_t: M/V_t (6)

Where; M: weight of chickpea powder, V: Volume of chickpea powder, V_t: Tapped volume of chickpea powder

Rehydration ratio

Rehydration ratio analysis was performed according to Vega-Gálvez et al., (2015) with small modifications. Distilled water was added to the chickpea powder samples at a ratio of 20:1 (w/v), and mixing was applied with Ultra Turrax for 20 minutes at room temperature. Following that, the samples have been centrifuged for 10 minutes at 4000 rpm. After centrifugation, the upper water phase has been removed, and the rehydration ratio has been calculated as a percentage using Equation 7. Each analysis was carried out three times.

$$R = \frac{Ws}{Wi}100 \quad (7)$$

where Ws and Wi, final (at end of the 10^{th} min.) and first mass (g) of dried chickpea purees.

Rheological analysis

To determine the effect of concentration on the rheological properties of dried chickpea powder purees at the most appropriate process parameters, purees were prepared by adding water at different dry matter contents (25, 26, 27.5, 30 % (w/w)). In order to obtain the homogeneous samples, they were mixed with a homogenizer (IKA Ultra Turrax T25) for 5 minutes and then kept at room condition for 15 minutes. Rheological analyses of the purees have been carried out with the TA DHR-1 (TA Instruments Inc., Moisture Cattle, DE, USA) rheometer using a 40 mm diameter parallel plate and the gap adjusted to 1 millimeter at room temperature. The shear rate and shear stress values were determined by using the device's software, and the flow behavior was shown by sketching a graph. Furthermore, using the oscillation test in puree samples, the modulus of G' and G" of purees has been evaluated at a tension of 1% and in the frequency range of 0.01 Hz (0.06 rad/s) to 10 Hz (62.8 rad/s). They were calculated using equations 8 and 9 (Dolores Alvarez et al., 2017). Based on these values, the viscoelastic properties of purees were evaluated.

$G' = G_0'*\omega n'$ (8)

$G'' = G_0''*\omega n''$ (9)

G' and G" at 1 rad/s, respectively, frequency ω (rad/s), n' and n" are exponential constants of the equation used to describe their effect on modulus ω, n' and n" are unitless.

Statistical analysis

The SPSS 22.0 (IBM SPSS Inc., Chicago, USA) has been used to perform statistical analysis. The obtained data statistical analyses have been performed using one-way analysis of variance (ANOVA) at a 95% confidence interval, and the data variance was compared that used the Duncan Multiple Comparison Test at a significance level of 0.05.

RESULTS AND DISCUSSION

Moisture content and a_w

Moisture content is important in terms of biochemical reactions and microbial activities for the long-term storage of powder products. The a_w value is directly related to the presence of water in the decomposition reactions and affects the storage stability of dry products (Chia & Chong, 2015). Moisture content and a_w values, which have been key in ensuring the drying process's efficacy, are important in demonstrating the performance of the drying process, accordingly as well as the dryer's establishing suitability for drying of the material (Soison et al., 2014; Tonin et al., 2018). Moisture contents and a_w of chickpea puree powders dried under different drying conditions by drum drying are shown in Figure 1. Depending on drying conditions, a significant difference was found between the dried samples ($P < 0.05$). Additionally, moisture content and a_w analyzed for raw chickpea and chickpea puree form before drying are also shown in Figure 1.

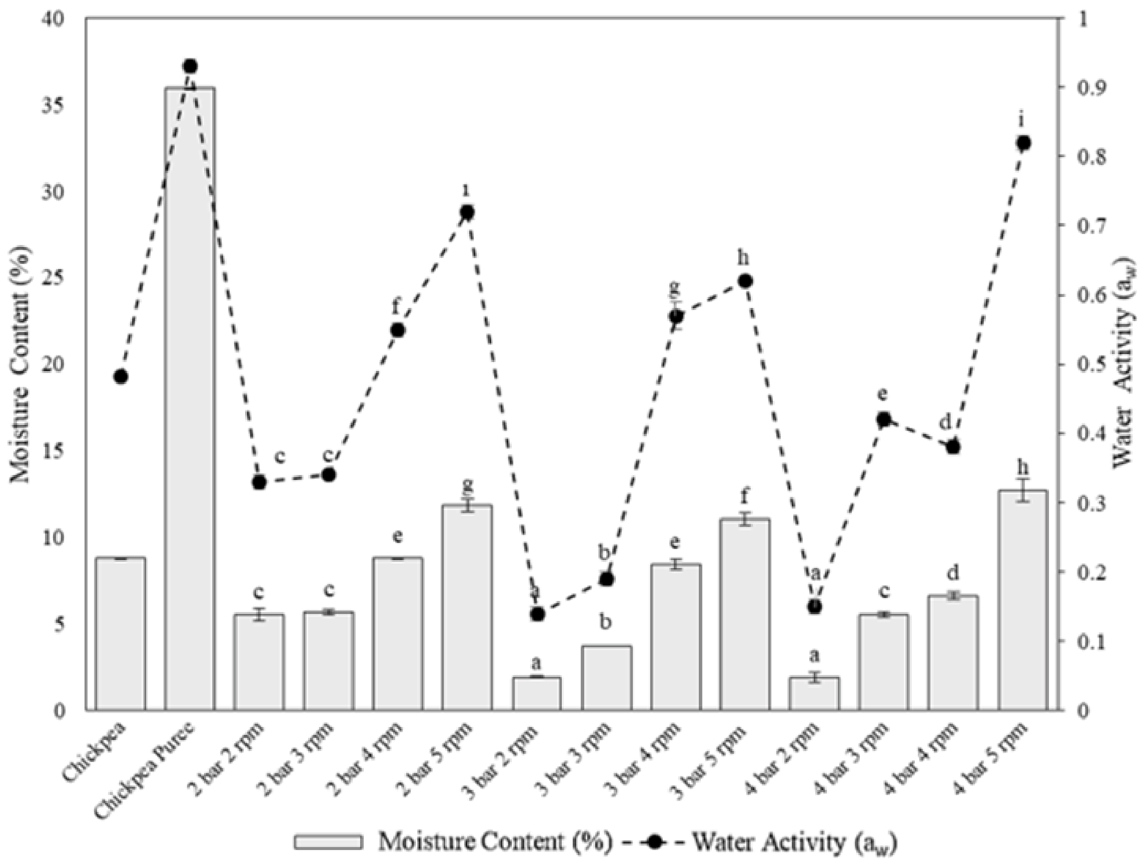

Figure 1. Moisture content and a_w of chickpea puree powder dried with different drying conditions.

* Data were expressed as mean value ± SD (n = 3). Different superscript lowercase in the same column indicated significant differences at $P < 0.05$.

The moisture content and a_w of raw chickpea samples were determined as 8.78 % and 0.483, respectively, while moisture content and a_w of puree form increased to 35.94±0.16% and 0.931, due to blanching prior to drying. After drying at different conditions, the final moisture contents of the chickpea powders were in the range of 1.93 % to 12.7 % wet bulb (wb) (Figure 1). Among the drum drying conditions, the highest moisture content and aw values were obtained at 4 bar steam pressure and 5 rpm rotation speed and followed by all 5 rpm rotation speeds at 2 and 3 bar steam pressures. In drum drying, the contact time of the product with the heated surface has been determined by the rotational speed of the drums, and the contact time of the product with the hot surface decreases as the speed of the drums increases (Galaz et al., 2017). Therefore, the chickpeas powders' moisture content and a_w values increased as the rotation speed increased. As seen in Figure 1, the minimum moisture content and a_w values were obtained at 4 bar steam pressure with 2 rpm and 3 bar with 2 rpm drying conditions ($P > 0.05$). Similar results were reported for apple puree powder (Topuz and Pazir, 2019), sweet potato flour (Soison et al., 2014), and mango powder (Tonin et al., 2018; Germer et al., 2018) by using the drum drying method. Based on these results, it can be concluded that the increase in steam pressure and decrease in drum rotational speed resulted in a powder product with decreased moisture content and a_w. Additionally, Henríquez et al., (2014) reported that drum drying is a low-cost technology that reduces moisture content and a_w, resulting in a long preservable and high nutritional value powder product production with an investigation on drum drying apple peel by-products with a dryer.

Chemical Properties

Chickpea is a type of legume that assists to satisfy the necessary protein requirement in a diet due to their high protein content, as well as to balance the daily calorie intake due to their low-fat content (Summo et al., 2019). Since dried chickpea puree powders can meet this requirement and will also be in ready-to-use form, their chemical composition is as important as raw chickpeas. The chemical composition of chickpea powders dried at different conditions by drum drying is given in Table 1.

Table 1. Composition of chickpea powder dried at different conditions.

DRYING CONDITIONS				Protein (% db)	Fat (% db)	Ash (% db)
Steam Pressure (bar)	2	Rotation Speed (rpm)	2	$26.62^{g} \pm 0.22$	$2.44^{a} \pm 0.33$	$2.09^{def} \pm 0.01$
			3	$25.97^{f} \pm 0.18$	$3.46^{bc} \pm 0.08$	$0.97^{a} \pm 0.17$
			4	$26.23^{fg} \pm 0.49$	$3.11^{ab} \pm 0.18$	$1.38^{bc} \pm 0.27$
			5	$26.06^{fg} \pm 0.35$	$2.44^{a} \pm 0.43$	$1.77^{bcd} \pm 0.03$
	3		2	$30.35^{i} \pm 0.18$	$4.37^{d} \pm 0.67$	$4.04^{g} \pm 0.13$
			3	$25.78^{f} \pm 0.08$	$3.77^{bcd} \pm 0.15$	$2.12^{ef} \pm 0.17$
			4	$27.36^{h} \pm 0.32$	$4.02^{cd} \pm 0.51$	$2.13^{def} \pm 0.07$
			5	$29.98^{i} \pm 0.29$	$4.49^{d} \pm 0.18$	$1.92^{cde} \pm 0.05$
	4		2	$19.38^{a} \pm 0.05$	$6.59^{e} \pm 0.39$	$2.47^{f} \pm 0.41$
			3	$21.05^{b} \pm 0.11$	$6.28^{e} \pm 0.36$	$1.13^{a} \pm 0.29$
			4	$21.79^{c} \pm 0.19$	$6.28^{e} \pm 0.36$	$1.50^{ab} \pm 0.09$
			5	$24.13^{d} \pm 0.22$	$4.62^{d} \pm 0.45$	$1.72^{bcd} \pm 0.03$
RAW CHICKPEA				30.05±1.24	2.63±0.11	6.13±0.55
CHICKPEA PUREE				36.06±0.79	2.49±0.16	1.07±0.11

*Data were expressed as a dry basis and expressed as mean value ± SD (n = 3). Different superscript lowercase in the same column indicated significant differences at $P < 0.05$.

The protein content of dried chickpea powders ranged between 19.38 - 30.35 % (dry basis (db), w/w) depending on the steam pressure and rotation speed, as shown in Table 1 ($P < 0.05$). During wetting and blanching, the addition of water to the structure changed the protein content of the chickpea from 30.05±1.24 to 36.06±0.79 on a dry basis when pureed. The increase in protein content after boiling has been observed by Summo et al., (2019), Avola, (2012), Wang et al., (2010). Dietary fibers in chickpea samples form a complex structure with proteins during the boiling process and prevent protein leakage into the boiling water. Since other water-soluble compounds passing into the boiling water affect the total dry matter in the puree, the protein content in dry matter increases (Summo et al., 2019). In addition, as reported in the literature, ash content loss occurs during the boiling process in this study. Ouazib et al., (2015) reported a significant decrease in ash content in kabuli chickpeas after soaking and blanching. Marconi et al., (2000) reported a 30% loss in ash content during cooking of chickpeas.

Comparing the average protein content of chickpea puree before (36.06±0.79) and after drying, it was concluded that the protein content of puree decreased as predicted during drying. The increase in saturated steam pressure resulted in a decrease in protein content. This can be explained by the denaturing of the protein structure as a result of the product being exposed to higher temperatures for a longer period. Similar results were reported for the chickpea snack obtained with drum drying and it has been observed that the use of high-pressure saturated steam caused to various reactions such as protein denaturation, starch gelatinization, and flavor component development (Kaur and Prasad, 2021).

When the fat content results were evaluated, it was found that the amount of fat increased as the steam pressure increased. Carcea Bencini, (1986) investigated the drying of chickpeas and soybeans with a drum dryer, as well as the flours and component properties of these legumes, and found that the fat content of raw chickpeas and soybeans was less than the fat content of the flours. Furthermore, this one has been reported that this result was produced by differences in protein content, the amount of non-polar amino acids, and changes in their sequences in polypeptide chains, especially as a result of protein denaturation. Similar behavior in fat content of chickpea puree powder during drying was seen in this study.

Color properties

Color is one of the most visual quality attributes for dried powders that influences consumer's choice and it can be used as an indicator to evaluate the extent of quality deterioration due to thermal processing (Horuz and Maskan, 2015). Color properties of chickpea powders dried at different conditions by drum drying are given in Table 2 in terms of L*, a*, b*, Hue, Chroma, ΔE and BI values. The value of the parameter L*, which indicates the lightness of chickpea powders varied from 74.46 to 77.54. Drying conditions had no significant effect on L* values ($P > 0.05$). Similarly, a study using dragon fruit peel showed that the L* value increased and the Chroma values were near to those of the fresh sample, after drum drying (Chia and Chong, 2015).

The BI value provides information about the color darkening of the product. The obvious color darkening is also clearly seen from the BI values during the drying of the chickpea puree powders at 4 bar of steam pressure. Similar results were reported by Soison et al., (2014) on the color of purple-flesh sweet potato flours obtained by drum drying. As drum surface temperature increased, the L*, b* and hue angle values decreased, whereas a* values increased and as a result a darker reddish brown color of the flours have been as well as visually observed. The lowest BI values for powders were obtained at lower steam pressure (2 bar) with higher rotation speeds. Similarly, high pressure steam treatment raised the BI values of apple puree samples dried by drum drying due to the increased pressure (Topuz and Pazir, 2019).

Table 2. Color properties of chickpea powder dried under different conditions by drum drying

Steam Pressure (bar)	Rotation Speed (rpm)	*L**	a*	b*
2	2	$74.46^{a}\pm2.51$	$-0.08^{abc}\pm0.32$	$33.17^{ab}\pm2.66$
2	3	$74.52^{a}\pm2.69$	$-0.25^{abc}\pm0.53$	$34.44^{bcd}\pm0.88$
2	4	$76.54^{ab}\pm3.44$	$0.22^{c}\pm0.55$	$34.47^{bcd}\pm1.62$
2	5	$76.66^{ab}\pm1.46$	$-0.17^{abc}\pm0.59$	$36.51^{d}\pm0.77$
3	2	$76.33^{ab}\pm1.27$	$0.07^{bc}\pm0.32$	$30.98^{a}\pm1.25$
3	3	$76.13^{ab}\pm0.67$	$-0.47^{ab}\pm0.42$	$34.08^{bcd}\pm2.10$
3	4	$77.49^{ab}\pm0.39$	$-0.64^{a}\pm0.25$	$34.15^{bcd}\pm2.01$
3	5	$75.07^{ab}\pm2.27$	$-0.19^{abc}\pm0.25$	$34.62^{bcd}\pm1.93$
4	2	$77.18^{ab}\pm1.45$	$-0.25^{abc}\pm 0.43$	$30.81^{a}\pm2.11$
4	3	$77.54^{ab}\pm1.77$	$-0.18^{abc}\pm0.37$	$33.76^{bc}\pm2.74$
4	4	$77.28^{ab}\pm0.97$	$-0.52^{ab}\pm0.13$	$35.36^{bcd}\pm0.57$
4	5	$76.41^{ab}\pm1.35$	$-0.27^{abc}\pm0.69$	$36.22^{cd}\pm1.48$
Chickpea Puree		70.39 ± 0.17	0.09 ± 0.02	35.98 ± 0.11

Steam Pressure (bar)	Rotation Speed (rpm)	Hue	Chroma	Δe	BI
2	2	$179.99^{abc}\pm0.01$	$35.37^{bc}\pm0.57$	$81.25^{a}\pm2.64$	$54.43^{bc}\pm3.38$
2	3	$179.99^{abc}\pm0.17$	$34.44^{b}\pm0.88$	$85.05^{bcd}\pm0.97$	$54.87^{bc}\pm5.72$
2	4	$180.01^{c}\pm0.270$	$35.25^{bc}\pm0.69$	$83.83^{bcd}\pm0.69$	$50.58^{ab}\pm2.17$
2	5	$179.99^{abc}\pm0.025$	$36.51^{cd}\pm0.77$	$85.54^{d}\pm1.41$	$48.99^{a}\pm4.06$
3	2	$180.01^{bc}\pm0.14$	$31.18^{a}\pm0.95$	$82.78^{abc}\pm1.38$	$59.28^{cd}\pm4.90$
3	3	$179.98^{ab}\pm0.18$	$34.88^{b}\pm0.68$	$82.85^{abc}\pm1.62$	$57.39^{cd}\pm5.09$
3	4	$179.98^{a}\pm0.07$	$35.15^{b}\pm0.99$	$85.51^{d}\pm1.46$	$56.74^{cd}\pm4.15$
3	5	$179.99^{abc}\pm0.05$	$34.62^{b}\pm1.93$	$82.82^{abc}\pm2.19$	$55.01^{bc}\pm4.32$
4	2	$179.99^{abc}\pm0.01$	$31.01^{a}\pm0.77$	$83.59^{bcd}\pm1.23$	$61.02^{d}\pm2.04$
4	3	$179.99^{abc}\pm0.01$	$35.16^{b}\pm0.93$	$82.50^{ab}\pm0.33$	$61.39^{d}\pm5.42$
4	4	$179.99^{ab}\pm0.01$	$35.37^{bc}\pm0.57$	$85.02^{cd}\pm0.81$	$60.34^{cd}\pm4.43$
4	5	$179.99^{abc}\pm0.02$	$36.82^{d}\pm0.76$	$84.19^{bcd}\pm0.79$	$60.83^{cd}\pm3.74$
Chickpea Puree		180.01 ± 0.14	30.08 ± 0.02	-	-

* Data were expressed as mean value ± SD (n = 5). Different superscript lowercase in the same column indicated significant differences at *P <0.05*.

Bulk density, tapped density and rehydration ratio

Two important criteria in establishing the particle features of powder products are bulk density and tapped density. Bulk density is an important quality criterion for the storage of dried products. The bulk density, tapped density and rehydration ratio of chickpea powders dried at different drying conditions are shown in Table 3.

The shape and size of the particles have a great influence on the bulk density of powder products. It is possible that the bulk densities of two different products, coarse and small particulates, with the same weight and characteristics, differ. Furthermore, particle size seems to have a similar effect on tapped density; as particle size decreases, tapped density increases, and as particle size increases, tapped density falls (Altay, 2020). At 2 bar and 2 rpm drying conditions, the highest bulk density and tapped density values were found (P <0.05). The high values of bulk density and tapped density indicate that agglomeration occurs in the samples and that the particle structure is poor. All of the chickpea puree powders dried under different process conditions have shown no obvious agglomeration or particle differences. When the bulk density and tapped density results have been evaluated, as seen in Table 3, it is clear that the chickpea puree powders produced under different processing conditions have no evident agglomeration because of the similar particle forms.

Table 3. Bulk density, tapped density, and rehydration ratio of chickpea powders dried under different drying conditions.

DRYİNG CONDİTİONS				Bulk Density (kg/m^3)	Tapped Density (kg/m^3)	Rehydration Ratio (%)
Steam Pressure (bar)	2	Rotation Speed (rpm)	2	291.47^{de}±0.05	421.17^{bcd}±0.02	449^{c}±0.05
			3	290.90^{de}±0.03	404.71^{ab}±0.02	449^{bc}±0.05
			4	267.04^{bcde}±0.01	330.22^{a}±0.01	442^{ab}±0.02
			5	245.23^{abcd}±0.01	367.85^{ab}±0.02	441^{ab}±0.01
	3		2	288.63^{de}±0.01	355.88^{abcd}±0.01	515^{e}±0.01
			3	214.83^{a}±0.06	355.55^{abcd}±0.02	393^{ab}±0.03
			4	273.33^{cde}±0.03	351.37^{abcd}±0.01	386^{a}±0.03
			5	227.50^{abc}±0.01	313.80^{ab}±0.01	372^{a}±0.01
	4		2	311.93^{e}±0.05	378.05^{d}±0.05	435^{cd}±0.03
			3	251.07^{abcd}±0.05	316.47^{cd}±0.02	419^{cd}±0.02
			4	247.71^{abcd}±0.02	286.94^{abc}±0.02	393^{c}±0.01
			5	218.85^{ab}±0.01	308.33^{abcd}±0.01	392^{c}±0.01

* Data were expressed as mean value ± SD (n = 3). Different superscript lowercase in the same column indicated significant differences at $P < 0.05$.

Low bulk density is desirable in dried products because it indicates that the rehydration ratio of the food may increase due to volume expansion caused to a more porous structure. Furthermore, the internal structure of the product's particle size may have a significant influence on the rehydration ratio, bulk density, and tapped density (Elmas et al., 2021). The rehydration ratio is an indicator of how much the dried powder product can be converted into its previous form when water is added into its structure. Therefore, this ratio is required to be high as much as possible, in products that are converted into puree form and ready for consumption, and it is greatly affected by the drying process conditions. When the rehydration ratio values of the chickpea puree powders dried under different drying conditions are compared, it is seen that the samples dried at 3 bar steam pressure and 2 rpm rotation speed had the highest rehydration ratio ($P < 0.05$). In addition, increasing the drum speed for each pressure resulted in a decrease in the rehydration ratio and in an inability to dry due to a decrease in contact time ($P < 0.05$). The higher bulk density of the powder dried at 3 bar, 2 rpm condition can be attributed to low rotation speeds in drum dryers, which causes the product to have more contact time with the hot surface, thus drying more effectively. Narayana and Narasinga Rao, (1982) reported similar results for mashed bean drying in a double drum dryer, establishing bean flours produced at low drum velocity had a higher rehydration ratio.

Rheological properties

The shear stress of chickpea puree increased as the dry matter content increased, and when the shear stresses were investigated at the initial shear rate (0.1 s^{-1}), the chickpea puree had the lowest shear stress at 25% DM content. The increase in dry matter concentration from 25% to 30% in chickpea puree induced an increase in yield stress at all concentrations. Similar to our study, shear stress increased as the shear rate increased in a study on quince puree in the shear rate range of 0-300 s^{-1} (Dolores Alvarez et al., 2017). Shear stress versus shear rate for chickpea purees having different dry matter contents are shown in Figure 2.

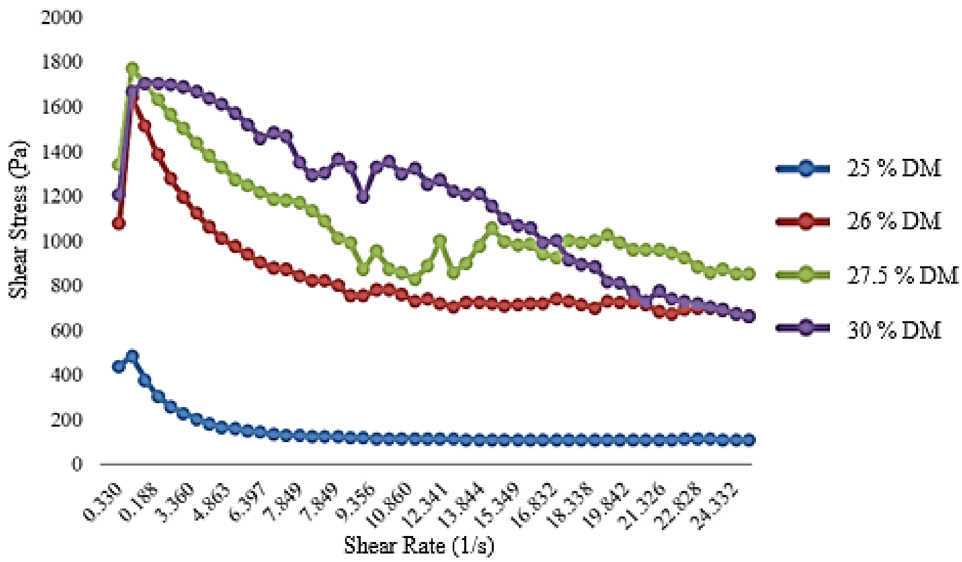

Figure 2. Shear stress versus shear rate in purees with different dry matter contents (25, 26, 27.5, 30 %)

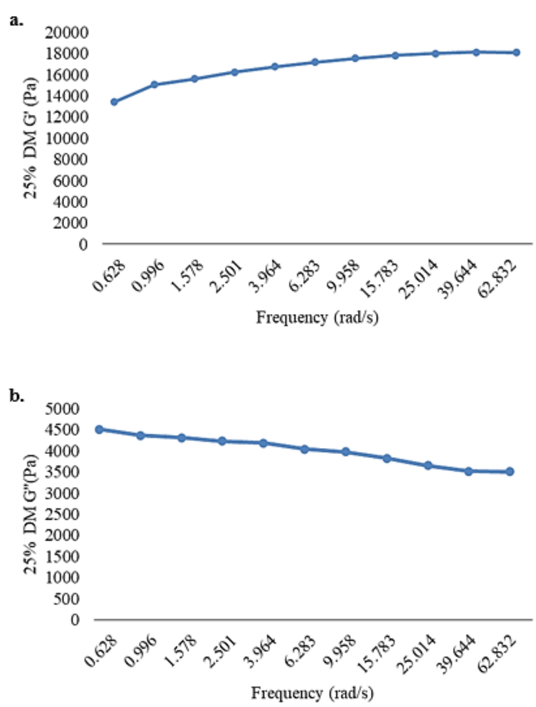

Figure 3. Viscoelastic properties of chickpea powder purees with 25% dry matter content: **a**) G' and **b**) G"

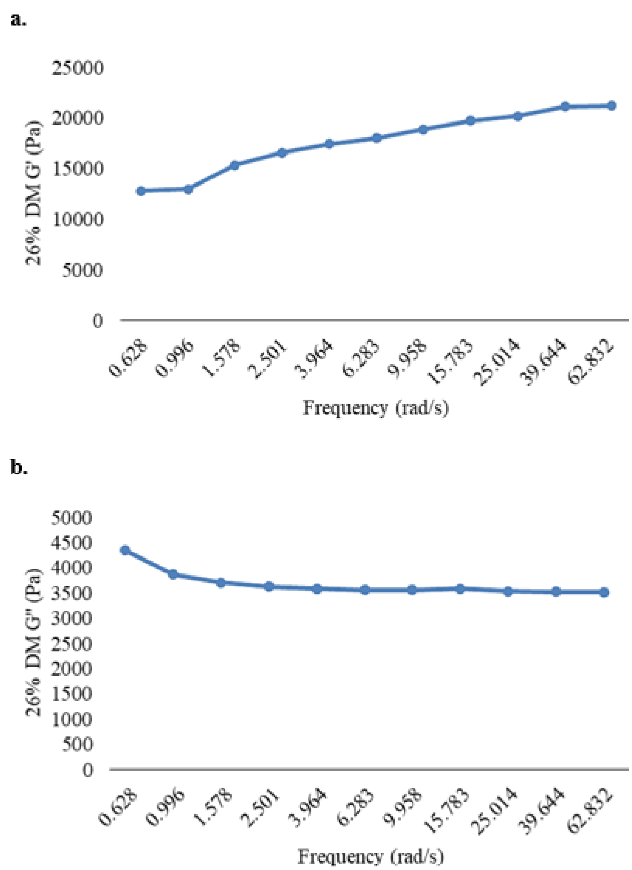

Figure 4. Viscoelastic properties of chickpea powder purees with 26% dry matter content: **a**) G' and **b**) G"

The shear rate-shear stress graphs of chickpea purees, which were varied with dry matter content showed oscillations starting at different shear rate levels (Figure 2). This can be attributed that the rehydrated puree produced from the powder product does not have a constant consistency, causing wall slippage in the parallel plates with flat surfaces utilized in the analysis (Wu and McClements, 2015). Similar studies have revealed that in rheological tests of hydrocolloidal and suspended foods, such food samples can be preferred to slide using smooth geometry (Buscall, 2010). In the rheological analysis of various food suspensions and dispersions such as chickpea puree (tomato puree, quince puree, ketchup, chickpea flour paste) to prevent wall slipping; pre-treatments such as using geometries with rough surfaces (Valencia et al., 2003), homogenizing particle size, using guar gum, xanthan gum and emulsifier additives (Bildir et al., 2018) were applied. After interpreting the shear rate versus shear stress graph by drawing, oscillation tests were also performed on chickpea purees prepared with the same dry matter content using dried chickpea puree powders, and the viscoelastic properties of the purees were determined.

The oscillation test was used to determine the modulus of G' of chickpea purees with 25% and 26% dry matter contents at a 1% tension and frequency scanning from 0.01 Hz (0.06 rad/s) to 10 Hz (62.8 rad/s)) values that increase depending on the frequency while the G" values were decreased depending on the frequency. Because of that, the firmness character of chickpea purees increases during the oscillation test and the consistency decreases. The slope value of the modulus of elasticity graph of the puree with 25% DM (Figure 3) content is higher than that of the puree with 26% DM content (Figure 4) as expected, parallel to the increase in stiffness. It means that the resistance to flow is higher at 26% DM content. Oscillation tests in chickpea purees, due to the increased dry matter content, were easily deformed and they have a very high rigidity character. Therefore, the modulus of G' and G" have been not detected.

CONCLUSION

Drum drying has been studied as an efficient drying technique to obtain chickpea puree and the effects of drum dryer parameters such as steam pressure and rotation speed of the drums on various physical, chemical, and rheological properties of chickpea puree powder were investigated. In order to determine the most appropriate process parameters, the maximum protein content, maximum rehydration ratio, and as low as possible BI value were targeted and the suitable conditions were determined as 3 bar steam pressure and 2 rpm rotation speed. According to the rheological analysis, when the shear stresses were investigated at 25% DM content and the initial shear rate (0.1 s^{-1}), the chickpea puree had the lowest shear stress, and the shear stress against the shear rate showed a smooth reduction. In addition, regarding elasticity, it has been found that the G' of chickpea purees with a dry matter content of 25% and 26% DM was higher than the G", and the rigidity character was higher. Viscoelastic properties showed that when chickpea puree powder is returned to the puree form, it has the desired rheological properties, considering the most appropriate drying conditions. Therefore, the drum drying method is suitable for the production of chickpea puree powder for ready-to-eat consumption with high nutritional value and high quality.

CONFLICT OF INTEREST

The authors have no conflict of interest with any person or organisation related to the article.

AUTHOR CONTRIBUTION

Esin Selçuk: Conceptualization, Methodology, Visualization, Validation, Investigation, Writing – review & editing. Özgül ALTAY: Conceptualization, Methodology, Visualization, Validation, Investigation, Writing – review & editing. Rabia AKÇAY SALIK: Conceptualization, Methodology, Visualization, Validation, Investigation, Writing – review & editing. Özgün KÖPRÜALAN AYDIN: Conceptualization, Methodology, Visualization, Validation, Investigation, Writing – review & editing. Figen KAYMAK-ERTEKİN: Investigation, Writing – review & editing, Supervision

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