Hindawi
Journal of Food Quality
Volume 2023, Article ID 3916692, 13 pages
https://doi.org/10.1155/2023/3916692

Research Article

Nutritional, Physicochemical, Functional, and Textural Properties of Red Pepper (*Capsicum annuum L.*), Red Onion (*Allium cepa*), Ginger (*Zingiber officinale),* and Garlic (*Allium sativum)*: Main Ingredients for the Preparation of Spicy Foods in Ethiopia

Biadge Kefale,[1,2] **Mulugeta Admasu Delele**,[1] **Solomon Workneh Fanta**,[1] **and Solomon Mekonnen Abate**[3]

[1]*Faculty of Chemical and Food Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia*
[2]*Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Centre, Food Science and Nutrition Research, Holeta, Addis Ababa, Ethiopia*
[3]*Ethiopian Institute of Agricultural Research, Head Quarter, Food Science and Nutrition Research, Addis Ababa, Ethiopia*

Correspondence should be addressed to Mulugeta Admasu Delele; mulugeta.admasu@bdu.edu.et

Received 18 August 2022; Revised 3 January 2023; Accepted 8 February 2023; Published 3 March 2023

Academic Editor: Sapna Langyan

Spices are known to have important benefits in our daily diet, and it is common to see industrial and traditional spicy foods in our households and markets. In the present work, a systematic profiling of the nutritional, physicochemical, and textural properties of red pepper, garlic, red onion, and ginger was conducted. The detailed data of forty eight (48) parameters that consisted of macronutrients, micronutrients, physicochemical properties, functional property, and rheological properties of each of the components were organized. The result showed that red pepper had the highest content of crude protein (14.7%), crude fat (11.3%), crude fiber (38.57%), ash (6.7%), redness (a^* value) (32.5), CI (37.4%), and porosity (37.43%) compared to garlic, ginger, and red onion. Garlic had the highest content of carbohydrate content (76.42%), energy (346.58 kcal), pH (6.03), total soluble solid (26.76), particle size (D_{90}, 561 μm), and volume weighted mean (238 μm) which is related to the high antimicrobial and antioxidant quality of garlic. Red onion had the highest content of Zn (71.16 mg/100 g), Na (94.5 mg/100 g), and Ca (71.16 mg/100 g) indicating that it is a rich source of minerals. The availability of data about the nutritional, physicochemical, functional, and textural properties of the ingredients is crucial for the production and formulation of industrial and traditional spicy foods with the highest quality and stability.

1. Introduction

Ethiopia produces more than 50 types of spices from 109 types of spices in the world listed by the International Organization for Standardization. The total spice production in the country has increased over the years, while the share of spices production in 2018 was peppers (83%), turmeric (11%), ginger (3%), and others (3%). The share of chili peppers is very high and has increased over the years in Ethiopia [1]. Ethiopia is one of the largest consumers of spices, and most of the spices produced (96%) are consumed domestically. In food applications, spices are the building components of flavors which are used to flavor sauces, bread, butter, meat, soups, and vegetables and in the production of medicines and perfumes. The spices commonly used for the preparation of condiments or spicy foods in Ethiopia are red pepper, garlic, ginger, onion, cardamom, chili, and fenugreek. These spices are used as an ingredient for the preparation of condiment such as spicy red pepper paste (*Awaze),* Ethiopian stew *(Shiro wot),* hot pepper paste

(Datt), Mitmita, Mekelesha, Selejo, Bekolt, and Nitirkibie [2]. Spices stimulate hunger, add flavor and texture to food, and give visual appeal to meals during consumption [3]. Spices are also important for their medical properties, including antioxidants and antimicrobials activity. Aspergillus a mold recognized for making aflatoxin, a carcinogen, is inhibited by ginger. Cloves are rich source of antioxidants which is crucial to their health beneficial effects, such as free radical scavenging activity [4]. Moreover, the addition of spices as an ingredient in modern and traditional processed foods helps to extend the shelf life of the foods.

Different previous studies reported the quality characteristics of spices, but those studies reported only limited quality characteristics and did not compare the quality characteristics of spices. Most of the published works on red pepper, garlic, red onion, and ginger concentrate on the production and production managements [5, 6].

Only very few studies have reported the quality parameters of spices such as proximate and mineral contents of red pepper and red onion [7–9]. Other important parameters such as macronutrients, micronutrients, physicochemical, functional, and textural properties of red pepper, red onion, garlic, and ginger have remained largely unexplored. Comprehensive studies of the functional, textural, and physicochemical properties of red pepper, red onion, ginger, and garlic are limited. It is, therefore, important that the current study aims to provide comprehensive information about the nutritional, functional, textural, physicochemical, and mineral content of red pepper, red onion, ginger, and garlic which are the commonly used spices in the preparation of different types of traditional spicy foods in Ethiopia.

2. Materials and Methods

2.1. Sample Collection and Preparation. Dried red pepper (*Capsicum annuum* L.) sample was collected from Finote Selam, Bure, and Dembecha in January 2022, Amahara region, Ethiopia. Matured red onion (*Allium cepa*), ginger (*Zingiber officinale*), and garlic (*Allium sativum*) were collected from vegetable improvement center, Holeta Agricultural Research Center, Ethiopia. Matured red onion, ginger, and garlic were sun-dried for three days, and foreign materials and stalks were manually removed. The samples were coarsely crushed in a cutter mixer and then processed in a laboratory hammer mill (Perten Instruments, Finland). Then, the powder was sieved using a 0.5 mm screen before being placed in a polyethylene bag for analysis. The workflow that was followed is given in Figure 1.

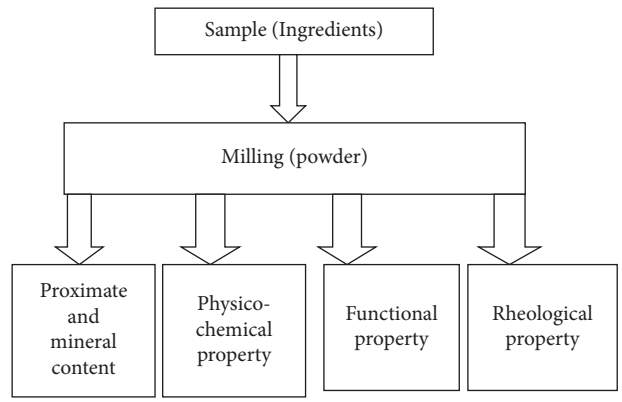

Figure 1: Work flowchart for the analysis of plant samples.

2.2. Proximate and Mineral Analysis

2.2.1. Moisture Content. The moisture content of the samples was determined by AOAC [10]. A 5-gram sample was dried in a hot air oven (model: Wagtech, Quality Product, UK) at a temperature of 105°C until the weight was constant. The dried sample was transferred to desiccators for 30 minute and cooled to room temperature. The weight loss during drying was used to calculate the moisture content of the wet base of the sample.

$$\mathrm{MC\,(wb)} = \frac{\mathrm{Mw}}{\mathrm{M}} \times 100, \tag{1}$$

where MC (wb) is the moisture content, Mw is the mass of water, and M is the sample weight.

2.2.2. Crude Protein Content. The Kjeldahl apparatus (Model: Food ALYT SBS 2000 digester and Food ALYT D 5000 Distillation unit) was used for the determination of percentage of nitrogen by the method AOAC [10]. Accordingly, a 0.5 gram sample was digested with concentrated H_2SO_4 by using a catalyst in the ratio 100 : 5 : 10 of K_2SO_4, $FeSO_4$, and $CuSO_4$, respectively. The digested sample was diluted until the color became light greenish in a 250 ml volumetric flask, and then 40 ml of 32% NaOH was added to distill it. The generated ammonia was collected in a beaker containing 4% boric acid solution using methyl red as an indicator. The resulted ammonium borate was used for nitrogen determination in the sample. The percentage of nitrogen was calculated by titrating the distillate with 0.1 N HCl solution until the color became light reddish.

$$\%\mathrm{N} = \frac{(\text{titre value} - \text{blank}) \times 0.14\,\mathrm{N}}{\text{weight of sample}}, \qquad \text{Protein} = \%\,\mathrm{N} \times 6.25. \tag{2}$$

2.2.3. Crude Fat Content. It was determined using the Soxhlet method by the AOAC [10].

$$\%\text{Crude fat} = \frac{(\text{weight initial} - \text{weight extracted}) \times 100\%}{\text{weight of sample}}. \tag{3}$$

2.2.4. Total Ash Content. The powder ash content was determined using the method AOAC [10]. 5 gram samples were ignited in a muffle furnace at 550–600 degree centigrade for 5-6 hours until white residues (ash) were obtained.

$$\text{Total ash content} = \frac{\text{weight of ash} \times 100\%}{\text{weight of sample}}. \quad (4)$$

2.2.5. Crude Fiber Content. The crude fiber content of the dried samples was determined by using the method AOAC [10]. 2 gram fat free samples were digested with 1.25% H_2SO_4 by adding 200 ml and 150 ml distilled water for 30 minutes. After filtration, the filter cake was digested using 200 ml 1.25% NaOH solution for 30 minutes using Rapid Digester (Labconco. corporation, Kansas, USA). The remaining residues were dried in an oven for 12 hour and ignited in a muffle furnace at a temperature of 550–650 degrees centigrade until the residue became white ash. The percentage of crude fiber was estimated according to the following formula:

$$\text{crude fiber} = \frac{(\text{weight of oven drying} - \text{weight of ash}) \times 100\%}{\text{weight of sample}}. \quad (5)$$

2.2.6. Carbohydrate Content. The carbohydrate content was calculated using the following formula:

$$\text{carbohydrate content (CHO) (\%)} = 100 - (\text{MC} + \text{CP} + \text{fat} + \text{total ash} + \text{crude fiber}), \quad (6)$$

where moisture, protein, fat, total ash, and crude fiber contents are represented by MC, CP, fat, total ash, and crude fiber, respectively.

2.2.7. Energy (Kcal). The energy content was calculated using the following formula:

$$\text{energy (Kcal.)} = 4\text{CP} + 4\text{CHO} + 9\text{fat}. \quad (7)$$

The values were expressed in Kcal.

2.3. Mineral Content. The mineral content of the samples was analyzed following the AOAC method [10]. 0.5 grams of sample was digested by using a muffle furnace at 550–600°C for 5-6 hours until the residue ash became white. The ash sample was digested by using concentrated HCl. The digested sample was diluted up to 100 ml for mineral analysis. Calcium, potassium, sodium, iron, and zinc contents were determined using atomic absorption spectrophotometer (Model: Agilent serious, America):

$$\text{mineral content (ppm)} = \frac{(\text{conc. AAS} - \text{blank}) \times \text{TV} \times \text{df}}{\text{weight of sample}}, \quad (8)$$

where conc. AASis the reading from atomic absorption spectrophotometer, TV is the Volume marked by 100 ml in the volumetric flask, and df is the dilution factor.

2.4. Physicochemical Property

2.4.1. pH Value. It was obtained following the method [11]. The samples of 5 g were measured and 45 ml of distilled water was added to the sample and homogenized for one minute. The solution was maintained at room temperature for 1 hour, and the pH of the supernatant was measured using a pH meter (Mettler Toledo, China).

2.4.2. Titratable Acidity. It was determined titrimetrically according to the method [11]. A 5 gram sample was measured, and 100 ml of deionized water was added and then stirred gently, and the mixture was allowed to stand for one hour. From the mixture, 20 ml solution was taken and added to 0.5 ml phenolphthalein in a 100 ml flask and then it was titrated using 0.1 N NaOH until a pink color appeared for 30 seconds.

$$\text{\% Titratable acidity} = \frac{(\text{titri.} - \text{blank}) \times \text{N} \times 90 \times 100\%}{\text{wt} \times 1000}, \quad (9)$$

where N is the ml of 0.1 N NaOH and wt is the weight of sample.

2.4.3. Total Soluble Solids. It was determined according to AOAC [10]. A sample of (10 g) was liquefied in 50 mL distilled water with a pH of 7.0. Subsequently, the mixture was filtered. Then, to determine the TSS, 1.0 mL aliquot was placed in a digital refractometer, and the results were expressed in °Brix.

2.4.4. Color Value (L^*, a^*, and b^*). The L^*, a^*, and b^* color values were observed by Aeros Hunter colorimeter following the method of [12]. The Aeros Hunter colorimeter was calibrated using the manufacturer's standard white plate. The powder colors were quantified in the L^*, a^*, and b^* color space. L^* refers to lightness, positive a^* refers to red purple color, negative a^* values indicate a green color, positive values of b^* indicate yellow color, and negative values of b^* indicate blue color. Chroma refers the color intensity (saturation), and hue angle indicates the specific color of the powder.

2.4.5. Determination of Viscosity. A 3 gram powdered sample was dissolved in 5 ml distilled water, and the viscosity of the solution was determined using a Brookfield viscometer (model Lv-3, Middleboro, MA 02346, USA) set at 60 rpm and a temperature of 25°C. The viscosity was recorded in centipoises (cps) [13].

2.5. Functional Properties of the Powder. The functional properties of red pepper powder, red onion powder, ginger powder, and garlic were evaluated according to the following methods.

2.5.1. Water and Oil Absorption. It was determined using the centrifugation method [14]. About one gram of the powder was mixed with 10 ml of distilled water or oil in a centrifuge tube and allowed to stand at room temperature of 30°C for 1 hr. Then, it was centrifuged at 200 rpm for 30 minutes, and the supernatant was measured in a 10 ml measuring cylinder.

2.5.2. Bulk Density. It was determined by using the method [15]. 50 gram of powdered sample was added in a 100 ml measuring cylinder, and the volume was measured and calculated as follows:

$$\text{bulk density}\left(\frac{\text{g}}{\text{ml}}\right) = \frac{\text{weight of powder}}{\text{volume of powder}}. \quad (10)$$

2.5.3. Tapped Density. It was measured using the same method with bulk density, but manually tapping the cylinder vertically until the height of powder in the cylinder does not change [16].

$$\text{Tapped density} = \frac{\text{mass of taping}}{\text{volume of taping}}. \quad (11)$$

2.5.4. Porosity. Porosity reflects the volume of pores in the bulk material and was measured using the method that was reported in [17], calculated as (ε (%)) as follows:

$$\varepsilon(\%) = \left[1 - \frac{\text{bulk density}}{\text{tap density}}\right] \times 100. \quad (12)$$

2.5.5. Hausner Ratio (Hr) and Carr's Index (CI). Hausner ratio (Hr) and Carr's index (CI) indicate the flowability of food powders [18]. Both Hr and CI were calculated by taking the tapped density and bulk density of powders using the method of [19].

$$\text{Hr} = \frac{\text{taped density}}{\text{bulk density}} \text{ and } \text{CI} = \frac{(\text{tap density} - \text{bulk density}) \times 100}{\text{tap density}}. \quad (13)$$

2.5.6. Dispersibility. Dispersibility of the powder was determined according to the method in [20]. Dispersibility was measured by placing 10 g of the sample in a 100 mL stoppered measuring cylinder, and distilled water was added to 100 mL, stirring vigorously and allowing it to settle for 3 hr. The volume of settled particles was subtracted from 100 and the difference was reported as percentage dispersibility as follows:

$$\text{dispersibility}(\%) = 100 - \text{volume of settled particle}. \quad (14)$$

2.5.7. Foaming Capacity. It was determined according to the method in [21]. 1 gram of the powdered sample was dispersed in 50 mL distilled water. The resulting solution was vigorously whipped for 30 min in a Kenwood blender and poured into a 100 ml graduated cylinder. The volume before and after whipping will be recorded, and the foaming capacity was calculated as the percentage volume increase. The foaming capacity was calculated from the following equation:

$$\text{volume increase}(\%) = \left[\frac{(\text{volume after whipping} - \text{volume before whipping})}{\text{volume before}}\right] \times 100. \quad (15)$$

2.6. Particle Size and Specific Surface Area. Particle size distributions of red pepper, red onion, ginger, and garlic powders were determined using a laser diffraction particle size analyzer (Master seizer 2000; Malvern Instruments Ltd., Worcestershire, UK) according to the method of [22]. The powder was dispersed in water (ISO 13320–1). In the particle size distribution curve, D_{10}, D_{50}, and D_{90} representing 10%, 50%, and 90% were used to describe the total percentage particle volume below the given diameter. The measurement was also used to determine the Sauter mean diameter (D_{32}), volume weighted mean diameter (D_{43}), and specific surface area (m^2/g).

2.7. Rheological Properties. Pasting properties of red pepper, red onion, ginger, and garlic powder samples were determined by using a rapid viscoanalyzer (RVA-RECHMASTER, Newport Scientific Pty. Ltd., Sidney, Australia). The pasting parameters were measured following the general pasting method. The sample was equilibrated at 50°C for 1 min, heated to 95°C in 7.5 min, and then held at 95°C for 5 min. The hot sample was subsequently cooled to 50°C within 7.5 min and maintained at 50°C for 4 min. Paddle speed was 960 rpm for the initial 10 sec. To disperse the sample, the speed of the paddle was set at 160 rpm during the measurement. Pasting parameters included peak

viscosity, trough viscosity, final viscosity, breakdown value, and set back value, and the viscosity parameters were expressed in centipoises (cPs) units [23].

2.8. Texture Profile Analysis (TPA). The textural properties of dried red pepper and fresh red onion, ginger, and garlic were measured as puncture forces which were a measure of hardness of the product as measured through Texture Analyzer (model: TA. XT. Stable Micro Systems, UK), based on the method in [24] using a 2 mm cylindrical probe with a speed of 2 mm/s and a penetration distance of 5 mm. The puncture force to rupture the dried pepper and fresh red pepper, ginger, and garlic was recorded as means for each sample.

2.9. Experimental Design and Data Analysis. The experiment was designed in a completely randomized design (CRD) for the four powder samples. Analyses were conducted in triplicate, and the results were presented as the mean value of replicates.

3. Results and Discussion

3.1. Proximate Composition. Quantitative analysis of proximate composition consisting of moisture content, crude protein, crude fat, crude fiber, total ash, carbohydrate content, and energy value (kcal.) for red pepper, red onion, ginger, and garlic is presented in Table 1. The data in Table 1 illustrate the proximate composition of red pepper, red onion, ginger, and garlic. Red pepper had the highest amount of protein which reached to 14.7% while garlic had the lowest protein content reached to 8.6%. Similarly, red pepper contained the highest crude fat, followed by ginger, while garlic contained the lowest content of crude fat ($p < 0.05$). Garlic had the lowest fiber content ($p < 0.05$) whereas red paper had the highest. Moreover, the fiber content in the red pepper was approximately twelve times higher than that that of garlic. Red pepper contained the highest ash content (6.7%), followed by ginger (6.33%), and red onion had the lowest ash content (3.37%). High ash content is an indication of high inorganic mineral content [25]. This indicates that red pepper and ginger are rich in inorganic minerals. Garlic contained the highest carbohydrate content (76.42%) and energy value (346.58 Kcal.), while red pepper had the lowest carbohydrate content (22.13%) and energy value (248.58 Kcal.).

The crude protein, fiber, and ash contents of red pepper powder that were obtained in this study appeared to be higher than the reported values for dried red pepper varieties with the values of protein, fiber, and ash content in the range of 8.7–11.8, 25.96–28, and 5.2–7.27%, respectively [26]. Another study obtained higher content of crude protein, crude fat, crude fiber, and ash content in red onion than the current study, and the values were 12.5, 2.96, 5.90, and 5.58%, respectively [27]. A previous study on ginger reported total fiber content, ash content, and fat content of 11.72, 8.25, and 1.85%, respectively [25], which is higher than the current study. The crude protein, crude fat, crude fiber, ash content, and carbohydrate content of garlic in this study appeared to be higher than the finding of [28] that obtained crude protein, crude fat, crude fiber, ash, and carbohydrate content of 7.87, 0.52, 2.3, 2.46, and 22.27%, respectively. The observed variation in the proximate compositions between the previous and the current study could be growing condition, season, or difference in agronomic practices. Generally, red pepper has relatively higher protein, fiber, and total mineral, while ginger, garlic, and red onion have relatively higher carbohydrate content and energy value needed for human nutrition.

3.2. Mineral Content. The mineral contents (K, Ca, Na, Fe, and Zn) of red pepper, red onion, ginger, and garlic were expressed in mg/100 g on a wet basis and are presented in Figures 2–4.

From the four spices, red pepper contained the highest iron and potassium content, while red onion contained the highest calcium, sodium, and zinc content (Figures 2–4). The general order of the mineral content for red pepper was K > Ca > Na > Fe > Zn. The K, Ca, Na, Fe, and Zn contents of red pepper were 450.7, 47.73, 30.23, 19.35, and 2.46 mg/100 g, respectively. The results of the current study were in agreement with the previous study that reported K, Ca, Na, Fe, and Zn contents of red pepper in the range of 49.57–133.25, 53.55–108.86, 69.65–111.83, 3.75–12.93, and 4.47–13.23 mg/100 g, respectively [29]. Potassium (K) was the first most abundant mineral element in the red pepper with a value of 450.7 mg/100 g. The mineral content of red onion was ranked in the order of K > Na > Ca > Zn > Fe. The previous study reported relatively lower values of K and Ca for onion with a sodium content of 277.9 mg/100 g and calcium content of 71.09 mg/100 g [30]. The Fe and Zn content of onion in the current results was higher than the result that was presented by [31], and the study reported Fe and Zn content of onion (3.17 mg/100 g) and (2.64 mg/100 g), respectively. The relative mineral content of ginger in descending order of abundance was found to be as follows: K > Na > Ca > Fe > Zn. The K, Fe, Na, Ca, and Zn contents of ginger were 330.4, 44.8, 36.18, 36.18, 5.14, and 2.27 mg/100 g, respectively. This order was in consistent with the result that was reported by [32] for different ginger varieties. The previous study reported mineral contents of ginger varieties in the range of K (148.7–254.7), Fe (6.74–61.7), Na (36.5–83,73), and Ca (26.05–67.38) mg/100 g, which were higher than the current study. Garlic had considerable amount of K (140.5 mg/100 g), Ca (36.14 mg/100 g), and Na (21.98 mg/100 g), while the quantity of Zn (3.22 mg/100 g) and Fe (1.6 mg/100 g) was the lowest. The mineral content of garlic that was reported from the previous study was K (54.65 mg/100 g), Ca (19.83 mg/100 g), Na (4.1 mg/100 g), and Zn (0.34 mg/100 g) [28], which was lower than that of the current study.

Collectively, our data highlighted that red pepper can be considered as a good source of iron and potassium while red onion can be considered as a good source of zinc, sodium, and calcium. Consequently, the study confirms that the health benefit of spices may be attributed to the

Table 1: Proximate composition of the samples of red pepper, red onion, ginger, and garlic.

Parameters	Food composition (%)			
	Red pepper	Red onion	Ginger	Garlic
Moisture content	6.55 ± 0.02^{d}	10.21 ± 0.24^{a}	8.8 ± 0.14^{b}	8.12 ± 0.15^{c}
Crude protein	14.7 ± 0.08^{a}	10.98 ± 0.06^{b}	9.01 ± 0.45^{c}	8.6 ± 0.07^{d}
Crude fat	11.36 ± 0.25^{a}	0.73 ± 0.15^{c}	1.33 ± 0.25^{b}	0.60 ± 0.20^{d}
Crude fiber	38.57 ± 1.13^{a}	3.87 ± 0.32^{c}	6.62 ± 0.12^{b}	3.03 ± 0.07^{d}
Ash	6.7 ± 0.28^{a}	3.37 ± 0.019^{b}	6.33 ± 0.25^{c}	3.34 ± 0.05^{d}
Carbohydrate content	22.13 ± 1.84^{d}	70.67 ± 0.41^{b}	67.81 ± 1.2^{c}	76.42 ± 0.28^{a}
Energy (Kcal)	248.58 ± 5.8^{d}	333.84 ± 0.65^{b}	319.47 ± 0.0^{c}	346.58 ± 0.4^{a}

Values with the same letter in the same row are not significantly different at $P < 0.05$.

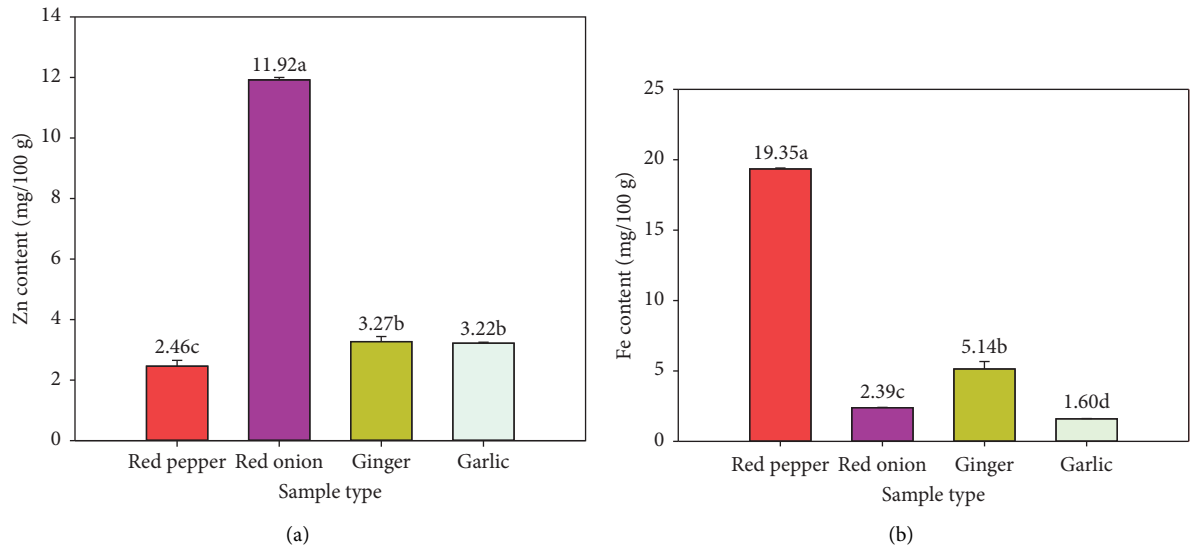

Figure 2: Zinc (a) and iron (b) contents of red pepper, red onion, ginger, and garlic.

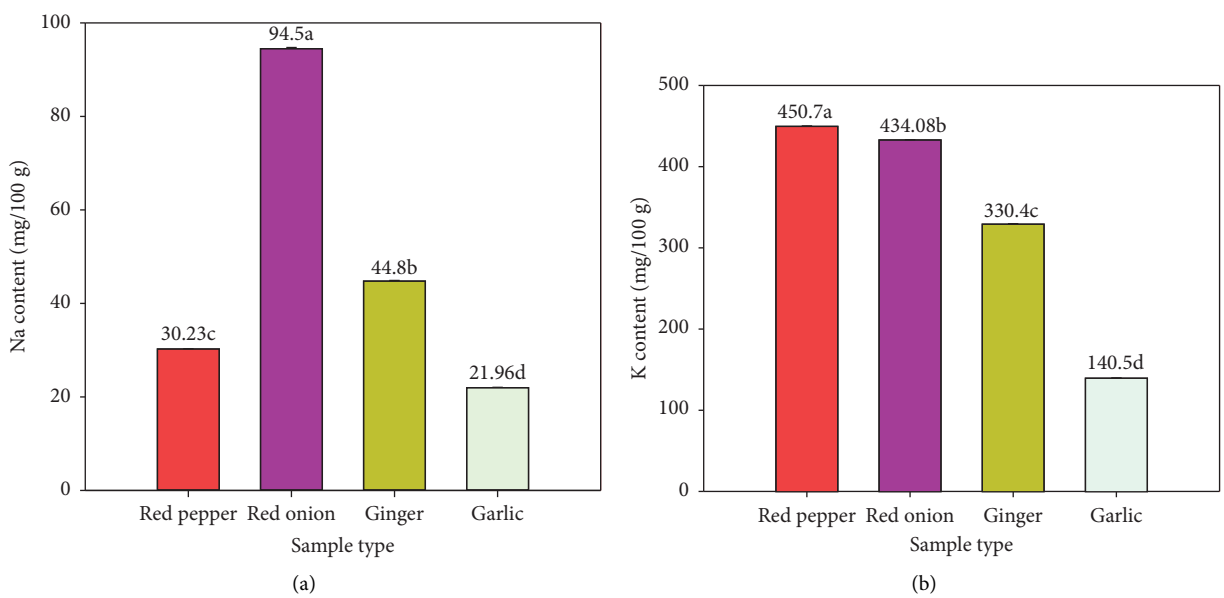

Figure 3: Sodium (a) and potassium (b) contents of red pepper, red onion, ginger, and garlic.

mineral element contents; these elements are useful as metabolism enhancer and antiallergen in the digestion system [33].

3.3. Physicochemical Property. The physicochemical properties of the powders of red pepper, red onion, garlic, and ginger are presented in Table 2.

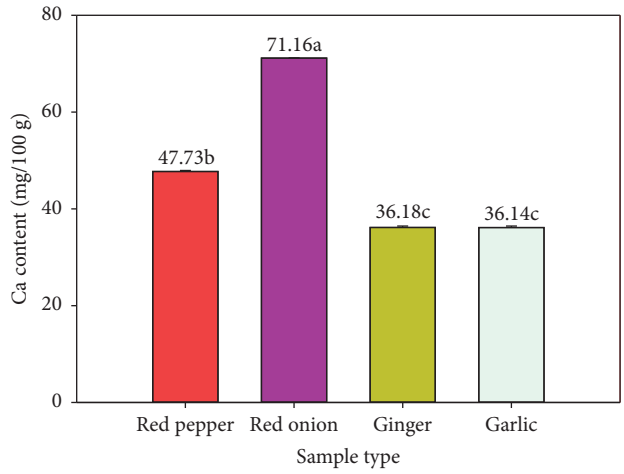

Figure 4: Calcium content of red pepper, red onion, ginger, and garlic.

Table 2: Physicochemical properties of the powders of red pepper, red onion, garlic, and ginger.

Parameters	Ingredients			
	Red pepper	Red onion	Ginger	Garlic
PH	5.23 ± 0.06^{c}	5.16 ± 0.15^{d}	5.76 ± 0.06^{b}	6.03 ± 0.06^{a}
Titratable acidity (%)	3.33 ± 0.63^{a}	1.77 ± 0.06^{b}	0.72 ± 0.13^{c}	1.83 ± 0.09^{bc}
Total soluble solid (°Brix)	8.5 ± 0.36^{c}	11.7 ± 0.30^{b}	6.93 ± 0.11^{d}	26.76 ± 0.15^{a}
Chroma	53.85 ± 0.77^{a}	25.27 ± 0.13^{d}	29.13 ± 0.04^{b}	25.62 ± 0.14^{c}
Hue angle (°)	52.85 ± 0.08^{d}	74.89 ± 0.42^{c}	83.84 ± 0.44^{a}	77.17 ± 0.99^{b}
Viscosity (cps)	296.0 ± 3.0^{c}	319.0 ± 4.0^{b}	475.66 ± 2.08^{a}	174.3 ± 2.88^{d}

Values with the same letter in the same row are not significantly different at $P < 0.05$.

3.3.1. pH and Titratable Acidity. The data obtained in Table 2 show the pH and titratable acidity of red pepper that were the highest compared to red onion, ginger, and garlic. The pH of red pepper (5.23) and red onion (5.16) showed that they have slightly acidic character compared to ginger (5.76) and garlic (6.03). The acidity for all powders was in the range of 0.7–3.33%. The acidity for the powder of red pepper was 3.33%, which was the highest acidic content compared to red onion (1.77%), ginger (0.72%), and garlic (1.83%) (Table 2); this is an indicator of shelf life and quality. The titratable acidity of onion was 1.77%. The previous study reported titratable acidity in the range 1.2–2.3% for onion bulbs for different storage condition and time [9], which is in agreement with the current study.

3.3.2. Total Soluble Solid (TSS). The highest TSS was observed in garlic with an average value of 26.76°Brix, and the lowest TSS was detected in ginger with an average value of 6.93°Brix. The TSS for red pepper was 8.5°Brix. The previous study that was conducted on green paper grown under open field and green house condition reported a TSS value in the range of 3.2 to 10.0°Brix [34], which agrees well with the current study. A study that was conducted on onion under different storage structures and storage time reported a TSS in the range of 10.53 to 13.29°Brix [9], which is in agreement with this study.

3.3.3. Color Value (L^*, a^*, and b^*). The colors of the powders are the most vital quality attribute and determine the quality and the market price of the product [35]. The color values of red pepper, red onion, ginger, and garlic are shown in Figure 5. Relatively highest L^* values were measured for garlic (80.33) and red onion (74.21) which resulted in the highest lightness index, while the highest a^* value was measured for red pepper (32.51) which resulted in the highest reddish color value. The red color of red pepper is due to the occurrence of carotenoid pigments. The Chroma and Hue angle values are shown in Table 2. In this study, the chroma value of the spice powders was in the range of 25.27 to 53.85. The highest chroma (color intensity) values for red pepper (53.85) resulted a saturation of reddish orange color value. The Hue angle values of the spices were in the range of 52.85 to 83.84. The color value of red pepper that was obtained from the current study was different from the one that was reported previously with L^* (44.46), a^* (17.79), and b^* (13.92) for red pepper [36]; this may be due to the difference in the variety of the red pepper, the maturity, or growing environment.

3.3.4. Viscosity. Considerable difference in viscosity was found between the spice powders (Table 2). The difference in viscosity of spices happened due to the molecular configuration and particle size of the samples [36]. The viscosity of onion paste reported from the previous study was 496 and 398 cps at different temperatures [37], which was higher than the current study. The previous study on garlic paste viscosity reported a value of 279 cps at 25°C and 100 rpm [38], which was higher than the current study.

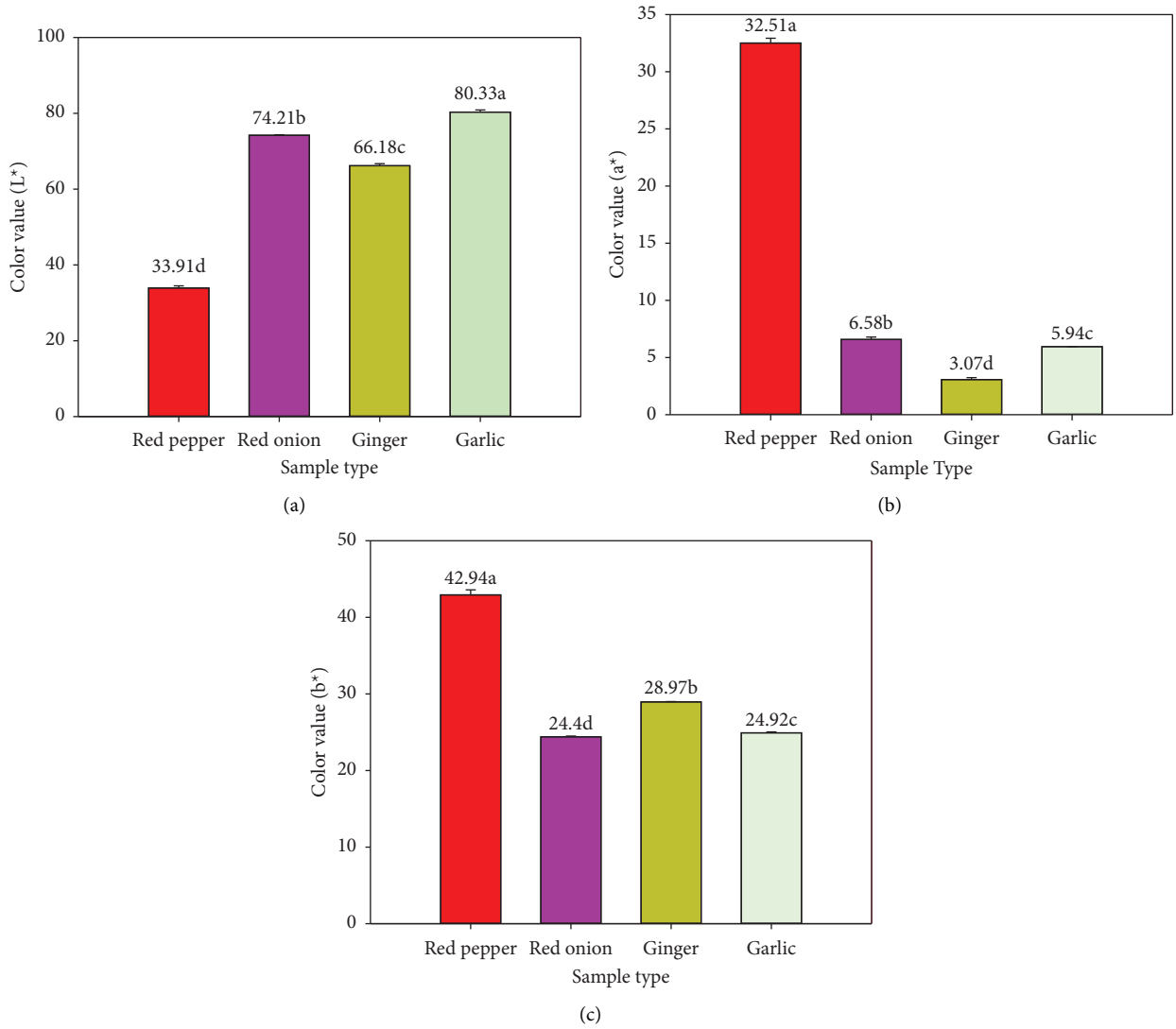

Figure 5: Color values (L*, a*, and b*) of red pepper, red onion, ginger, and garlic.

3.4. Functional Property. Measured functional properties that consisted of water absorption, oil absorption, bulk density, tapped density, Hausner ratio (Hr), Carr's index (CI, %), porosity (ε, %), dispersibility (%), foaming capacity (%), and foaming stability (%) for red pepper, red onion, ginger, and garlic are presented in Table 3.

3.4.1. Oil Absorption and Water Absorption. The water and oil absorption capacities for onion were the highest than those of the others, with the water absorption capacity of 2.51 g/ml and oil absorption of 2.16 g/ml. The highest value of water absorption for powders attributes to the swelling of the fiber and other carbohydrates, and the higher oil absorption capacity of the powder explains the limited amount of nonpolar protein side chains that would bind to the side chains of hydrocarbons of the oil and affects the texture and sensory property of foods [39].

3.4.2. Bulk Density, Tapped Density, Porosity, and Dispersibility. The measured values of bulk density, tapped density, porosity, and dispersibility for spice powders are given in Table 3. The porosity value of red pepper, red onion, ginger, and onion powders was in the range of 14.8–37.4%. The bulk density and tapped density of garlic and red onion were higher than those of red pepper and ginger. The porosity of red pepper power was the highest (37.7%), followed by red onion (32.39%), ginger (27.78%), and garlic (14.77%).

The porosity of red pepper was higher than the result that was reported previously for red pepper (32.3%) [35]. These properties are related to packaging, storage, and transportation costs. High bulk density and lower tapped density indicate the development of interparticulate interaction or increased cohesiveness or enhancement of compressibility of the powder. The action of tapping force brings extra force to overcome the cohesive attraction and

Table 3: Functional properties of the powders of red pepper, red onion, ginger, and garlic.

Parameters	Ingredients			
	Red pepper	Red onion	Ginger	Garlic
Water absorption (g/ml)	1.86 ± 0.32^{b}	2.20 ± 0.36^{b}	2.51 ± 0.21^{a}	2.43 ± 0.40^{b}
Oil absorption (g/ml)	1.06 ± 0.30^{d}	1.5 ± 0.1^{ab}	2.16 ± 0.20^{a}	1.2 ± 0.61^{c}
Bulk density (%)	0.38 ± 0.07^{a}	0.48 ± 0.03^{a}	0.39 ± 0.06^{a}	0.75 ± 0.014^{a}
Tap density (%)	0.61 ± 0.09^{a}	0.71 ± 0.05^{a}	0.54 ± 0.07^{a}	0.88 ± 0.02^{a}
Hausner ratio, Hr	1.59 ± 0.06^{a}	1.48 ± 0.02^{b}	1.39 ± 0.067^{c}	1.17 ± 0.068^{d}
Carr's index, CI (%)	37.4 ± 0.26^{a}	32.7 ± 0.97^{b}	28.3 ± 0.34^{c}	14.8 ± 0.49^{d}
Porosity, ε (%)	37.4 ± 0.26^{a}	32.73 ± 0.9^{b}	28.39 ± 0.34^{c}	14.86 ± 0.49^{d}
Dispersibility (%)	64.33 ± 1.5^{b}	85.0 ± 1.0^{a}	41.6 ± 1.50^{d}	63.3 ± 1.15^{c}
Foaming capacity (%)	2.89 ± 1.2^{b}	2.82 ± 1.33^{b}	3.54 ± 2.66^{a}	2.82 ± 1.33^{b}

Values with the same letter in the same row are not significantly different at $P < 0.05$.

causes the particles to fall towards the void spaces that decrease the volume of the powder [40]. The dispersibility value of red onion, red pepper, and garlic was in the range of 63.3–85.0%. Red onion had the highest dispersibility in water (85%), followed by red pepper (64.3%), garlic (63.3%), and ginger (41.6%). The dispersibility value of red onion in the current study was in line with the dispersibility (67–99%) of onion that was reported by [41]. Generally, higher bulk density is related to higher dispersibility.

3.4.3. Flowability. The powders having CI greater than 25% and HR greater than 1.34 can be considered as poor in flowability. According to the standard, red pepper with the HR value of 1.59% and CI value of 37.4%, red onion with the HR value of 1.48% and CI value of 32.7%, and ginger with the HR value of 1.39% and CI value of 28.3% indicated poor in flowability, while garlic with the HR value of 1.17% and CI value of 14.8% had the highest flowability compared to the other spice powders (Table 3). Particles having relatively uniform particle size have better flowability compared to particles with nonuniform particle size. In our current study, the flowability of garlic was the highest which showed that garlic powder had better particle size uniformity compared to the other spice powders. The flowability of powders is an important parameter in the design of systems for handling, packaging, processing, storage, and transportation of powder food products [42].

3.5. Particle Size Distribution and Specific Surface Area. The particle size distribution (D_{10}, D_{50}, and D_{90}), specific surface area, Sauter mean diameter (D_{32}), and volume weighted mean diameter (D_{43}) of the powders are shown in (Table 4). The particle size distribution of the powder that was generated using a similar crusher/mill and screen setting is shown in (Figure 6). From the particle size distribution, it was obvious that ginger powder was the finest of all which indicates more ability for mixing with other spices or ingredients. The highest particle size value was measured for garlic with the D_{90} value of 561 μm. It is known that particle size, specific surface area, and volume weighted mean diameter influence the characteristics of food, such as fluidity, water holding capacity, water solubility index, protein solubility, moisture content, extractable matter, color, and antioxidant activity of the food. The particle size (D_{10}, D_{50}, and D_{90}) and volume weighted mean diameter of garlic were the highest compared to those of red pepper, red onion, and ginger which is an indication for its potential for antimicrobial and antioxidant activity. Previous report on the specific surface area of garlic was in the range of 53.31 to 136.4 m^2/g [43], which is in agreement with the current result for garlic (77.41 m^2/g). Ginger powder had the highest specific surface area value (126.17 m^2/g). The highest specific surface area of ginger indicates the influence of food characteristics, such as moisture content, extractable matter, color, and antioxidant activity [44]. The particle size of ginger influenced the extraction efficiency of antioxidants [45]. The highest volume weighted mean diameter and Sauter mean diameter values were measured for red pepper (238 μm and 52.1 μm), respectively. It was reported that the particle size of red pepper affected the microbial activity of *Escherichia coli* ATCC25922 in red pepper powder [46].

3.6. Rheological Properties. Rheological properties of the powders are given in Table 5 and Figure 7.

3.6.1. Pasting Property. Table 5 presents the pasting property of the samples. Ginger exhibited the highest final viscosity (311.50 cps) and final pasting temperature (91.12°C) while onion showed the lowest viscosity (42.50 cps) and pasting temperature (50.72°C) (Figure 7). Thus, ginger requires more cooking energy than onion, and it can be used in processing of food products under high temperature and acidic condition that requires high viscosity. A similar study on ginger starch reported a final viscosity of 2066.5 cps and pasting temperature of 89.42°C [47], which is higher than the current study; this may be due to the use of pure starch from ginger rather than the whole ginger powder.

3.6.2. Texture. Ginger (1516.66 g) produced the highest puncture force (hardness), followed by garlic (860.033 g), red onion (675.83 g), and red pepper (572.3 g) (Table 5). This showed that red pepper and red onion need lower

Table 4: Particle size distribution and specific surface area.

Parameter	Powder type			
	Red pepper	Red onion	Ginger	Garlic
Small, D_{10} (μm)	11.6 ± 0.26^{d}	13.70 ± 0.10^{b}	12.77 ± 0.12^{c}	18.33 ± 0.32^{a}
Medium, D_{50} (μm)	98.1 ± 1.51^{c}	117.00 ± 1.0^{b}	90.80 ± 3.37^{d}	173.00 ± 2.00^{a}
Large, D_{90} (μm)	433.67 ± 10.4^{c}	536.33 ± 11.01^{b}	544.67 ± 12.5^{ab}	561.00 ± 9.53^{a}
Specific surface area (m^2/g)	77.41 ± 0.42^{c}	102.00 ± 0.43^{b}	126.17 ± 1.86^{a}	77.41 ± 0.42^{c}
D_{32} (μm)	52.07 ± 0.98^{a}	39.20 ± 0.17^{b}	31.70 ± 0.45^{c}	51.67 ± 0.28^{a}
D_{43} (μm)	168.33 ± 3.05^{a}	202 ± 3.46^{b}	191.67 ± 4.16^{c}	238 ± 4.00^{a}

Values with the same letter in the same row are not significantly different at $P < 0.05$.

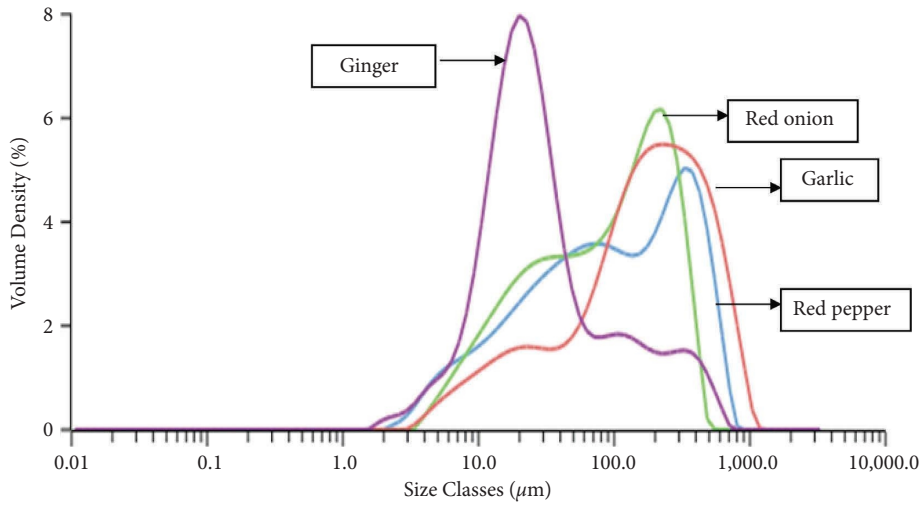

Figure 6: The particle size distribution of red pepper, red onion, ginger, and garlic.

Table 5: The pasting property and texture property of red pepper, red onion, ginger, and garlic.

Parameters	Spice type			
Pasting property	Red pepper	Red onion	Ginger	Garlic
Peak viscosity (cps)	38.0 ± 1.4^{c}	61.5 ± 0.7^{b}	176.5 ± 2.12^{a}	27.5 ± 2.1^{c}
Trough (cps)	36.5 ± 0.7^{b}	32.5 ± 2.1^{b}	150.0 ± 1.3^{a}	19.5 ± 1.8^{c}
Break down (cps)	2.5 ± 0.6^{c}	28 ± 1.4^{a}	28.5 ± 0.8^{a}	6 ± 1.2^{b}
Final viscosity (cps)	45 ± 1.3^{b}	42.5 ± 2.2^{b}	311.5 ± 2.12^{a}	27 ± 1.41^{c}
Set back (cp)	6.5 ± 0.6^{b}	7 ± 0.0^{b}	159.5 ± 2.0^{a}	6.5 ± 2.3^{b}
Peak time (s)	5.3 ± 0.2^{b}	1.23 ± 0.23^{c}	6.8 ± 0.28^{a}	5.7 ± 0.42^{b}
Pasting temperature (°C)	0.00 ± 0.0^{c}	50.72 ± 0.67^{b}	91.12 ± 0.88^{a}	0.00 ± 0.0^{c}
Texture (hardness)				
Force (g)	572.3 ± 6.49^{ab}	675.83 ± 4.85^{ab}	1516.66 ± 6.56^{a}	860.033 ± 6.192^{b}

Values with the same letter in the same row are not significantly different at $P < 0.05$.

force to process and easy in product formulation compared to ginger and garlic. The puncture forces (hardness) for the fresh red onion, ginger, and garlic were the highest compared to the dried red pepper puncture force (hardness) that showed that the samples in the dried form required low-puncture force than the fresh samples. A study on fresh red onion samples and freeze-dried red onion samples reported that freeze-drying substantially reduces the hardness of onions, and there was a decrease from the fresh (1529.55 gram) to the dried state (305.91 gram) [48], which is higher than the current study result from the fresh onion.

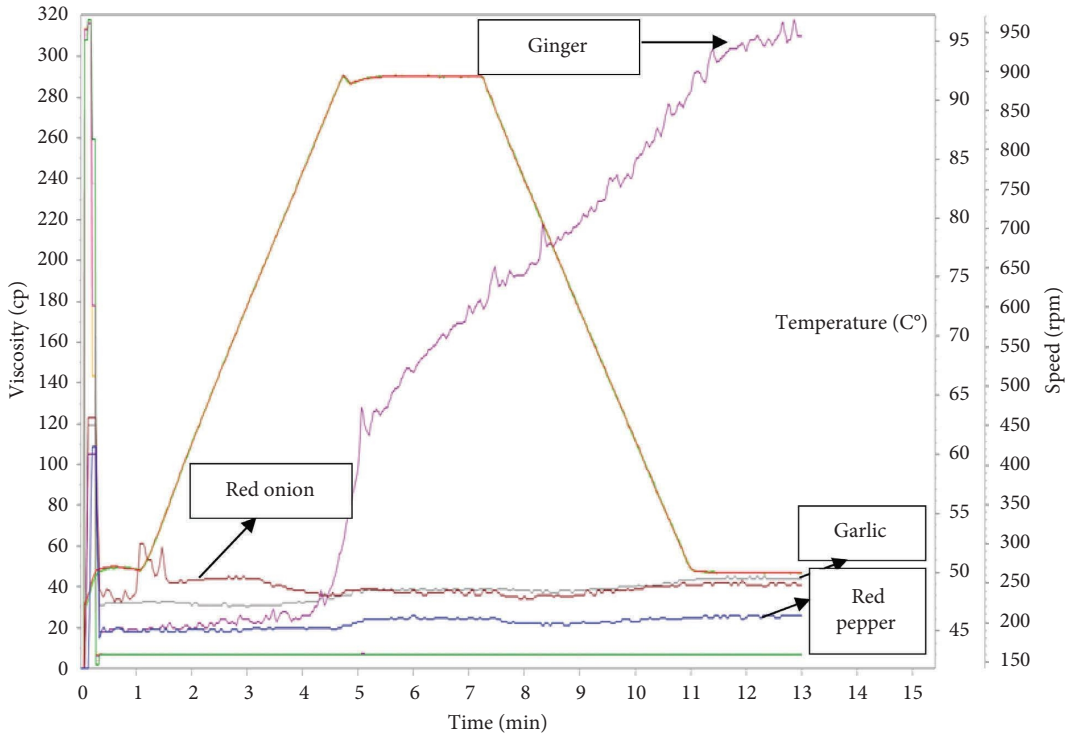

Figure 7: Pasting properties of red pepper, red onion, ginger, and garlic.

4. Conclusion

A comprehensive study of the functional, textural, and physicochemical properties of red pepper, red onion, ginger, and garlic was conducted. Given their chemical composition, red pepper, red onion, garlic, and ginger are good sources of protein, fiber, carbohydrate, and minerals. Potassium, calcium, sodium, and iron were the most abundant minerals present in the spices. It can also be stated that garlic had the highest flowability and particle size which are important properties in the design of systems for food processing and indication for its potential for antimicrobial and antioxidant activity. Moreover, the results indicated that ginger had a relatively good pasting property with the highest final viscosity compared to red pepper, red onion, and garlic. It is, therefore, important that spices are mixed with the appropriate proportions to get the required functional, textural, and physicochemical properties of formulated foods. Further studies on the formulation, optimization, and packaging of the traditional Ethiopian spicy foods would be valuable using red pepper, red onion, ginger, and garlic as main ingredients.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

The authors would like to thank Ethiopian Institute of Agricultural Research (EIAR), Bahir Dar University-Institute of Technology, for their administrative, financial, and resource support for the project.

References

[1] H. Deribe, "Spices production in Ethiopia: a review," *Agricultural Reviews*, vol. 7, pp. 11–17, 2021.

[2] D. Demeke, B. Getahun, and D. Mulualem Atinafu, "Assessing ethnophysiological use of spices and condiments in Bahir Dar city market, Bahir Dar, Ethiopia: ethnophysiological qualitative study," *Biomedical Science*, vol. 6, no. 2, p. 25, 2020.

[3] C. Okonkwo and A. Ogu, "Nutritional evaluation of some selected spices commonly used in the south-eastern part of Nigeria," *Journal of Biology, Agriculture and Healthcare*, vol. 4, no. 15, pp. 97–103, 2014.

[4] M. H. Carlsen, B. L. Halvorsen, K. Holte et al., "The total antioxidant content of more than 3100 foods, beverages, spices, herbs and supplements used worldwide," *Nutrition Journal*, vol. 9, no. 1, p. 3, 2010.

[5] T. Tesfa, W. Bayu, A. Gashaw, and H. Beshir, "Spice production, marketing, and utilization in south wollo, Ethiopia," *East African Journal of Sciences*, vol. 11, no. 1, pp. 27–36, 2017.

[6] Y. Yebirzaf, N. Belete, W. Tegibew, G. Yohaness, M. Abayneh, and Y. Kassahun, "Collection and characterization of garlic (Allium sativm L.) germplasm for growth and bulb yield at Debre Markos, Ethiopia," *Journal of Horticulture and Forestry*, vol. 10, no. 3, pp. 17–26, 2018.

[7] M. Tefera and B. S. Chandravanshi, "Assessment of metal contents in commercially available ethiopian red pepper

assessment of metal contents in commercially available ethiopian red pepper," *International Food Research Journal*, vol. 25, 2018.

[8] M. Seifu, Y. B. Tola, A. Mohammed, and T. Astatkie, "Effect of variety and drying temperature on physicochemical quality, functional property, and sensory acceptability of dried onion powder," *Food science \& nutrition*, vol. 6, pp. 1–9, 2018.

[9] S. G. Eriballo, N. Satheesh, and S. W. Fanta, "Performance evaluation of low-cost storage structures for onions (Allium cepa L," *)Storage*, vol. 151, pp. 437–448, 2022.

[10] AOAC Official Method 2001, "Association of official agricultural chemists," *Journal of the Franklin Institute*, vol. 219, no. 2, p. 236, 1935.

[11] J. E. Choi and J. H. Lee, "Non-Newtonian characteristics of gochujang and chogochujang at different temperatures," *Preventive Nutrition and Food Science*, vol. 22, no. 1, pp. 62–66, 2017.

[12] M. C. D. Andrade Júnior, J. Souza Andrade, and S. D. Souza Costa, "Biochemical changes of cubiu fruits (*Solanum sessiliflorum* dunal, solanaceae) according to different tissue portions and ripening stages," *Food and Nutrition Sciences*, vol. 07, no. 12, pp. 1191–1219, 2016.

[13] A. A. Rahman, "Chemical and physical characteristics of pepper mash and hot pepper sauce," vol. 183, Dissertation, 1986.

[14] L. R. Beuchat, "Functional and electrophoretic characteristics of succinylated peanut flour protein," *Journal of Agricultural and Food Chemistry*, vol. 25, no. 2, pp. 258–261, 1977.

[15] A. M. Goula, K. G. Adamopoulos, and N. A. Kazakis, "Influence of spray drying conditions on tomato powder properties," *Drying Technology*, vol. 22, no. 5, pp. 1129–1151, 2004.

[16] B. M. Ghodki and T. K. Goswami, "Effect of moisture on physical and mechanical properties of cassia," *Cogent Food & Agriculture*, vol. 2, no. 1, pp. 1–11, 2016.

[17] A. M. Sereno, M. A. Silva, and L. Mayor, "Determination of particle density and porosity in foods and porous materials with high moisture content," *International Journal of Food Properties*, vol. 10, no. 3, pp. 455–469, 2007.

[18] N. Jinapong, M. Suphantharika, and P. Jamnong, "Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration," *Journal of Food Engineering*, vol. 84, no. 2, pp. 194–205, 2008.

[19] M. Meghwal and T. K. Goswami, "Ambient and cryogenic grinding of fenugreek and flow characterization of its powder," *Journal of Food Process Engineering*, vol. 36, no. 4, pp. 548–557, 2013.

[20] K. D. Kulkarni, D. N. Kulkarni, and U. M. Ingle, "Sorghum malt-based weaning food formulations: preparation, functional properties, and nutritive value," *Food and Nutrition Bulletin*, vol. 13, no. 4, pp. 1–7, 1991.

[21] M. O. Aremu, O. Olaofe, and E. T. Akintayo, "Functional Properties of some Nigerian Varieties of legume seed flours and flour concentration effect on foaming and gelation properties," *Journal of Food Technology*, vol. 5, no. 2, pp. 109–115, 2007.

[22] X. Sun, Y. Zhang, J. Li et al., "Effects of particle size on physicochemical and functional properties of superfine black kidney bean (Phaseolus vulgaris L.) powder," *PeerJ*, vol. 2019, p. e6369, 2019.

[23] S. Balet, A. Guelpa, G. Fox, and M. Manley, "Rapid visco analyser (RVA) as a tool for measuring starch-related physiochemical properties in cereals: a review," *Food Analytical Methods*, vol. 12, no. 10, pp. 2344–2360, 2019.

[24] L. Chen, Y. Tian, Q. Tong, Z. Zhang, and Z. Jin, "Effect of pullulan on the water distribution, microstructure and textural properties of rice starch gels during cold storage," *Food Chemistry*, vol. 214, pp. 702–709, 2017.

[25] Yusuf, "Evaluation of phytochemical, mineral, and nutrient content of ginger," *Zingiber Officianale) in Mubi*, vol. 7, no. 2, pp. 41–47, 2019.

[26] T. B. and G. D. Esayas K., A. Shimelis, F. Ashebir, and R. Negussie, "Proximate composition, mineral content and antinutritional factors of some capsicum (Capsicum annum) varieties grown in Ethiopia," vol. 25, no. 3, pp. 451–454, 2011.

[27] T. I. A. Abiola, "The international journal of science & technoledge evaluation of nutritional composition and antioxidants properties of onion (allium cepa) and garlic (allium sativum)," *The International Journal of Science and Technology*, vol. 5, 2018.

[28] M. Sajid, M. S. Butt, A. Shehzad, and S. Tanweer, "Chemical and mineral analysis of garlic: a golden herb," *Pakistan Journal of Food Sciences*, vol. 24, 2014.

[29] I. Ogunlade, A. A. Alebiosu, and A. I. Osasona, "Proximate, mineral composition, antioxidant activity, and total phenolic content of some pepper varieties," *Capsicum species*, vol. 6, pp. 2221–2227, 2012.

[30] J. Mlček, M. B. Tunde Juríková, M. valšíková, and H. družbíková, "The antioxidant capacity and macroelement content of several onion cultivars," *Turkish Journal of Agriculture and Forestry*, vol. 39, pp. 999–1004, 2015.

[31] M. Gibczynska, "Comparison of chemical composition of selected cultivars of white," *Yellow and Red Onions*, vol. 21, no. 4, pp. 736–741, 2015.

[32] A. Shukla, V. V. Goud, and C. Das, "Antioxidant potential and nutritional compositions of selected ginger varieties found in Northeast India," *Industrial Crops and Products*, vol. 128, pp. 167–176, 2019.

[33] J. J. León, J. L. Elías, and M. A. H. López, "Postharvest quality and shelf life of green pepper (capsicum annuum l.) grown under open-field and greenhouse conditions," *Idesia (Chile)*, vol. 31, pp. 35–42, 2013.

[34] A. Topuz, H. Feng, and M. Kushad, "The effect of drying method and storage on color characteristics of paprika," *LWT - Food Science and Technology*, vol. 42, no. 10, pp. 1667–1673, 2009.

[35] H. W. Woldemariam, S. Admassu Emire, P. Getachew Teshome, S. Toepfl, and K. Aganovic, "Physicochemical, functional, oxidative stability and rheological properties of red pepper (Capsicum annuum L.) powder and paste," *International Journal of Food Properties*, vol. 24, no. 1, pp. 1416–1437, 2021.

[36] S. Khushbu, C. K. Sunil, D. V. Chidanand, and R. Jaganmohan, "Effect of particle size on compositional, structural, rheological, and thermal properties of shallot flour as a source of thickening agent," *Journal of Food Process Engineering*, vol. 43, no. 3, pp. 1–13, 2020.

[37] S. Naqash, H. R. Naik, S. Z. Hussain, H. A. Makroo, and B. N. Dar, "Effect of thermal treatment on physicochemical, phytochemical, and microbiological characteristics of brown Spanish onion paste," *Quality Assurance and Safety of Crops & Foods*, vol. 13, no. 4, pp. 1–12, 2021.

[38] U. S. JASIM-AHMED, "Physico-chemical and storage characteristics of garlic paste," *Journal of food processing and preservation*, vol. 25, pp. 15–23, 2001.

[39] M. H. Jaspal, M. Ijaz, H. Au Haq et al., "Effect of oregano essential oil or lactic acid treatments combined with air and modified atmosphere packaging on the quality and storage

properties of chicken breast meat," *Lebensmittel-Wissenschaft & Technologie*, vol. 146, Article ID 111459, 2021.

[40] L. Chen, X. Wei, S. Irmak, B. D. Chaves, and J. Subbiah, "Inactivation of *Salmonella enterica* and Enterococcus faecium NRRL B-2354 in cumin seeds by radiofrequency heating," *Food Control*, vol. 103, pp. 59–69, 2019.

[41] S. Jan, S. I. Rafiq, and D. C. Saxena, "Effect of physical properties on flow ability of commercial rice flour/powder for effective bulk handling," *International Journal of Computers Applications*, vol. 29, no. 7, 2016.

[42] S. Jan, S. I. Rafiq, and D. C. Saxena, "Effect of physical properties on flow ability of commercial rice flour/powder for effective bulk handling," *International Journal of Computers and Applications*, vol. 975, pp. 1–5, 2015.

[43] A. H. Bahnasawy, "Some physical and mechanical properties of garlic," *International Journal of Food Engineering*, vol. 3, no. 6, 2007.

[44] L. Ratnawati, "The Effect of Particle Size and Brewing Time of Ginger (Zingiber Officinale) Powder to the Characteristic and Acceptance of the Herbal Product the Effect of Particle Size and Brewing Time of Ginger (Zingiber Officinale) Powder to the Characteristic," in *Proceedings of the IOP Conference Series: Materials Science and Engineering*, England, UK, June 2021.

[45] S. A. Makanjuola, "Influence of particle size and extraction solvent on antioxidant properties of extracts of tea, ginger, and tea – ginger blend," *Food science \& nutrition*, vol. 5, pp. 1–7, 2017.

[46] B. Zhang, L. Zhang, T. Cheng, X. Guan, and S. Wang, "Effects of water activity, temperature and particle size on thermal inactivation of *Escherichia coli* ATCC 25922 in red pepper powder," *Food Control*, vol. 107, Article ID 106817, 2020.

[47] C. S. d. Oliveira, R. Z. B. Bisinella, C. D. Bet, C. Beninca, I. M. Demiate, and E. Schnitzler, "Physicochemical, thermal, structural and pasting properties of unconventional starches from ginger (zingiber officinale) and white yam (Dioscorea sp.)," *Brazilian Archives of Biology and Technology*, vol. 62, 2019.

[48] R. P. F. Guin, "Texture of Onions before and after Freeze-Drying," *5 th Central European Congress on food*, vol. 19, 2010.