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ORIGINAL ARTICLE

Artichoke, eggplant and tomato flours as nutritional ingredients for wheat dough: hydration properties

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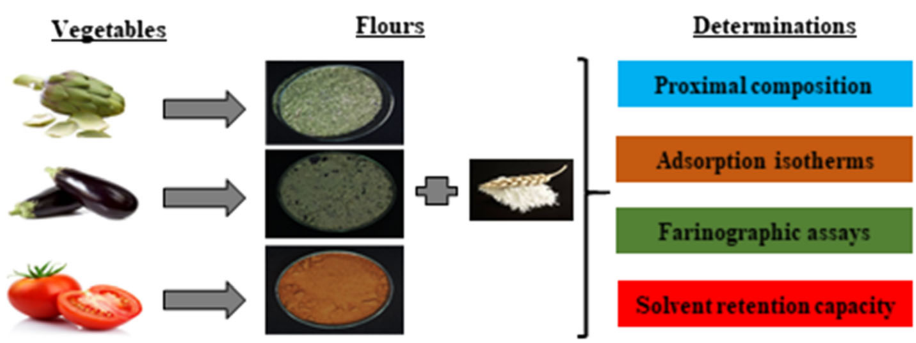
Abstract Artichoke (AF), eggplant (EF) and tomato (TF) flour were used as nutritional ingredients for wheat dough. A replacement of wheat flour with 5 or 10% of these vegetable flour was performed. Hydration properties (equilibrium adsorption isotherms, solvent retention capacity), capacity of blends for dough development (farinographic assay) and the proximal composition of flours were evaluated. Samples with high content of soluble sugar and low of insoluble fiber (EF and TF) presented higher equilibrium water sorption at 20 °C and 40 °C, at aw > 0.5. The solvent retention capacity of wheat–vegetable flour blends increased mainly at higher levels of replacement (10%) and with samples of artichoke and eggplant. The highest and the lowest stable dough with 10% of replacement was obtained with AF and EF, respectively. Water sorption and absorption parameters should be previously determined so as to obtain the optimum dough structure that lead to a high technological quality bread.

Graphic abstract



Keywords Vegetable · Flour · Composition · Sorption isotherm · Water retention · Farinographic assay

Introduction

Fruits and vegetables are a very important source of fibre and antioxidants, therefore their consumption in adequate amounts is considered extremely beneficial for health (Loke et al. 2016). In recent years, there has been an increase in the development of new foods with bioactive compounds naturally present in vegetables. Worldwide, the

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amount of food produced is much higher to those sold, therefore in the post-harvest stage losses are up to 50% of total primary production, where tons of fresh vegetables are discarded due to noncompliance with quality parameters of the product (shape, size, color) (Gustauson et al. 2012). The use of these products not suitable for commercialization is a current trend in the food industry (Boubaker et al. 2016; Nour et al. 2015), although processing of vegetables for subsequent incorporation in a food matrix can induce changes in physicochemical properties (Muthukumarappan and Tiwari 2010).

One of the most widely used value-added processes is drying; it decreases water activity, reducing microbiological and enzymatic activity and physicochemical reactions during storage (Russo et al. 2013). However in some cases the use of hot air or vacuum reduces the nutritional value of vegetables (Gümüşay et al. 2015);while by freeze drying nutritional quality similar to that of fresh products can be obtained (Georgé et al. 2011; Zhang et al. 2018).

The most important horticultural region of the province of Buenos Aires in Argentina is La Plata, were the main products are artichoke, eggplant and tomato. The artichoke (*Cynara scolymus*) is an immature inflorescence of the Asteraceae family, while the eggplant (*Solanum melongena*) and tomato (*Lycoprsicum esculentum*) are fruits belonging to the Solanaceae family. Within each plant studied we can highlight the importance of a certain group of major bioactive compounds: fibre for artichoke with inulin as the most relevant soluble fibre, phenolic compounds for eggplant (anthocyanins and chlorogenic acid), and carotenoids in tomato with lycopene being the most active compound.

The flour of vegetables obtained by drying and subsequent grinding could be used as ingredients in the production of baked goods (breads, crackers and pasta), adding nutritional value to those products. However, because the composition of the flour is related to their physicochemical properties, the vegetable flour would have rheological and baking properties different from those of wheat flour, where the main components are starch and gluten proteins, while in vegetables the most abundant product is the fibre (USDA 2018). Some researchers studied the addition of commercial fibre (Blanco Canalis et al. 2017; Linlaud et al. 2009; Salinas and Puppo 2013), artichoke fibre (López et al. 1996; Sirbu and Arghire 2017) and non-cereal fibre (Bigne et al. 2017) to wheat flour; however no previous studies on physicochemical properties of wheat–vegetable flour blends were performed. Therefore, the objective of this work was to characterize the flour of various vegetables (artichoke, eggplant and tomato) and evaluate the hydration properties (adsorption isotherms, farinographic assay and solvent retention capacity) at different levels of addition to wheat flour.

Materials and methods

Materials

A commercial wheat flour (WF) for bread making was used (type 0000, Molino Campodónico Ltda., Argentina) while artichoke *cv.* Hybrid 4051, eggplant *cv.* Monarca and tomato *cv.* Yigido were harvested in La Plata (Argentina), frozen in liquid nitrogen and dried in a freeze-dryer (RIFICOR, Argentina) set at 1.6 mmHg of pressure at room temperature with a condenser plate temperature of − 50 °C for 48 h, and then, the dried samples were milled in a domestic mill used for coffee (Peabody, PE-MC9100, China) to obtain the flour of artichoke (AF), eggplant (EF) and tomato (TF). The AF was produced using only the bracts (non-edible parts) meanwhile the EF and TF were produced using the whole fruit. The different flours were pass through a 500 μm sieve, and the larger particles containing skin were left in the eggplant flour (less than 15% of the total flour). Finally, the granulometry of the vegetables flours was less or equal to 500 μm.

Proximal composition

The proximal composition of flour was determined according to AOAC (1998) methods. Moisture of samples was determined by triplicate after drying in oven at 105 °C until constant weight. Protein content was determined according to Kjeldahl method (conversion factor: 6.25). Lipid content was determined using Soxhlet method (3 h extraction with petroleum ether: 35–60 °C fraction). The ash content was determined using the direct method according to AACC 08-01.01. Carbohydrate content was determined by difference. Soluble sugars were determined by HPLC method according to Sciammaro et al. (2018) whit minor modifications, using a HPLC Waters 1525 (Millipore Corp., Milford, MA, USA) supplied with a XBridge Amide column (i.d.: 4.6 mm, large: 15 cm, with particle size of 3.5 μm) maintained at 30 °C. A system of acetonitrile:water 75:25 with 0.2% TEA (triethylamine) was used as mobile phase at a flow rate of 1 mL/min. Refraction index detection system was used. Glucose, fructose and sucrose were reported. Total dietary fibre (TDF) and insoluble dietary fibre (IDF) were determined by enzymatic hydrolysis (Megazyme kit, K-TDRF, Megazyme, Wicklow, Ireland) according to the official AOAC 991.43 method. Soluble dietary fibre (SDF) was calculated by difference between total and insoluble fibre contents. Assays were performed by duplicate.

Determination of adsorption isotherms by the static gravimetric method

Water adsorption isotherms of flour at 10, 20 and 40 °C were determined by Rahman (2009) method. Temperatures were selected in the range from refrigeration to room conditions storage. Nine saturated salt solution (slurries), generating constant a_w atmospheres, were prepared for sample equilibration following the AOAC method 978.18 (AOAC 1998). Their water activities vary in the range of 0.63–0.879 at the experimental temperatures. Salt solutions were placed in sealed flasks covering the bottom with salt crystals, and a plastic structure was put inside each flask to support the sample. The flour (0.0002 kg) was placed in glass dishes onto the plastic supports and the flasks were sealed. For environments with $a_w > 0.75$, a small container with toluene was included in the flask to prevent microbial spoilage of the sample (Rahman 2009). Each point of the isotherms was determined in triplicate. One set of flasks was maintained at 10 °C in a cold store, while for 20 °C samples were placed in a temperature-controlled room. For the material corresponding to 40 °C, a convection culture oven with automatic temperature control was utilized. The flasks were periodically open to weigh the samples. Equilibrium was assumed after the variation in the moisture content of samples (calculated by weight variations considering constant dry matter) was less than 0.003 kg water/kg dry solids, which is the ordinary error accepted for oven-moisture determinations (Lomauro et al. 1985). Mathematical models used to fit the experimental data were:

GAB	$W = \left(\frac{W_M C k a_w}{(1-ka_w)(1-ka_w+Cka_w)}\right)$	(Hossain et al. 2001)	(1)
Halsey	$W = \left(\frac{-A}{\ln(a_w)}\right)^{1/B}$	(Kaya and Kahyaoglu 2005)	(2)
Oswin	$W = \left(\frac{D}{\left(\left(\frac{1}{a_w}\right)-1\right)^F}\right)$	(Kaya and Kahyaoglu 2005; Kaymak-Ertekin and Gedik 2004)	(3)
Iglesias–Chirife	$He = A_I * \left(\frac{a_w}{(1-a_w)}\right) + B_I$	(Hossain et al. 2001)	(4)
Leiva Díaz	$W = C_1 \exp\left(C_2 a_w^{C_3}\right)$	(Leiva Díaz et al. 2009)	(5)

where W is the equilibrium moisture content (kg water/kg dry solids), A, B, C, D, F, AI, BI, C1, C2, C3, k, W_M were sorption isotherm constants and aw is the water activity.

Farinographic assays

Development of dough was followed by farinographic assays. A Brabender farinograph (0.3 kg capacity) (Brabender, Duigsburg, Germany) was utilized for measuring water absorption, development time, stability and softening degree of dough AACC 54-21.02 method. Dough consisted of mixing wheat flour, NaCl [2 kg/100 kg wheat flour basis (w.f.b.)] and AF, EF and TF at levels of 5 and 10% (kg flour/100 kg w.f.b.). Assays were performed by duplicate.

Solvent retention capacity profile (SRC)

The solvent retention capacity profile (SRC) was obtained according to AACC (2000) approved Method 56-11.02. Flour samples (0.001 kg) were suspended with 0.005 kg of water, 50% sucrose, 5% sodium carbonate, and 5% lactic acid aqueous solutions. The samples were mixed, hydrated for 20 min and centrifuged at 1610 *g* for 15 min. Supernatant was discarded and each precipitate obtained was weighed and the SRC for each sample was calculated according to the approved method. Assays were performed by triplicate.

Statistical analysis

The experiments were carried out in a completely randomized design. Results were subjected to analysis by ANOVA and means were compared by a Fisher test at $p < 0.05$ performed in InfoStat software (Di Rienzo et al. 2011).

Results and discussion

Proximal composition of flours

The artichoke, eggplant, tomato and wheat flour composition is compared in Table 1. We observed that the AF, EF and TF had higher levels of some of the components in comparison with those of the WF. The composition of the fresh vegetables was studied (USDA 2018) but not in the present form as freeze dried flour.

The protein content was similar in all the samples studied being around a value of 13% (Table 1). In the case of AF, EF and TF these flour do not contain gluten proteins, so they don't contribute to the formation of the gluten network in the dough and actually they will dilute the gluten from the wheat as it was previously observed for other composite blends (Bigne et al. 2016; Mohammed et al. 2012). Lipid content was similar for wheat EF and TF, AF had the smallest quantity being almost the half of the amount present in the other flour. Flour from eggplant and tomato presented the highest amount of moisture after being freeze dried and milled in the same way, so the difference in the moisture content is due to the

Table 1 Proximal composition (kg/100 kg of dry sample) of wheat (WF), artichoke (AF), eggplant (EF) and tomato (TM) flour

Flour	Wheat (WF)	Artichoke (AF)	Eggplant (EF)	Tomato (TF)
Moisture* (kg/100 kg)	13.61 ± 0.13[c]	10.07 ± 0.18[d]	15.98 ± 0.52[b]	17.33 ± 0.52[a]
Proteins (kg/100 kg)	13.20 ± 0.03[a]	13.13 ± 0.02[a]	12.94 ± 0.21[a]	12.49 ± 0.12[b]
Lipids (kg/100 kg)	1.53 ± 0.06[a]	0.73 ± 0.06[b]	1.79 ± 0.34[a]	1.88 ± 0.07[a]
Ash (kg/100 kg)	0.84 ± 0.03[c]	7.70 ± 0.08[b]	8.55 ± 0.83[b]	10.06 ± 0.36[a]
Carbohydrate** (kg/100 kg)	84.43	78.44	76.72	75.57
Glucose (kg/100 kg)	nd	5.32 ± 1.01[b]	19.79 ± 4.32[a]	18.18 ± 10.12[a]
Fructose (kg/100 kg)	nd	0.43 ± 0.60[b]	17.11 ± 3.41[a]	21.73 ± 10.77[a]
Sucrose (kg/100 kg)	0.43 ± 0.00[c]	1.66 ± 0.34[a]	1.16 ± 0.07[b]	nd
Total soluble sugar*** (kg/100 kg)	0.43	7.41	38.06	39.91
Total dietary fibre (kg/100 kg)	6.13 ± 0.25[d]	68.71 ± 1.06[a]	47.68 ± 1.21[c]	26.41 ± 2.60[b]
Insoluble fibre (kg/100 kg)	5.13 ± 0.37[d]	62.37 ± 3.25[a]	36.93 ± 3.96[b]	23.88 ± 0.95[c]
Soluble fibre (kg/100 kg)	1.00	6.34	10.76	2.53

*kg/100 kg of wet sample

**Carbohydrate = 100 − proteins − lipids − ash

***Total soluble sugar = glucose + fructose + sucrose

Mean value ± SD, *nd* not detected, different letters in the same row indicate significant differences at ($p < 0.05$)

vegetable characteristics, i.e. the presence of molecules capable of retaining or loosing water, and cannot be attributed to the drying process. In addition, for AF, EF and TF ash and dietary fibre (soluble and insoluble) contents were higher respect to WF. It is important to remember that the total amount of carbohydrates calculated by difference (Table 1) include the total fibre, soluble sugars and starch (if present) in the samples. In the case of WF only 6% is total dietary fibre, therefore total carbohydrate was almost represented by starch, only 0.43% sucrose was found as soluble sugar (Table 1). It can be deduced from data of Table 1 that carbohydrate content of AF is represented mostly by total dietary fibre, no starch is present and the content of soluble sugar was low, with glucose being the major component. While in EF and TF the carbohydrate content was represented both by the total dietary fibre (47.68% and 26.41% respectively) and the total soluble sugar (38.06% and 39.91%, respectively), without the presence of starch. Glucose and fructose were the main soluble sugar found in EF and TF, around 20%, while in EF sucrose is also present in smaller proportion (Table 1). Therefore, we can state that the composition and proportion of the different types of soluble sugar was different in the different flour studied: the vegetable flour presented majority simple sugar, while in WF complex sugar were the main components of this soluble fraction.

A major content of total dietary fiber (TDF) was found in the vegetables flours respect to the cereal flour (wheat flour WF), reaching values 10 times higher in the case of AF (Table 1); it is important to take into account that AF is made from the non-edible bracts of the capitula, being the amount of insoluble fibre higher than the soluble one in all the cases studied.

The physicochemical effects of dietary fibre depends of the proportion of soluble and insoluble fiber present (Elleuch et al. 2011); and is because of this that beyond the absolute values, results interesting to evaluate this proportions respect to the total amount. For the IDF/TDF ratio in percentage (insoluble dietary fibre × 100/total dietary fibre), the higher values (around 90%) were for AF and TF, followed by WF with 83.68% and EF with 77.45% (Table 1). The SDF/TDF ratio in percentage (soluble dietary fibre x 100/total dietary fibre) was 22.57% for EF, and values of 16.31%, 9.58% and 9.23% were obtained for WF, TF, and AF, respectively. These values suggest that the total dietary fibre (TDF) could almost be represented in all cases by the IDT.

The difference in the IDF/TDF ratio combined with the fact that the flours are made of "vegetables" that do not contain gluten, will influence the water absorption capacity of the composite flour during dough formation.

Adsorption isotherms

The time elapsed until reaching apparent water adsorption equilibrium varied between 53 days for isotherms at 10 °C, 12 days at 20 °C and 18 days at 40 °C. Experimental data for wheat, artichoke, eggplant and tomato flour at the different temperatures are shown in Fig. 1. Mathematical models described in "Determination of adsorption isotherms by the static gravimetric method" section were used to fit the experimental data, GAB model was the less

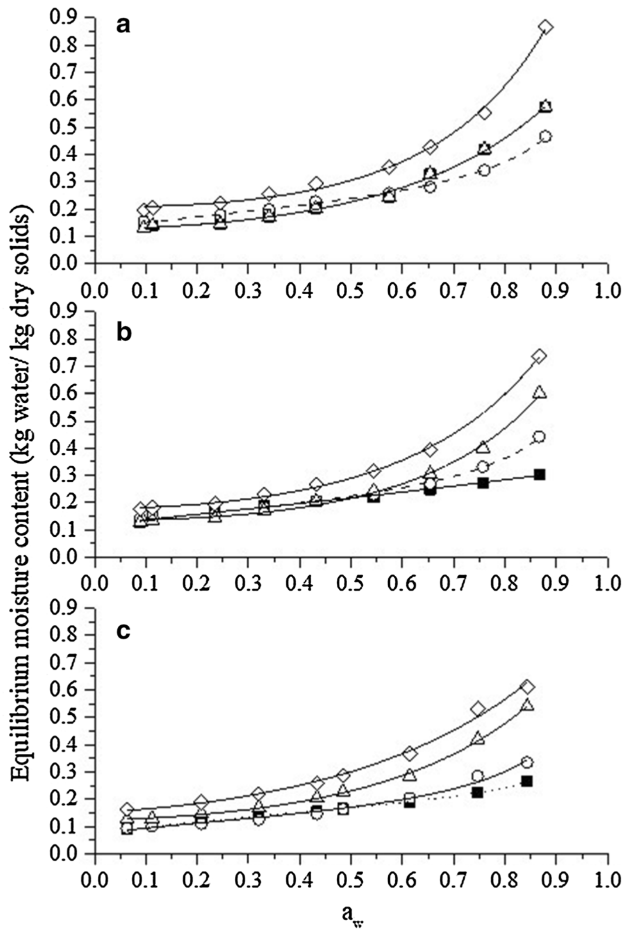

Fig. 1 Absorption isotherm of the wheat (filled square), artichoke (open circle), eggplant (open triangle), and tomato (open diamond) flour at 10 °C (**a**), 20 °C (**b**), 40 °C (**c**). Leiva Diaz (solid line), Halsey (dashed lines) and Oswin models (dotted lines)

appropriate having in all cases a r^2 value lower than 0.8, the Iglesias–Chirife model had a good fitting but the other three models (Halsey, Oswin, Leiva Díaz) better fitted experimental data. Table 2 lists the fitted parameters of the best models (Leiva Diaz, Halsey and Oswin), their corresponding coefficients of determination (r^2) calculated by nonlinear least squares, and the root mean square error (E_{RMS}) which takes into account the number of fitting parameters (Eq. 6) using a statistical software (OriginLab 2013). Fitting was considered the best when the r^2 value was high ($r^2 > 0.9$) and E_{RMS} value was the lowest from all predictions. Figure 1 also illustrates the models providing more accurate fitting

$$E_{RMS} = \sqrt{\frac{\sum_{i=1}^{n} (W_i - W_{ic})^2}{n - p}}. \quad (6)$$

At low a_w the water content of the flour did not represent differences, above a_w of 0.5 the curves were more disperse and the behavior depend on the temperature. At 20 °C (Fig. 1b) WF presented the lower water content at $a_w > 0.5$, with the following tendency for this parameter: WF < AF < EF < TF. At 40 °C (Fig. 1c) the behavior was similar, and WF and AF curves were practically the same. Finally, at 10 °C (Fig. 1a), the behavior was different compared to the other two temperatures, the lowest water content was for AF, meanwhile WF and EF were over lapse and TF had the higher amount of water respect to 20 and 40 °C for the same a_w.

From the best adsorption isotherms fittings, it was possible to calculate a security value of the moisture content (i.e. were no pathogenic or unhealthy microorganisms can grow $a_w < 0.7$) for storing the flour in function of the temperature studied. For the wheat flour the safe limit of moisture to prevent spoilage was 0.275 ± 0.0723 kg/kg, while for AF, EF and TF values were 0.282 ± 0.038, 0.357 ± 0.009 and 0.463 ± 0.0156 kg/kg, respectively.

Dough development properties

In the farinographic profiles we can observe a first peak at short times related to the hydration of the starch, and a second peak related to the optimal consistency of the dough and the development of the gluten network (Fig. 2).

In the case of WF a rapid increase in the consistency of the dough was observed, reaching in about 2 min the 500 Brabender Units (BU), followed by a slight increase in the consistency giving a rise to the second peak around 9 min (Fig. 2a); which is consistent with good quality flours for baking (Salinas et al. 2015; Salinas and Puppo 2013). For mixtures of wheat flour with vegetable flour, a rapid increase in consistency was also observed at 2 min, but with a second peak much more pronounced at shorter times (Fig. 2b–e), behavior that would be related to the addition of fibre to the dough. A similar behavior was observed by Salinas and Puppo (2013) when using inulin enriched with oligofructose to supplement wheat flour to a level of 12% (flour base); as well as in a work on mixing wheat and carob flour (Salinas et al. 2015), attributing in both cases the farinographic behavior to the presence of fibre. Katina (2003) describes that when starting the mixing of flour with added fibre, a rapid absorption of the free water is observed and it seems that the water is in defect, but after a few minutes of mixing the dough develops its characteristic properties reaching its point of optimal consistency; at the same time, the low tolerance to over-mixing of the fibre-enriched dough is highlighted.

Replacement of WF with the distinct vegetable flour conducted to differences in the farinographic behavior (Fig. 2). In the case of 5% AF and EF, the behavior was similar, presenting a second peak of maximum consistency around 10 min. However, for the 10% replacements the maximum consistency was shifted towards longer times for

Table 2 Fitting parameters of the best mathematical model for the absorption isotherms of wheat (WF), artichoke (AF), eggplant (EF) and tomato (TF) flour at the studied temperatures

Temperature (°C)	MP	WF	MP	AF	MP	EF	MP	TF
10	C1	0.127 ± 0.004	A	0.018 ± 0.001	C1	0.127 ± 0.004	C1	0.207 ± 0.004
	C2	1.901 ± 0.034	B	0.394 ± 0.004	C2	1.901 ± 0.034	C2	1.915 ± 0.023
	C3	1.736 ± 0.090			C3	1.736 ± 0.090	C3	2.275 ± 0.082
	r^2	0.993	r^2	0.997	r^2	0.993	r^2	0.997
	E_{RMS}	1.019	E_{RMS}	0.522	E_{RMS}	1.019	E_{RMS}	1.231
20	C1	0.108 ± 0.006	A	0.021 ± 0.001	C1	0.135 ± 0.003	C1	0.178 ± 0.003
	C2	1.120 ± 0.044	B	0.426 ± 0.006	C2	1.995 ± 0.024	C2	1.870 ± 0.014
	C3	0.685 ± 0.061			C3	2.069 ± 0.074	C3	1.950 ± 0.046
	r^2	0.993	r^2	0.995	r^2	0.997	r^2	0.999
	E_{RMS}	0.466	E_{RMS}	0.635	E_{RMS}	0.867	E_{RMS}	0.652
40	D	0.169 ± 0.001	C1	0.092 ± 0.002	C1	0.125 ± 0.002	C1	0.154 ± 0.008
	F	0.262 ± 0.004	C2	1.682 ± 0.021	C2	1.949 ± 0.017	C2	1.791 ± 0.041
			C3	1.483 ± 0.059	C3	1.670 ± 0.045	C3	1.417 ± 0.102
	r^2	0.997	r^2	0.996	r^2	0.998	r^2	0.993
	E_{RMS}	0.306	E_{RMS}	0.491	E_{RMS}	0.540	E_{RMS}	1.256

MP mathematical models parameters

the AF case and shorter for EF, presenting in turn AF a high dough stability (≅ 50 min) while a low value around 15 min for EF was observed. In the case of TF, a similar behavior to that obtained for WF was experienced and without evidence of changes with the level of replacement.

The differences found in the farinograms can be better described through their parameters shown in Table 3.

The absorption of water respect to WF was greater for AF and EF, in values around 16% and 7% respectively, and similar for TF, not being affected to a large extent with the increase in replacement, except for AF, where the contribution of fibre with respect to free sugar is significantly higher. The absorption of water is a parameter that is related to the type and content of fibre, therefore the increase in water absorption of AF and EF could be correlated with the increase in the fibre content. In other work, an increase in the absorption of water with the addition of dietary fibre has already been mentioned, which could be related to the large number of hydroxyl groups existing in the fibre that allow greater interaction with water through hydrogen bonds (Wang et al. 2002).

The development time was affected by the replacement level and type of vegetable used. In the case of 5% replacement, all vegetable flour presented a development time similar to WF, approximately 10 min. While for the 10% replacement the vegetable flour behaved differently than WF, AF and TF increased it by 2 and 1.5 times respectively, while EF decreased it by half. Salinas and Puppo (2013) observed an increase in the development time with the addition of inulin, to which they related that it affects the formation of the gluten network, needing more time to form an elastic dough, perhaps due to its interaction with water through the high number of hydroxyl groups, thus competing with the other components (proteins) and starch for water.

The stability of the dough with vegetable replacements decreased with respect to WF. A direct effect of the increase of the replacement on the stability of the dough was observed, for AF, this increase in stability with the increase in replacement, is about 8 times more, being the most pronounced and even exceeding the value obtained with WF, while the increase for EF was 1.5 times more, and for TF no significant differences in stability were observed with the increase in replacement.

The stability of the dough is an indicator of the strength of the matrix, so the effect of the incorporation of vegetable flours could be related to the contribution of fibres and its effect of dilution of gluten, according to the physicochemical properties of its constituents that they would be affecting in a different proportion the strengthening of the gluten network (Knorr and Betschart 1978). In the case of TF, this effect of dilution of gluten would be mild due to its low fibre content and high soluble sugar that do not influence the dough. In the case of EF and AF, both generate a dilution of the gluten and have a greater fibre contribution, being the effect observed dependent on the type of fibre, in the case of AF inulin can gel (Chiavaro et al. 2007) stabilizing the gluten network and taking into account the fact that their carbohydrates are represented only by fibre, their contribution is high, while in EF, where 13% of their carbohydrates are soluble sugar, the fibre present would not favor the formation of the gluten network.

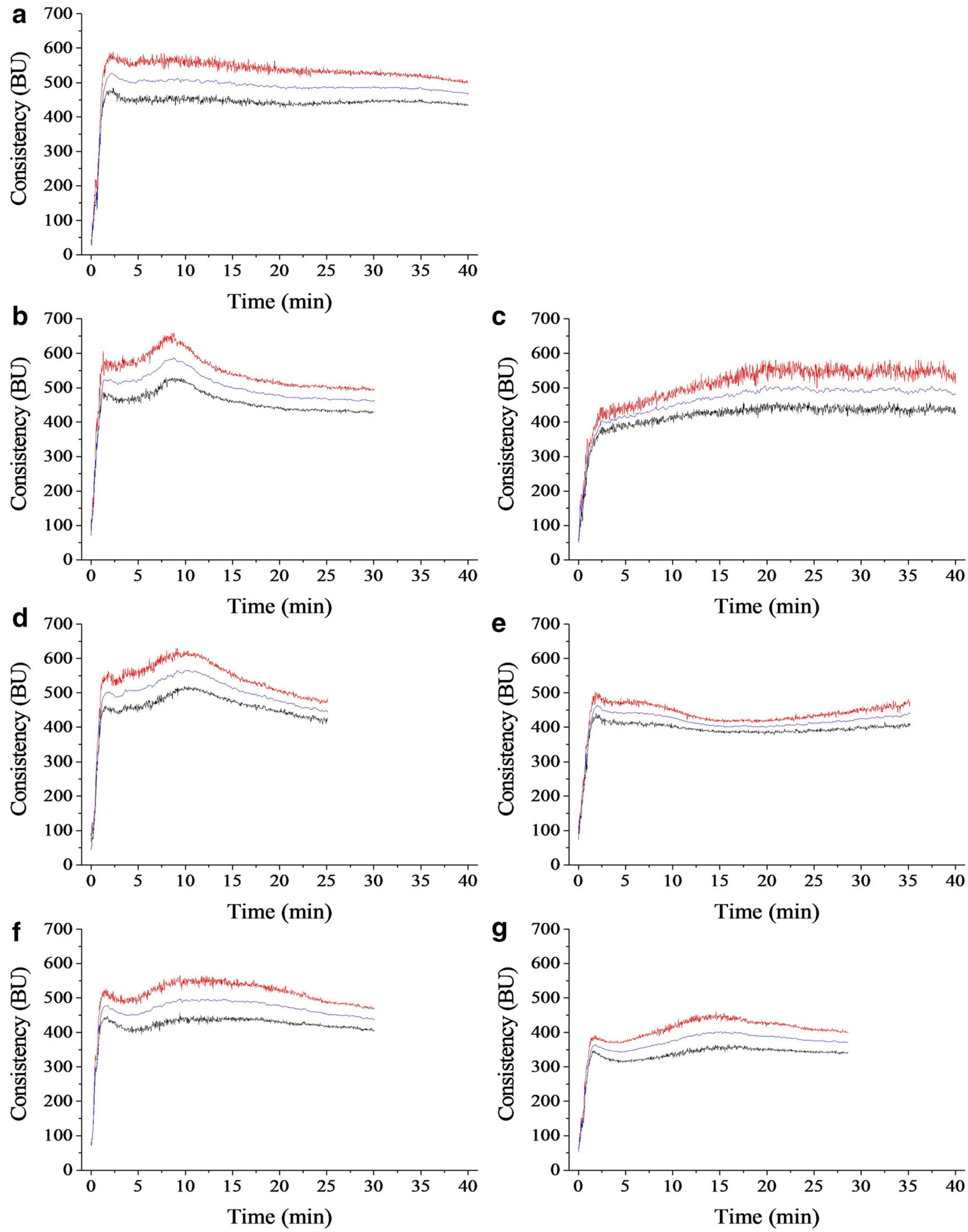

Fig. 2 Farinograms of flour blends. Wheat flour (**a**), 5% artichoke (**b**), 10% artichoke (**c**), 5% eggplant (**d**), 10% eggplant (**e**), 5% tomato (**f**), 10% tomato (**g**)

Finally respect to the farinographic assay an increase in the stability of the dough was accompanied by a decrease in the degree of softening thereof. This behaviour was evidenced in all dough for all the replacements.

Solvent retention capacity

The retention capacity of different solvents is shown in Table 4, in general the vegetable flours had a greater capacity of solvent retention with respect to WF, for the four solvents

Table 3 Farinographic parameters of wheat (WF), artichoke (AF), eggplant (EF) and tomato (TM) flours

Sample	Water absorption (%)	Development time (min)	Stability (min)	Degree of softening (BU)
WF	57.00 ± 0.28^{e}	9.00 ± 0.00^{de}	36.30 ± 0.71^{b}	18.50 ± 6.36^{c}
AF 5%	64.20 ± 0.00^{b}	8.80 ± 0.14^{e}	5.97 ± 0.30^{f}	114.00 ± 1.41^{a}
AF 10%	67.15 ± 0.07^{a}	20.90 ± 1.56^{a}	46.95 ± 0.78^{a}	16.50 ± 10.61^{c}
EF 5%	61.00 ± 0.00^{d}	10.35 ± 0.21^{cd}	8.80 ± 0.28^{e}	105.00 ± 0.00^{a}
EF 10%	61.70 ± 0.14^{c}	5.50 ± 0.00^{f}	13.50 ± 2.12^{d}	47.00 ± 8.49^{b}
TF 5%	56.90 ± 0.14^{e}	10.50 ± 0.00^{c}	19.32 ± 1.33^{c}	29.00 ± 7.07^{c}
TF 10%	55.65 ± 0.07^{f}	15.05 ± 0.49^{b}	20.40 ± 0.28^{c}	28.50 ± 0.71^{c}

Mean value ± SD, different letters in the same column indicate significant differences at ($p < 0.05$)

Table 4 Solvent retention capacity (SRC) of wheat (WF), artichoke (AF), eggplant (EF) and tomato (TM) flours

Sample	Sucrose SRC (%)	Lactic acid SRC (%)	Carbonate SRC (%)	Water SRC (%)
WF	83.00 ± 1.58^{f}	73.67 ± 1.67^{e}	84.93 ± 1.18^{g}	59.94 ± 1.12^{g}
AF 5%	132.14 ± 0.85^{c}	103.13 ± 2.02^{c}	113.20 ± 2.25^{d}	93.42 ± 2.20^{d}
AF 10%	155.00 ± 4.75^{b}	126.62 ± 4.26^{a}	147.41 ± 1.48^{b}	116.29 ± 1.65^{b}
EF 5%	120.20 ± 0.34^{c}	107.21 ± 2.34^{b}	134.84 ± 0.80^{c}	103.67 ± 3.40^{c}
EF 10%	167.84 ± 5.66^{a}	125.26 ± 1.59^{a}	170.70 ± 0.84^{a}	122.22 ± 0.34^{a}
TF 5%	94.47 ± 2.85^{e}	76.55 ± 0.72^{de}	92.25 ± 1.55^{f}	70.41 ± 2.65^{f}
TF 10%	103.08 ± 2.45^{d}	79.21 ± 1.18^{d}	96.14 ± 1.46^{e}	76.26 ± 0.27^{e}

Mean value ± SD, different letters in the same column indicate significant differences at ($p < 0.05$)

analysed, increasing with the increase in the percentage of replacement studied. AF and EF had the highest capacity of retention of sucrose with respect to WF, being the value double for the replacements of 10%, while in the case of TF the increase was much lower. In general, the retention capacity of lactic acid is associated with the formation of the glutenin network (AACC 2000) and the strength of gluten of flour. The stabilization of this protein network is mediated by the presence of soluble polymeric carbohydrates such as pentosans, favoring the formation of gluten macropeptides. That is why both AF and EF showed a considerable increase of the lactic SRC with 5% and even more with 10% of flour replacement, while in the case of TF no variation was observed at any level, because these polymers are absent in the tomato flour, being this flour mainly formed by soluble sugar of low molecular mass (Coyago-Cruz et al. 2019).

On the other hand, the retention capacity of sodium carbonate is usually related to the content of damaged starch (AACC 2000). In spite of the damage starch content did not change, an increase for AF and EF was observed while for TF this parameter practically was not modified. These results suggest that vegetable flours affect in certain manner the interaction of the sodium carbonate with flour components.

An increase in the water retention capacity was observed for the blends with vegetable flour with respect to WF, being up to 100% for the EF case, followed by around 60% for AF and 20% for TF (Table 4). The water retention capacity is related to the quality of all the constituents of the flour (AACC 2000), so the combined effect of the contribution of TDF and soluble sugar of the vegetable flour with respect to WF could be used to explain this behavior. As previously mentioned, AF provides a higher content of TDF comparing to EF, and both higher than TF. In turn, regarding the content of soluble sugar, they predominate in EF and TF, with glucose and fructose being the main ones, while in AF their content is practically negligible (Table 1). On the contrary, in WF both the content of FDT and soluble sugar is low, and in turn this flour contains sucrose as the main sugar, being this sugar less hygroscopic than glucose and fructose.

The values of water retention capacity were higher and were more dependent on the percentage of replacement studied than water absorption; this is due to the difference in the kind of technique. The water retention capacity test can be related to the aptitude of the hydrophilic groups of the different components of the flour to absorb water spontaneously, while the farinographic test, in which it is applied a mechanical work due to kneading, implies the development of the gluten network, so in both techniques the competition between the components of the samples for the available water would be different (Linlaud et al. 2009).

Conclusion

Vegetable flour used as source of fibre presented different composition depending on the nature of the horticultural product. The major differences were observed in the amount of soluble sugar and total and insoluble dietary fibre. These components directly influence water adsorption behaviour: artichoke flour (low sugars, high insoluble fibre) presented at 20 and 40 °C an equilibrium sorption behaviour similar to that of wheat flour, with curves that were below of those of eggplant and tomato flour. In addition, the solvent retention capacity of wheat–vegetable flour blends was increased, mainly with higher contents of this flour (10%); the artichoke and eggplant flour presented the highest values of retention for all solvents. Nevertheless, a different form of absorbing water during dough formation was observed with the replacement level. Artichoke flour at 10% stabilized dough considerably, while eggplant flour contributed to form dough with a high degree of softening. Results of this work contribute to the knowledge of the better conditions for making dough for breadmaking of high-fibre functional bread.

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