Acta Alimentaria 52 (2023) 4, 570–578
DOI: 10.1556/066.2023.00130

AKADÉMIAI KIADÓ

Rheological properties and characterisation of some bioactive components in flours made of different coloured sweet potato (*Ipomoea batatas* L.) genotypes

B. Mihály-Langó[1*], K. Ács[1], A. Berényi[1], K. Maróti Tóth[2], Zs. Táborosi Ábrahám[2], T. Gáll[3] and E. Ács[1]

[1] Cereal Research Non-profit Ltd., Alsó Kikötő sor 9., H-6726 Szeged, Hungary

[2] Hungarian University of Agriculture and Life Sciences, Vegetable Cultivation Research Centre, Szeged Research Station, Külterület 7., H-6728 Szeged, Hungary

[3] Hungarian University of Agriculture and Life Sciences, Vegetable Cultivation Research Centre, Kalocsa Research Station, Obermayer tér 9., H-6300 Kalocsa, Hungary

ORIGINAL RESEARCH PAPER

Received: May 30, 2023 • Accepted: August 21, 2023
Published online: October 2, 2023

ABSTRACT

The popularity of sweet potatoes in Central Europe has been increasing recently, mainly the high-quality, perfect, fresh tubers are in demand. However, out of class grade tubers could be marketed in dried, grounded form as sweet potato flour.

The aim of this study was to characterise some important nutritional properties of flours of three sweet potato genotypes with different tuber colours (white, purple, and orange) and to investigate how this raw material affects the rheological properties of sweet potato-wheat flour blends.

Dietary fibres are present in sweet potatoes in a significant proportion, orange coloured flour showed the highest values. The main free sugars were sucrose, glucose, and fructose, but sucrose was the dominant one. Antioxidant capacity and total phenolic content also varied considerably, the purple flour had the highest values. Mineral composition showed significant variability, the purple flour contained the highest level of minerals. It was confirmed that adding sweet potato flour to wheat flour affected its rheological

* Corresponding author. Tel.: +3662435235. E-mail: bernadett.lango@gabonakutato.hu

properties, however in a varied manner. For the orange flour these properties have lightly decreased, though it had no significant effect on dough quality, while the white and purple flours with a dosage of 5, 10 and 15% could improve the dough behaviour. Thus, sweet potato in this form is a valuable raw material.

KEYWORDS

sweet potato, fibres, sugars, fructan, antioxidant capacity, rheological characteristics

1. INTRODUCTION

Sweet potato (*Ipomoea batatas*), along with corn, wheat, rice and potatoes, is one of the world's most important food crop. About 110 million tons are grown annually, primarily in Asia (75.1%) and Africa (20.8%). Sweet potato is a typical tropical plant, which does not tolerate frost. Nevertheless, its cultivation is also present in Europe, and 0.1% of the world's total crop is produced here (FAOSTAT, 2019). Recently, its popularity in Central Europe has been increasing, we can see a rapid spread of its cultivation and use for human purposes, as it has favourable sensory characteristics and, based on its taste, it can be well integrated into the European food culture.

Although sweet potato can be considered a good source of carbohydrates based on its 20–24% (on fresh basis) carbohydrate content, several studies have been published on its applicability in diabetic diets (Mohanraj and Sivasankar, 2014), which can be related to its slower absorption due to its higher amylose/amylopectin ratio compared to potatoes (*Solanum tuberosum*). Raw sweet potato is characterised with lower glycaemic index (GI: 32–41), which can be strongly influenced by the variety and the growing conditions. The glycaemic index of ready-to-eat sweet potato can increase as a result of the heat transfer methods used during its preparation (GI: 63–66). The amount of dietary fibre that determines carbohydrate absorption ranges within wider limits from 9 to 15 dw% (Mullin et al., 1994). Those free sugars - glucose, fructose, sucrose, and maltose -, responsible for its sweet taste, are present in relatively large amounts (4.5–8.41%) (Lai et al., 2013). Fructan is typically not or barely detectable, which suggests the applicability of this crop in the FODMAP diet (Muir et al., 2007). Based on its bioactive components (phenolic components, anthocyanins) and mineral composition (K, Mg, Ca, P, Fe, and Zn), sweet potato can be considered a valuable protective food material (Dako et al., 2016).

Mainly the high-quality, perfect tubers can be sold, also leaves can be used (Sun et al., 2014). However, during cultivation due to environmental reasons, a significant number of tubers with unfavourable size or shape are also produced, and these are difficult to sell fresh. It can contribute to its economical cultivation if out of class grade rubbers are marketed as sweet potato flour. Other economic benefit of selling sweet potato flour is that it can be stored for a longer period of time and can be further used for baking and confectionery purposes.

In the literature, significant nutritional variability is described among sweet potato varieties as a result of genotype, cultivation, and year effects. The primary goal of our present investigation is to learn and characterise some important nutritional properties in flours of three sweet potato genotypes with different tuber colours from cultivation in Hungary - taking into account the crop year effect. Another goal is to investigate how this valuable raw material affects the rheological properties of sweet potato-wheat flour blends.

2. MATERIALS AND METHODS

2.1. Plant materials and experimental design

Three sweet potato genotypes with different flesh colours (white, purple, and orange) were selected and investigated from the gene collection gathered during sweet potato-related research. All three genotypes were added to the collection from Bivalyos Tanya Ltd. for cultivation technology experiments in 2015. The genotypes were grown in the site of the Hungarian University of Agriculture and Life Sciences, Institute of Horticulture Vegetable Research Centre, Szeged Research Station (Latitude N 46.291685, Longitude E 20.088217). Plants were produced in chernozem soil, open field, using semi-intensive agriculture in two consecutive years: 2017 and 2018. Water and nutrient supply were ensured constantly by strip irrigation system.

White sweet potato genotype (WSP), Emmur has white flesh and light rose skin. The flesh has soft tissue, high water content, and it is slightly fibrous. The tuberous roots can have diverse shapes and sizes, but it tends to grow large roots. In case of irregular water supply, the roots can split. It is moderately resistant to soil pests.

Purple sweet potato genotype (PSP), Purple has dark purple flesh and skin. The flesh has hard tissue, its juice can be used as dye similarly to beetroot and has a perfume-like odour. In case of loose soil, PSP can have elongated, cylindrical shape. It has low tendency to split, and is resistant to soil pests. The root yield can vary, in certain years it grows very long, pencil thick roots.

Orange genotype (OSP), Ássothalmi-12 is rich in beta-carotene and has a taste similar to carrot or pumpkin. The roots have cylindrical shape. It is susceptible to soil insects, so higher ratio of poor graded roots can be expected.

2.2. Sample preparation

The dried samples were prepared from the fresh sweet potatoes by washing, peeling, cutting into cubes, and airdrying on trays at room temperature until no weight loss were measured. Then the dried samples were milled by hammer mill (Perten LM 3100, Perkin Elmer Inc., USA) to produce sweet potato flours (WSPF-white, PSPF-purple, OSPF-orange) to pass through a 200 μm sieve. Flour blends were made containing 5, 10, 15, 20, and 30% of sweet potato flours from all 3 genotypes, using all-purpose wheat flour with average quality from the local supermarket. Each blend was homogenised by kitchen blender for 5 min. The samples of wheat-sweet potato flour blends were stored in plastic bags at 4 ± 2 °C until analysis.

2.3. Methods

2.3.1. Determination of carbohydrates. Dietary fibre was measured using Megazyme Total Dietary Fibre kit (Megazyme, Ireland) according to AACC 32-05.01. Fructose, glucose, and sucrose contents were measured by Agilent 1200 HPLC system (Agilent Technologies, USA) equipped with refractive index detector (Tihomirova et al., 2016). Total fructan content was determined with the enzymatic/spectrophotometric AOAC 999.03 method using commercially available enzymatic kits (Fructan HK Assay kit, Megazyme, Ireland).

2.3.2. Determination of antioxidant capacity and total phenol content. For analysis of antioxidant capacity, the method according to Benzie and Strain (1996) was used with some modifications: 0.02 g flour sample was extracted with 5 mL of methanol for 1 h on a vertical shaker. The extracts were centrifuged at 8,700 r.p.m. for 10 min. 100 μL of the supernatant was removed, 900 μL of distilled water and 2 mL of FRAP reagent were added. The samples were kept in the dark at 37 °C for 30 min. The absorbance values were measured at 593 nm. Total phenol content was determined by the method of Singleton et al. (1999) with the following modifications: a 200 μL sample was taken from the supernatant from previous sample preparation and treated with 1.5 mL of ten times diluted Folin–Ciocalteu reagent. After waiting five min, 1.5 mL of 60 g L^{-1} sodium carbonate solution was added to the mixture. The mixture was homogenised and kept in the dark for 1 h. The absorbance values of the samples were measured at 735 nm. The result is given as gallic acid equivalent (GAE).

2.3.3. Determination of mineral components. The mineral content of the flour samples were determined by iCAP 7200 (Thermo Fisher Scientific, USA) inductively coupled plasma optical emission spectrometer (ICP-OES). Nitric acid digestion in a Mars 6 (CEM Corporation, USA) enclosed microwave digester was used to prepare the samples.

2.3.4. Determination of farinographic properties. Farinographic examination was carried out according to standard ISO 5530-1:2013 with Brabender farinograph (Brabender GmbH & Co., Germany).

2.4. Statistical analysis

The results were analysed for genotype and crop year effect with factorial analysis of variance (ANOVA) using a general linear model (GLM) by StatSoft STATISTICA 12 program (StatSoft Inc., USA). Significance level was set to $P < 0.05$ and 0.01. Normality of distributions and homogeneity of variances were determined, the results met the criteria of ANOVA. Post-hoc Tukey's HSD test was used to determine differences between means.

3. RESULTS AND DISCUSSION

Dietary fibre and sugar values of three sweet potato genotypes from two different crop year are presented in Table 1. Following starch, dietary fibres are present in the largest proportion among carbohydrates with values ranging from 10.30 to 13.65 dw%. Slightly significant difference could be detected between genotypes, where OSPF showed the highest total dietary fibre (TDF) values in both years. Significant crop year effect was also found, the difference was more than 10% between the two years' averages. These results correspond to earlier studies (Mullin et al., 1994; Sun et al., 2014). Also, the highest fibre levels were found in the orange genotype as it was published by Dako and co-workers (2016) as well. Furthermore, soluble dietary fibre (SDF) content had little variability, while nonsoluble dietary fibre (NSDF) had high variability along with significantly higher content compared to SDF, as 86–88% of the TDF is made up of NSDF. The same tendency was also reported by Huang et al. (1999). Due to the high NSDF ratio, sweet potato can be beneficially used in weight loss diet or in case of type II diabetes (Ötles and Ozgos, 2014). In accordance with Dincer and co-workers (2011), main free sugars in sweet potato were sucrose, glucose and fructose, but sucrose was the dominant one. Free sugars in sweet potato flour are in higher amounts compared to fresh sweet potato due to the lower moisture content.

Table 1. Total (TDF), soluble (SDF) and nonsoluble (NSDF) dietary fibres, fructose, sucrose, glucose, and fructan contents of sweet potato flours (WSPF – white, PSPF – purple, OSPF – orange) in two crop years (2017; 2018)

	2017				2018				
	WSPF	PSPF	OSPF	Average	WSPF	PSPF	OSPF	Average	SD
TDF (dw%)	10.30[a]	10.57[a]	11.72[b]	10.86[A]	11.19[a]	11.65[b]	13.65[c]	12.16[B]	0.54
SDF (dw%)	1.45[a]	1.45[a]	1.36[a]	1.42[A]	1.34[a]	1.42[a]	1.40[a]	1.45[A]	0.03
NSDF (dw%)	8.85[a]	9.10[a]	10.36[b]	9.44[A]	9.85[a]	10.23[a]	12.25[b]	10.71[B]	0.41
Fructose (mg g^{-1})	17.9[b]	9.6[a]	26.9[c]	18.1[A]	13.5[a]	19.3[b]	46.0[c]	22.9[B]	0.63
Glucose (mg g^{-1})	20.9[b]	14.5[a]	38.4[c]	24.6[A]	15.1[a]	20.6[b]	51.7[c]	29.1[B]	0.71
Sucrose (mg g^{-1})	96.3[a]	173.9[b]	92.9[a]	121.0[B]	69.8[a]	133.2[b]	72.2[a]	91.7[A]	1.38
Fructan (dw%)	ND	ND	ND	–	ND	ND	ND	–	–

ND: not detected via fructan Megazyme assay if fructan values were in the range of 0–0.4 g/100 g dw
Means with unequal letters significantly differ at $P < 0.05$ (lowercase (a–c) for genotype and uppercase (A-B) for crop year).

Sucrose content in PSPF showed significantly higher levels than in WSPF and OSPF, while fructose and glucose had higher values in OSPF. When total sugar content is calculated from glucose, fructose, and sucrose, significant differences can be observed between samples. Sample WSPF in 2018 had the lowest (98.4 mg g^{-1}) and sample PSPF in 2017 had the highest (198 mg g^{-1}) total sugar contents. For this reason, it can be assumed that there can be differences in the sweetness of the flour and in its glycaemic index, too. Also, when sweet potato flour is used for baking or cooking, it undergoes heat treatment, which alters further the sugar content (Chan et al., 2014). Therefore, sugar analysis of end-products should consider if it is a determinant factor in diet. As it was expected, fructan were not detectable in any genotypes, thus sweet potato in dried form can be used in low FODMAP diet as well.

Antioxidant capacity (AC) ranged from 13.75 to 47.55 mg Fe^{2+}/100 g, total phenolic content (TPC) also varied considerably, between 9.42 and 41.27 mg GAE/100 g. Figure 1 illustrates that PSPF showed significantly higher AC and TPC values compared to both WSPF and OSPF, which are related to the anthocyanin content responsible for the purple colour. Also, OSPF presented slightly higher levels in AC and TPC than in WSPF. These results are consistent with previous studies where purple varieties were described as the ones with the highest AC or TPC values, followed by the orange and white varieties (Rumbaoa et al., 2009; Ji et al., 2015). Beside genotype, the year effect can also be significant on AC and TPC levels. The difference between the two years is as follows: antioxidant capacity only showed significant difference in case of OSPF, in 2018 it was significantly higher (by 25%), on the other hand, total phenolic content had higher values (by 15–31%) in 2017 among all analysed genotypes. Therefore, it can be stated that crop year has an effect on these parameters as well. Compared to fresh, baked, and cooked sweet potato, the flour contains a higher amount of antioxidants, because these materials are decomposable when exposed to heat (Dincer et al., 2011).

In case of mineral content, there were also significant differences between the sweet potato flours. As it is presented in Table 2, the PSPF contained the highest level of minerals in general. The difference between the varieties was particularly significant in 2017, in 2018 significantly lower and more equal values were measured. In case of Mg, K, Na, Se, Mn, and Cu, the purple

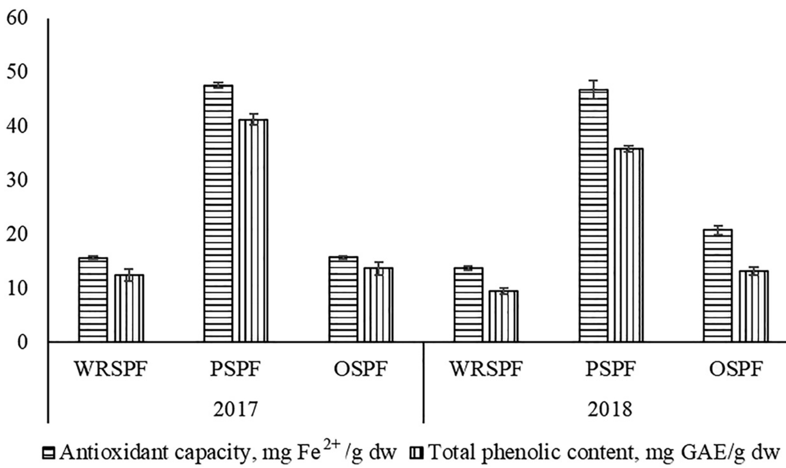

Fig. 1. Antioxidant capacity and total phenolic contents of sweet potato flours (WSPF – white, PSPF – purple, OSPF – orange) in two crop years (2017; 2018)

Table 2. Mineral composition of sweet potato flours (WSPF – white, PSPF – purple, OSPF – orange) in two crop years (2017; 2018)

Mineral	2017				2018				
(mg kg^{-1})	WSPF	PSPF	OSPF	Average	WSPF	PSPF	OSPF	Average	SD
Mg	1129^a	3235^c	3000^b	2455^B	921^a	1564^c	1123^b	1203^A	15
K	1599^a	7000^c	5000^b	4533^B	1235^a	2548^b	2564^b	2116^A	22
Na	14.85^b	25.01^c	10.02^a	16.63^A	13.38^a	21.24^b	19.76^b	18.13^A	0.84
Fe	46.09^a	48.71^a	44.02^a	46.27^B	38.95^a	41.64^a	40.35^a	40.31^A	1.12
Zn	120.03^c	98.38^b	81.47^a	99.96^B	94.57^c	32.15^a	63.74^b	63.49^A	0.82
Se	0.43^a	1.15^c	0.87^b	0.82^A	0.57^a	0.92^b	0.82^b	0.77^A	0.05
Cr	32.96^b	30.34^a	30.00^a	31.10^B	28.95^a	28.68^a	29.21^a	28.95^A	0.72
Mn	97.42^b	106.25^c	52.01^a	85.23^B	12.52^a	97.56^c	71.22^b	60.43^A	2.31
Cu	6.40^a	11.47^b	7.11^a	8.33^A	6.21^a	6.45^a	8.42^b	7.03^A	0.38

Means with unequal letters significantly differ at $P < 0.05$ (lowercase (a–c) for genotype and uppercase (A-B) for crop year).

genotype had outstanding results, while the white genotype contained the highest Zn content. Fe and Cr had the same levels in all three genotypes. The year effect was highly significant in case of Mg, K, Zn, and Mn, where the average differences were between 30 and 50%. However, sweet potatoes, though containing lots of minerals, are not suitable for covering the RDA of minerals, but can be a good source for contribution (Neela and Fanta, 2019).

Adding sweet potato flour to wheat flour affects its rheological properties, however, it depends highly on the used variety. WSPF and PSPF can be characterised similarly, but OSPF acted differently. In general, it can be said that with addition of sweet potato flour, water absorption did not change significantly, ranging between 49.7 and 51.2%. Dough development time decreased in blends of 5, 10, and 15%, but increased with higher dosage of sweet potato

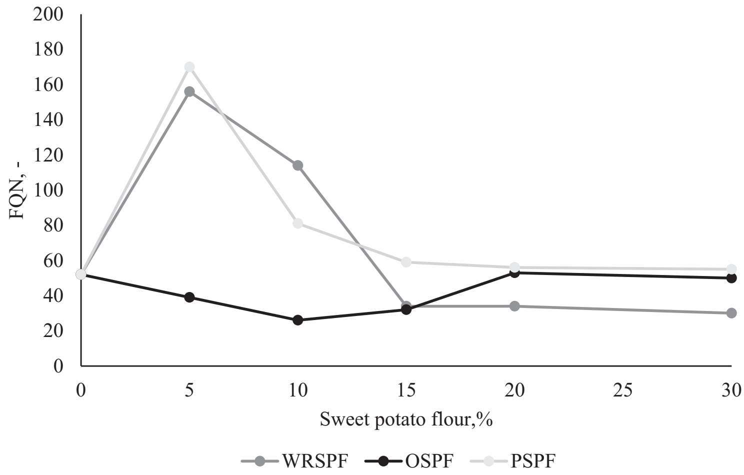

Fig. 2. Farinograph Quality Number (FQN) of wheat and sweet potato flour blends (WSPF – white, PSPF – purple, OS – orange) as average of two crop years (2017; 2018)

flour. Also, increasing dosage of sweet potato flour decreased dough stability. As it is shown in Fig. 2, FQN increased with dosages of 5, 10, and 15% in case of WSPF and PSPF, whilst OSPF slightly decreased but had no significant effect on FQN. A few studies investigated earlier the rheological behaviour of wheat and sweet potato flour mixture and similar results were reported: increased water absorption, decreased dough development time, and decreased stability at increasing sweet potato content (Trejo-González et al., 2014). However, in the present study, we also experienced dough quality improvement when 5–10% sweet potato flour was used in the blends. This rheological phenomenon probably shows that a certain amount of fibre component can contribute to gluten formation and thus improve the dough if the wheat flour is of poor quality, but further investigation is necessary to prove this hypothesis. According to our results, no significant crop year effect could be detected in case of rheological properties.

4. CONCLUSIONS

According to the results, sweet potato in flour form is a valuable and advantageous raw material. By selling it in a dried, ground form as flour, we can contribute to the economic cultivation of sweet potatoes as flour can be stored for a longer period of time and can be further used for baking and confectionery purposes.

ACKNOWLEDGEMENT

This research was supported by the Hungarian Ministry of Agriculture (Project number: 17K020010. Title: *Developing the cultivation technology of profitable vegetable species in the Southern Great Plain region under adverse effects of climate change.*).

REFERENCES

AACC, (1999). *Soluble, insoluble, and total dietary fiber in foods and food products.* AACC International. Approved Methods of Analysis. AACC 32-05.01.

AOAC, (1999). *AOAC official methods*. Measurement of fructan in foods. Enzymatic/spectrophotometric method. AOAC 999.03.

Benzie, I.F.F. and Strain, J.J. (1996). The reducing ability of plasma as a measure of 'antioxidant power'- the FRAP assay. *Analytical Biochemistry*, 239(1): 70–76.

Chan, C.F., Chiang, C.M., Lai, Y.C., Huang, C.L., Kao, S.C., and Liao, W.C. (2014). Changes in sugar composition during baking and their effects on sensory attributes of baked sweet potatoes. *Journal of Food Science and Technology*, 51(12): 4072–4077.

Dako, E., Retta, N., and Desse, G. (2016). Comparison of three sweet potato (*Ipomoea Batatas* (L.) Lam) varieties on nutritional and anti-nutritional factors. *Global Journal of Science Frontier Research: Agriculture and Veterinary*, 16(4): 63–72.

Dincer, C., Karaoglan, M., Erden, F., Tetik, N., Topuz, A., and Ozdemir, F. (2011). Effects of baking and boiling on the nutritional and antioxidant properties of sweet potato [*Ipomoea batatas* (L.) Lam] cultivars. *Plant Foods for Human Nutrition*, 66: 341–347.

FAOSTAT, (2019). The food and agriculture organization corporate statistical database, Available at http://www.fao.org/faostat/en/#data/QC (last accessed 05 January 2023).

Huang, A.S., Tanudjaja, L., and Lum, D. (1999). Content of alpha-, beta-carotene, and dietary fibre in 18 sweet potato varieties grown in Hawaii. *Journal of Food Composition and Analysis*, 12(2): 147–151.

ISO, (2013): *Wheat flour — physical characteristics of doughs — Part 1: determination of water absorption and rheological properties using a farinograph.* ISO Method No. 5530-1:2013.

Ji, H., Zhang, H., Li, H., and Li, Y. (2015). Analysis on the nutrition composition and antioxidant activity of different types of sweet potato cultivars. *Food and Nutrition Sciences*, 6(1): 161–167.

Lai, Y., Huang, C., Chan, C., and Liao, W.C. (2013). Studies of sugar composition and starch morphology of baked sweet potatoes (*Ipomoea batatas* (L.) Lam). *Journal of Food Science and Technology*, 50(6): 1193–1199.

Mohanraj, R. and Sivasankar, S. (2014). Sweet potato (*Ipomoea batatas* (L.)) – a valuable medicinal food: a review. *Journal of Medicinal Food*, 17(7): 733–741.

Muir, J.G., Shepherd, S.J., Rosella, O., Rose, R., Barrett, J.S., and Gibson, P.R. (2007). Fructan and free fructose content of common Australian vegetables and fruit. *Journal of Agricultural and Food Chemistry*, 55(16): 6619–6627.

Mullin, W.J., Rosa, N., and Reynolds, B.L. (1994). Dietary fibre in sweet potatoes. *Food Research International*, 27(6): 563–565.

Neela, S. and Fanta, S.W. (2019). Review on nutritional composition of orange-fleshed sweet potato and its role in management of vitamin A deficiency. *Food Science & Nutrition*, 7(6): 1920–1945.

Ötles, S. and Ozgoz, S. (2014). Health effects of dietary fiber. *Acta Scientiarum Polonorum, Technologia Alimentaria*, 13(2): 191–202.

Rumbaoa, R.G., Cornago, D.F., and Geronimo, I.M. (2009). Phenolic content and antioxidant capacity of Philippine sweet potato (*Ipomoea batatas*) varieties. *Food Chemistry*, 113(4): 1133–1138.

Singleton, V.L., Orthofer, R., and Lamuela-Raventos, R.M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Method Enzymology*, 299: 152–178.

Sun, H., Mu, T., Xi, L. Zhang, M., and Chen, J. (2014). Sweet potato (*Ipomoea batatas* L.) leaves as nutritional and functional foods. *Food Chemistry*, 156: 380–389.

Tihomirova, K., Dalecka, B., and Mezule, L. (2016). Application of conventional HPLC RI technique for sugar analysis in hydrolysed hay. *Agronomy Research*, 14(5): 1713–1719.

Trejo-Gonzáles, A.S., Loyo-González, A.G., and Munguia-Mazariegos, M.R. (2014). Evaluation of bread made from composite wheat-sweet potato flours. *International Food Research Journal*, 21(4): 1683–1688.