

# Effect of Different Solvents on the Extraction of Phytochemicals in Colored Potatoes

Jelisa Thomas<sup>1,2</sup>, Alexey Barley<sup>2\*</sup>, Shantrell Willis<sup>1</sup>, Jasmine Thomas<sup>1</sup>, Martha Verghese<sup>1</sup>, Judith Boateng<sup>1,2</sup>

<sup>1</sup>Food Safety and Toxicology Laboratory, Alabama Agricultural and Mechanical University, Department of Food and Animal Sciences, Normal, USA

<sup>2</sup>Nutrition Biochemistry Laboratory, Alabama Agricultural and Mechanical University, Department of Food and Animal Sciences, Normal, USA

Email: \*judith.boateng@aamu.edu

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## Abstract

Colored potatoes are an interesting alternative to the traditional, white-creamed potatoes, due to their high phytochemical content, which have been proved to have antioxidative properties. The extraction of polyphenols is highly dependent on using the appropriate solvent systems. Therefore, polyphenol extraction in colored potatoes [Vermillion Fingerling (VF); Jester Potato (JP); Magic Molly (MM); Blue Belle (BB); All Blue (AB)] using different solvents [Solvent A (24% water, 67% ethanol 9% acetic acid); Solvent B (5% acetic acid); and Solvent C (95% water, 5% acetic acid, 0.5 g sodium bisulfate)] may have significant effects on extraction efficiency and phytochemical content. Total phenolic content (TPC), Total flavonoid content (TFC), Total anthocyanin content (TAC) and antioxidant activities [Trolox Equivalent Antioxidant Capacity (TEAC) and Ferric reducing-antioxidant power (FRAP)] were determined. Solvent A extracted significantly ( $p < 0.05$ ) higher TPC from BB (13.93 mg GAE/100g) compared to the other solvents. VF and JP displayed higher TFC (14.53 and 19.46 mg CE/100g, respectively) when Solvent C was utilized. VF and JP extracts with Solvent C displayed the highest FRAP value compared to Solvent B. MM displayed the highest TAC using Solvent A and C. Potato variety resulted in high variability in polyphenols content and antioxidant activity. The utilization of colored potatoes or extracts in the food industry could provide innovative products and a functional alternative to the traditional.

## Keywords

Colored Potatoes, Polyphenols, Solvent Extraction, Antioxidative Activities, Anthocyanins

## 1. Introduction

*Solanum tuberosum*, potato, is categorized as a tuberous starchy vegetable from the nightshade, Solanaceae family [1]. Potato has become one of the predominant staple foods in the world [2]. Potatoes contain several polyphenols such as phenolics (chlorogenic acid derivatives), flavonoids, (anthocyanins) and carotenoids [3]. Cinnamic acid and its derivatives, more specifically chlorogenic acid, are the major phenolic acids found in potatoes [4]. Chlorogenic acid can range from 50% to 95% of the total phenolic acid content of potatoes [4]. Studies have shown that chlorogenic acid inhibits nitrosamine formation in A549 human lung cancer cells [5] [6].

Colored potatoes are now the rave among consumers. These potato varieties have gained notoriety because they are different, and an interesting choice compared to the traditional white-cream/fleshed potatoes. The unusual colors of these potatoes lend to their high polyphenol content. These vibrant (red, purple, and blue) colored potatoes are noted for their high anthocyanins contents [4]. Research has shown that anthocyanins can protect against free radicals, lower LDL cholesterol thus reducing the risks of heart disease. Anthocyanins also have anti-inflammation and cancer properties [7] [8] [9]. The colors of these potatoes are attributed to the acylated glucosides of pelargonidin, malvidin, petunidin, peonidin, and delphinidin [10]. Predominantly, red-fleshed potato contains high amounts of pelargonidin and those with blue and purple flesh contain acylated glucosides, petunidin and peonidin with small amounts of delphinidin and malvidin [11]. According to Lachman [7], petunidin has potent antioxidant potential due to the number of free hydroxyl groups when compared to pelargonidin, peonidin, or malvidin. Other types of flavonoids include catechin, epicatechin, erodictyol, kaempferol, quercetin, naringenin, and rutin [4]. According to Moser *et al.* [12], colored potatoes can provide up to 20 mg of phenolics per serving, thus making them one of the prominent sources of polyphenols in the diet.

Polyphenols from colored potatoes are of major interest due to their antioxidant properties and potential applications in food technology to enhance functionality [13], *i.e.*, for preventing oxidation in certain foods [14] [15]. A major step in retrieving these compounds is through extraction. Several solvents have been used to extract phytochemicals from plants including methanol, water, acetone, ethanol, hexane, and chloroform [16]. To ensure convenient separation of phytochemicals from food and plant matrices, the uses of single solvents (ethanol, methanol, acetone, diethyl ether, etc.) and binary systems or hydro-organic solvents (such as methanol: water or ethanol: water) are usually required [15] [17] [18]. Concerning their structure, it is widely indicated that phenolic compounds create polymerized derivatives of various dissolubility, hence impacting their solubility in solvents of different polarity [14] [15] [17] [18]. Thus, it is crucial to select the best solvent and extraction systems that allow optimum extraction or yield of antioxidant components and other poly-

phenols without modifying their varied chemical characteristics [14] [15] [18] [19].

This study investigated the effects of three solvent systems [Solvent A (24% water, 67% ethanol 9% acetic acid); Solvent B (5% acetic acid); and Solvent C (95% water, 5% acetic acid, 0.5 g sodium bisulfate)] on total phenolic content, total flavonoid content, total anthocyanin content, and antioxidant activities of extracts of five colored potatoes varieties. The five potato cultivars were Vermillion Fingerling (VF); Jester Potato (JP); Magic Molly (MM); Blue Belle (BB); All Blue (AB). The study will screen the optimum solvent system for extracting phytochemicals from the colored potato cultivars.

## 2. Materials and Methods

### 2.1. Sample Preparation

Five potato cultivars [Vermillion Fingerling (VF); Jester Potato (JP); Magic Molly (MM); Blue Belle (BB); All Blue (AB)] were purchased from Irish Eyes Garden Seeds (Ellensburg, WA) (**Figure 1**). Following the methods of [20], potatoes were cleaned, then cut in one-inch cubes. After slicing, 30 g of the sample was homogenized with 75 mL of extracting solvent in a domestic blender. Three extracting solvents was used: Solvent A (24% water, 67% ethanol 9% acetic acid); Solvent B (5% acetic acid); and Solvent C (95% water, 5% acetic acid, 0.5 g sodium bisulfate). This mixture was then placed in the dark for 30 min; afterwards, samples were stirred (medium speed) for an additional 30 min [20]. Following stirring, the resulting solution was sonicated for 20 min and centrifuged at 4696 g (2504 rpm) for 10 min. The supernatant was recovered and filtered. The organic solvent was evaporated (Buchi Rotavapor R-215, US) and the resulting extract regarded as solid liquid extraction (SLE) was resuspended in appropriate solvents and subjected to solid phase extraction (SPE).



**Figure 1.** Selected colored potatoes.

## 2.2. Preparation of Samples for SPE (Solid-Phase Extraction)

Sep Pak Vac 6cc C18 cartridge was conditioned with ethanol followed by water, both at pH 7 before phenolics acids fractionation. Following conditioning step, 2 mL of previously prepared SLE extracts were passed through the column and washed with 5 mL of water (pH 7). Afterwards, 20 mL 20% (v/v) ethanol/water was used to elute polyphenols. The extracts obtained was stored at  $-80^{\circ}\text{C}$  and later used for the analysis.

## 2.3. Determination of Polyphenols Content and Antioxidants

**Total Phenolics Content (TPC) of Colored Potatoes:** The TPC of potato extracts was determined by a modification of the Folin-Ciocalteu (FC) colorimetric method [21]. The sample was incubated for 90 min then absorbance was taken at 750 nm and compared to a gallic acid standard curve. The results were expressed as mean (mg gallic acid equivalents/100g potato).

**Total Flavonoids Content (TFC):** The TFC of colored potatoes were determined using a modified aluminum colorimetric method [21]. The sample was mixed with distilled water in a 96 well plate followed by 5% sodium nitrate solution. After 5-minute incubation, 10% aluminum chloride solution was added and incubated for another 5 minutes before 1 M NaOH was added. The mixture was adjusted with distilled water and the absorbance was measured at 510 nm. Results were expressed as mg CAE/ 100g of potato.

**Total Anthocyanins Contents (TAC):** The TAC was determined using a pH differential method [22]. Potassium chloride buffer (0.025 M, pH = 1.0) and sodium acetate buffer (0.04 M; pH 4.5) were the two buffer systems utilized. In a 96 well microplate, 10  $\mu\text{L}$  of the extract was added to 290  $\mu\text{L}$  each of buffer 1 (pH 1.0) and 2 (pH 4.5). The testing solution was equilibrated for 30 min. The absorbance was measured at 520 nm and 700 nm. Total anthocyanin content was calculated according to the following formula:

$$\text{Total Anthocyanin} \left( \text{mgC3G} = \frac{A * \text{MW} * \text{DF} * 1000}{\epsilon * 1} \right)$$

where: Absorbance (A) = [pH 1.0 ( $A_{520\text{nm}} - A_{700\text{nm}}$ ) - pH 4.5 ( $A_{520\text{nm}} - A_{700\text{nm}}$ )]; Molecular Weight (MW) = 449.2 g/mol cyanidin-3-glucoside; Dilution Factor (DF); molar extinction coefficient ( $\epsilon$ ) = 26,900  $\text{L} \cdot \text{mol}^{-1} \cdot \text{cm}^{-1}$ . Monomeric anthocyanin results are expressed as cyanidin-3-glucoside equivalents in mg/g.

**Ferric Reducing Antioxidant Power (FRAP):** The FRAP assay was determined following the modified methods by Gajula *et al.* [21]. Potato extracts were added to FRAP reagent (300 mM acetate buffer pH 3.6, 10 mM 2,4,6-tri(2-pyridyl)-s-triazine (TPTZ) in 40 mM HCL and 20 mM ferric chloride ( $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ ). Samples were incubated for 10 minutes under restricted light at  $37^{\circ}\text{C}$ , then absorbance was read at 590 nm. The absorbance was compared to ferrous sulfate standard (0.1 mM - 0 mM).

**Trolox Equivalent Antioxidant Capacity (TEAC):** The TEAC was determined according to the protocol by Rice-Evans, Miller (1994). The ABTS solution was

diluted with deionized water. Potato extracts were added to ABTS solution and the absorbance reading was carried out for 6 minutes at 1-minute intervals. Absorbance was read at 734 nm.

**Statistical Analysis:** Results from this study were expressed as means ( $\pm$ SEM) for three replications. Data was evaluated using the SAS statistical software and comparison was performed using a one-way analysis of variance (ANOVA) followed by Tukey's test. A p-value of  $\leq 0.05$  was considered statistically significant.

### 3. Results

#### 3.1. Effect of Solvent Systems on Polyphenolic Content of Color Potatoes

The total phenolics content (TPC) and total flavonoids content (TFC) of colored potatoes (VF, JP, MM, BB, and AB) are shown in **Table 1**. Results indicated significant  $p \leq 0.05$  variation in the TPC in relation to solvent system and potato variety. TPC determined by the different extracting solvents ranged from 13.93 to 47.86 mg GAE/100g for solvent A, 9.46 to 46.11 mg GAE/100g for solvent B and from 9.27 to 48.53 mg GAE/100g for solvent C, respectively. Data showed that all three solvents resulted in the highest  $p \leq 0.05$  TPC in MM [47.86 mg/100g (Solvent A); 46.11 mg/100g (Solvent B); 48.53 mg/100g (Solvent C)] compared to the other potato varieties. This was closely followed by AB with a range of 35.12 to 38.63 mg GAE/100g. On the other hand, all three solvents were found least effective extracting TPC from BB (9.27 to 13.93 mg/100g), though, Solvent A showed higher  $p \leq 0.05$  extraction capacity compared to the other solvents. The trend for TPC was as follows:  $BB < JP < VF < AB < MM$ . From the present data, Solvent C extracts exhibited the highest value of TPC, in BB, VF and JP, whereas Solvent A resulted in higher extraction capacity of TPC in BB and AB.

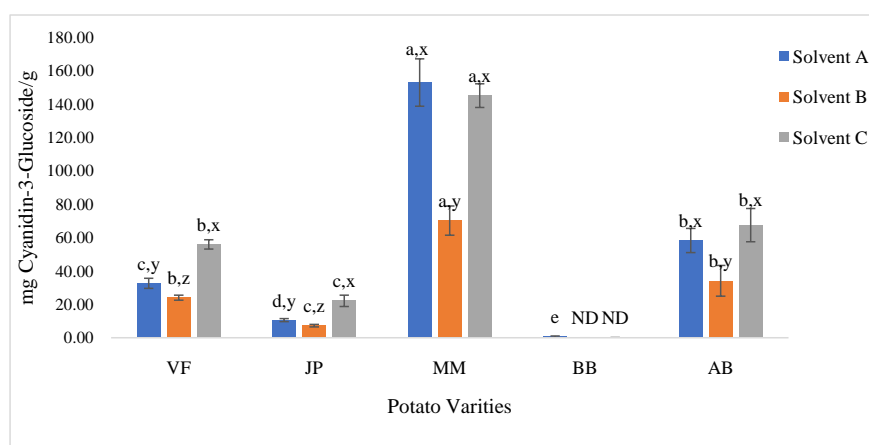
The results for TFC showed a similar trend as TPC whereas, MM exhibited the highest ( $p \leq 0.05$ ) TFC in all three solvents [36.86 mg/100g (Solvent A); 33.78 mg/100g (Solvent B); 38.73 mg/100g (Solvent C)] compared to other potato varieties. The trend for TFC was as follows  $BB < VF < JP < AB < MM$ . Solvent C extracts exhibited the highest TFC in VF, JP, and MM meanwhile, Solvent A resulted in higher TFC in BB and AB.

The results of TAC using the pH differential method are shown in **Figure 2**. MM displayed the highest ( $p < 0.05$ ) TAC (70.22 - 152.95 mg C3G/g) with all three solvents followed by  $AB > VF > JP > BB$ . Based on the results, the extraction efficiency of TAC was influenced by extraction solvent properties. The best solvent systems were found to be solvents A and C, while Solvent B had the lowest ( $p < 0.05$ ) extraction yield in MM (70.22 mg C3G/g), VF (24.08 mg C3G/g) and JP (7.26 mg C3G/g). There was no significant difference in the extraction efficiency between Solvent A and C (6.94 mg C3G/g) in AB and MM. Solvent C had the highest TAC in JP (22.20 mg C3G/g) and VF (55.96 mg C3G/g) compared to other solvents. TAC in MM was increased ( $p < 0.05$ ) when compared to VF, JP, and AB by 59% - 91%; 49% - 89% and 51% - 86% with solvents A, B and

**Table 1.** Total phenolic and flavonoid content of selected potato varieties.

Potato Varieties	TPC mg GAE/100g Potato (Fwb)			TFC mg CE/100g Potato (Fwb)		
	Solvent A	Solvent B	Solvent C	Solvent A	Solvent B	Solvent C
VF	30.65 ± 1.01 <sup>c,w</sup>	31.11 ± 0.66 <sup>c,w</sup>	32.81 ± 1.30 <sup>bc,w</sup>	9.52 ± 1.00 <sup>d,y</sup>	11.67 ± 1.36 <sup>c,xy</sup>	14.53 ± 1.22 <sup>c,x</sup>
JP	26.68 ± 0.78 <sup>c,wx</sup>	20.05 ± 0.34 <sup>d,x</sup>	28.37 ± 0.76 <sup>c,wx</sup>	15.63 ± 0.84 <sup>c,xy</sup>	11.91 ± 1.90 <sup>c,y</sup>	19.46 ± 2.71 <sup>bc,x</sup>
MM	47.86 ± 2.50 <sup>a,w</sup>	46.11 ± 1.31 <sup>a,w</sup>	48.53 ± 1.27 <sup>a,w</sup>	36.86 ± 3.81 <sup>a,x</sup>	33.78 ± 2.30 <sup>a,x</sup>	38.73 ± 4.13 <sup>a,x</sup>
BB	13.93 ± 1.40 <sup>d,wx</sup>	9.46 ± 0.23 <sup>c,wx</sup>	9.27 ± 0.61 <sup>d,wx</sup>	9.12 ± 2.78 <sup>d,x</sup>	2.89 ± 0.74 <sup>d,y</sup>	6.10 ± 0.60 <sup>d,xy</sup>
AB	38.63 ± 1.66 <sup>b,w</sup>	36.07 ± 1.61 <sup>b,w</sup>	35.12 ± 2.24 <sup>b,w</sup>	28.21 ± 2.41 <sup>b,x</sup>	22.73 ± 1.66 <sup>b,x</sup>	23.26 ± 2.22 <sup>b,x</sup>

**Abbreviations:** Vermillion Fingerling (VF), Jester Potato (JP), Magic Molly (MM), Blue Bell (BB), All Blue (AB), Gallic Acid Equivalent (GAE), Catechin Equivalent (CE) [Solvent A = water: ethanol: acetic acid (24:67:9); Solvent B = 5% acetic acid and Solvent C = water: acetic acid: sodium bisulphate (95:5:0.5)] Values (n = 3) are means ± SEM; Means in a column with common superscripts (<sup>abc</sup>) differ p ≤ 0.05. Means in a row with common superscripts (<sup>wxyz</sup>) differ p ≤ 0.05.



**Figure 2.** Total anthocyanin content of colored potatoes. **Abbreviations:** Vermillion Fingerling (VF), Jester Potato (JP), Magic Molly (MM), Blue Belle (BB), All Blue (AB), [Solvent A = water: ethanol: acetic acid (24:67:9); Solvent B = 5% acetic acid; and Solvent C = water: acetic acid: sodium bisulphate (95:5:0.5)] Values (n = 3) are means ± SEM; Means with common superscripts (<sup>abc</sup>) differ p ≤ 0.05 within the solvents. Means with common superscripts (<sup>xyz</sup>) differ p ≤ 0.05 within individual potato.

C, respectively. As expected, TAC was barely detected (Solvent A) or not detected (Solvents B and C) in BB due to the color of this variety.

### 3.2. Effect of Solvent Systems on Antioxidant Activity in Colored Potatoes

**Table 2** displays the antioxidative activity of colored potatoes using FRAP and TEAC assays. Reduction potential detected in colored potatoes were as follows MM > AB > VF > JP > BB. Overall, MM potatoes displayed the highest (p < 0.05) FRAP values with all solvents compared to the other varieties of potatoes, albeit AB using solvent A (533.10 μM Fe (II)/100g). Solvent C extracts presented a higher FRAP value [VF 300.54 and JP 298.99 mmol Fe (II)/100g respectively]

than those values from Solvent B extracts.

The ability of the potato samples to scavenge the stable radical cation ABTS<sup>+</sup> is displayed in (Table 2). Selected solvents demonstrated no differences ( $p \leq 0.05$ ) in the TEAC values of colored potatoes. However, variation was observed among varieties for example MM samples had the highest ABTS<sup>+</sup> scavenging ability using all three solvent [107.57 (Solvent A), 106.22 (Solvent B) and 108.57 (Solvent C) mg TE/100g]. TEAC values from different extracting solvents ranged from 42.75 to 107.57 mg TE/100g for Solvent A, 41.19 to 106.22 mg TE/100g for Solvent B, 47.74 to 108.57 mg TE/100g for Solvent C, respectively.

### 3.3. Correlation between Functional Components and Antioxidant Activity

A positive correlation ( $p \leq 0.05$ ) was noted between functional components and antioxidant activity of colored potatoes Table 3. TEAC results showed a positive correlation with TPC ( $r = 0.709$ ), TAC ( $r = 0.678$ ), and TFC ( $r = 0.456$ ). However, FRAP showed a higher correlation between the polyphenol content TPC ( $r = 0.838$ ), TFC ( $r = 0.796$ ) and TAC ( $r = 0.773$ ).

**Table 2.** Antioxidative potential of selected potato varieties.

Potato Varieties	FRAP (Mmol Fe (II)/100g Potato (Fwb))			TEAC (MM TE/100g Potato (Fwb))		
	Solvent A	Solvent B	Solvent C	Solvent A	Solvent B	Solvent C
VF	234.42 ± 16.57 <sup>b,xy</sup>	204.54 ± 12.96 <sup>c,y</sup>	300.54 ± 7.68 <sup>c,x</sup>	78.02 ± 3.70 <sup>bc,x</sup>	68.06 ± 2.06 <sup>bc,x</sup>	80.42 ± 3.58 <sup>ab,x</sup>
JP	273.23 ± 8.07 <sup>b,x</sup>	167.66 ± 21.93 <sup>c,y</sup>	298.99 ± 40.58 <sup>c,x</sup>	66.72 ± 4.88 <sup>c,x</sup>	58.79 ± 3.99 <sup>bc,x</sup>	68.88 ± 5.96 <sup>b,x</sup>
MM	594.16 ± 38.55 <sup>a,x</sup>	544.17 ± 27.50 <sup>ab,x</sup>	616.07 ± 26.41 <sup>a,x</sup>	107.57 ± 8.71 <sup>a,x</sup>	106.22 ± 10.36 <sup>a,x</sup>	108.57 ± 16.29 <sup>a,x</sup>
BB	188.41 ± 62.37 <sup>b,x</sup>	82.25 ± 28.14 <sup>d,x</sup>	80.84 ± 34.97 <sup>d,x</sup>	42.75 ± 2.68 <sup>d,x</sup>	41.19 ± 6.41 <sup>c,x</sup>	47.74 ± 7.77 <sup>b,x</sup>
AB	533.10 ± 35.69 <sup>a,x</sup>	443.15 ± 24.59 <sup>b,x</sup>	442.66 ± 37.57 <sup>b,x</sup>	86.46 ± 8.73 <sup>b,x</sup>	75.35 ± 9.70 <sup>b,x</sup>	65.49 ± 14.01 <sup>b,x</sup>

**Abbreviations:** Vermillion Fingerling (VF), Jester Potato (JP), Magic Molly (MM), Blue Belle (BB), All Blue (AB) [Solvent A = water: ethanol: acetic acid (24:67:9); Solvent B = 5% acetic acid, and Solvent C = water: acetic acid: sodium bisulphate (95:5:0.5)] Values (n = 3) are means ± SEM; Means in a column with common superscripts (abc) differ  $p \leq 0.05$ . Means in a row with common superscripts (xy) differ  $p \leq 0.05$ .

**Table 3.** Correlation between functional components and antioxidant activity of Selected Potato Varieties.

	TPC	TFC	TAC	FRAP	TEAC
TPC	1.000	0.740	0.947	0.838	0.709
TFC		1.000	0.680	0.796	0.456
TAC			1.000	0.773	0.678
FRAP				1.000	0.525
TEAC					1.000

Total phenolic content (TPC), Total flavonoid content (TFC), Total anthocyanin content (TAC), Trolox Equivalent Antioxidant Capacity (TEAC) and Ferric Reducing Antioxidant Power (FRAP)  $p < 0.05$ .

## 4. Discussion

The aim of the current study was to evaluate the efficiency of acidified solvents on the extraction of polyphenolic compounds in colored potatoes. The solubility of polyphenols is reliant on the polar properties of the extracting solvents [23]. Research suggests that the best solvent system for the extraction of phytochemicals is hydroalcoholic mixtures such as water and ethanol [24]. Although the solvent polarities are a critical aspect, it is also crucial to evaluate the extraction efficiency of low toxic solvents, such as ethanol and acetic acid, for possible industrial applications, especially as they relate to human consumption acceptability [25]. It has also been suggested that the addition of acids, like acetic acid to hydroalcoholic solution creates an acidified environment, which leads to better extraction efficiency of antioxidant compounds such as polyphenols [25]. For these reasons, this study evaluated the proficiency of three extracting solvents: Solvent A (24% water, 67% ethanol 9% acetic acid); Solvent B (5% acetic acid in 95% water); and Solvent C (95% water, 5% acetic acid, 0.5 g sodium bisulfate).

Based on present observation, the solvent efficiency varied based on the potato variety. For example, Solvent C was more efficient when extracting anthocyanins and phenolics from all the potato varieties, albeit MM for anthocyanins and, BB and AB for phenolics, respectively. According to Hosseini [26], water, due to its dipole momentum of 1.95, is more efficient when extracting polyphenols than ethanol. Furthermore, studies have suggested that organic acids, such as acetic acid, disrupt the cell membranes allowing for faster polyphenol extraction, especially as it relates to anthocyanin extraction [18] [26] [27]. Partial hydrolysis of polyphenols from insoluble complexation with polysaccharides is said to be one mechanism by which acidified aqueous alcohols improve extraction efficiency [18] [26]. Research conducted by Sipahli *et al.* [28] suggests that pigment retention was more stable in an acetic acid solvent system than citric and formic acid. Aliphatic or aromatic acids such as acetic acid can be used in the chemical acylation of anthocyanins, thus leading to an increased in stability when compared to unacylated anthocyanins [29]. This could be a major benefit to the food industry by not only addressing extraction efficiency but also the stability of polyphenol compounds. Issues regarding the stability of natural colorant such anthocyanins have been a major problem for the food industry, considering that anthocyanins are highly valuable compounds. A study by Złotek *et al.* [23] indicated addition of acetic acid to aqueous acetone mixture intensified the extraction of phenolic compounds from basil leaves. Furthermore, results from Imen *et al.* [30] suggested that ethanolic solutions yielded the highest TPC in horseradish.

Due to increased consumption, it can be supposed that most of the daily polyphenol consumption comes from potatoes than from fruits and vegetables [31]. Colored potatoes have gained popularity because of their color and rich phytochemical contents when compared to traditional white-cream colored potatoes [32] [33]. The levels of polyphenols in purple-blue potatoes are two to

three times higher than in yellow-fleshed potatoes [33] [34]. The results of this study suggested that darker colored potatoes (MM and AB potatoes) displayed the highest polyphenolic content as well as antioxidant activity when compared to the mixed (JP) and the yellow (BB) colored potatoes. Contrary to the results, Madiwale [31] observed that the mixed colored variety had the highest polyphenolic content and antioxidant activity when compared to purple, red and yellow-colored potatoes. Furthermore, Kalita [35], showed that mixed colored potatoes had the higher phenolic content than purple tubers and red tubers. The results of this study indicated that yellow potatoes have lower polyphenol content than colored potatoes. Similarly, Lee *et al.* [36] reported that yellow potatoes (Seohong and Jaseo) had significantly higher polyphenol content when compared to white potatoes (Superior). Brown [37] reported that yellow and orange flesh potatoes contain 5 - 16-fold (800 - 2000 µg/100 g FW) more phytochemicals than that observed in white potatoes (50 - 350 µg/100g FW) [37]. The current study showed that MM potatoes, with its deep purple flesh and skin had more polyphenols compared to the other varieties. Similar results were reported in studies conducted by Madiwale [31], where Purple Majesty and purple-fleshed clones displayed significantly ( $p < 0.05$ ) higher total phenolic and anthocyanin content than Atlantic (white), Yukon Gold (yellow), and two yellow clones.

Both FRAP and TEAC assays are used to determine the antioxidant capacity in several food products [38]. The antioxidant activities in potatoes utilized in this study were varied, as observed with the polyphenolic content. Purple (MM), blue (AB), and red-colored (VF) potatoes displayed higher antioxidant activity than yellow (BB) and mixed colored (JP) potatoes. Similar results were reported by Bellumori [39], who observed that blue-violet potato showed a higher antioxidant capacity than the yellow-colored varieties. Based on the results of the current study, colored potatoes are a good source of phytonutrients that can participate as an antioxidant via a single electron transfer mechanism (SET) [40]. Polyphenols including certain flavonoids and anthocyanins protect against blood clotting; act as chemical messengers, and play a significant role in protecting against vascular dementia and Alzheimer's disease [41]. It is hypothesized that polyphenols and anthocyanin compounds in colored potatoes could decrease inflammation and oxidative stress via mechanisms such as antioxidant, antimutagenic, and antimicrobial activities thus, potentially leading to reduced risks of heart disease, hypertension, diabetes, and cancer [39].

## 5. Conclusion

The results indicated that solvent type and potato variety resulted in high variability in polyphenols content and antioxidant activities. The present study showed that Solvent C was the best extracting solvent for TPC TFC and TAC in selected potatoes. Solvent C was composed of water, acetic acid and sodium bisulfate all of which are utilized in the food industry for polyphenols extractions. Sodium bisulfate is a chemical additive used as a leaven agent and pH lowering

agent used in several food applications without adding the sour taste. Meanwhile acetic acid is a weak organic acid used as a natural preservative, and lower pH agent with adding a sour taste. Anthocyanins stability depends heavily on pH and several other factors; thus, the combination of these compounds used in Solvent C has great potential to extract nutraceuticals that could be incorporated into foods as additives. This is important information as it relates to maximizing the food industry application of colored potatoes as a source of nutraceuticals. As the trend for natural sources for food color continues to rise, this study proved that the selected colored potatoes such as MM and AB are good sources of anthocyanins, a natural coloring agent. Furthermore, colored potatoes are a great source of polyphenol compounds with antioxidant activities and, could have the potential to significantly reduce oxidative.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

### References

- [1] Camire, M.E., Kubow, S. and Donnelly, D.J. (2009) Potatoes and Human Health. *Critical Reviews in Food Science and Nutrition*, **10**, 823-840. <https://doi.org/10.1080/10408390903041996>
- [2] Omayio, D.G., Ooko, A.G. and Okoth, M.W. (2016) A Review of Occurrence of Glycoalkaloids in Potato and Potato Products. *Current Research in Nutrition and Food Science*, **4**, 195-202. <https://doi.org/10.12944/CRNFSJ.4.3.05>
- [3] Cvejić, J.H., Krstonošić, M.A., Bursać, M. and Miljić, U. (2017) Polyphenols. In: Galanakis, C.M., Eds., *Nutraceutical and Functional Food Components*, Academic Press, Cambridge, 203-258. <https://doi.org/10.1016/B978-0-12-805257-0.00007-7>
- [4] Ezekiel, R., Singh, N., Sharma, S. and Kaurb, A. (2013) Beneficial Phytochemicals in Potato—A Review. *Food Research International*, **50**, 487-496. <https://doi.org/10.1016/j.foodres.2011.04.025>
- [5] Feng, R., Lu, Y.J., Bowman, L.L., Qian, Y., Castranova, V. and Ding, M. (2005) Inhibition of AP-1, NF- $\kappa$ B and MAPKs and Induction of Phase 2 Detoxifying Enzyme Activity by Chlorogenic Acid. *Journal of Biological Chemistry*, **280**, 27888-27895. <https://doi.org/10.1074/jbc.M503347200>
- [6] Friedman, M. (1997) Chemistry, Biochemistry, and Dietary Role of Potato Polyphenols. A Review. *Journal of Agricultural and Food Chemistry*, **45**, 1523-1540. <https://doi.org/10.1021/jf960900s>
- [7] Lachman, J. and Hamouz, K. (2004) Red and Purple Coloured Potatoes as a Significant Antioxidant Source in Human Nutrition—A Review. *Plant, Soil and Environment*, **51**, 477-482.
- [8] Szymanowska, U., *et al.* (2015) Anti-Inflammatory and Antioxidative Activity of Anthocyanins from Purple Basil Leaves Induced by Selected Abiotic Elicitors. *Food Chemistry*, **172**, 71-77. <https://doi.org/10.1016/j.foodchem.2014.09.043>
- [9] Thibado, S.P., *et al.* (2018) Anticancer Effects of *Bilberry anthocyanins* Compared with NutraNanoSphere Encapsulated *Bilberry anthocyanins*. *Molecular and Clinical Oncology*, **8**, 330-335. <https://doi.org/10.3892/mco.2017.1520>
- [10] Brown, C.R. (2005) Antioxidants in Potato. *American Journal of Potato Research*,

- 82, 163-172. <https://doi.org/10.1007/BF02853654>
- [11] Tierno, R., Hornero-Méndez, D., Gallardo-Guerrero, L., López-Pardo, R. and Ruiz de Galarreta, J.I. (2015) Effect of Boiling on the Total Phenolic, Anthocyanin and Carotenoid Concentrations of Potato Tubers from Selected Cultivars and Introgressed Breeding Lines from Native Potato Species. *Journal of Food Composition and Analysis*, **41**, 58-65. <https://doi.org/10.1016/j.jfca.2015.01.013>
- [12] Moser, S., *et al.* (2018) Potato Phenolics Impact Starch Digestion and Glucose Transport in Model Systems But Translation to Phenolic Rich Potato Chips Results in Only Modest Modification of Glycemic Response in Humans. *Nutrition Research*, **52**, 57-70. <https://doi.org/10.1016/j.nutres.2018.02.001>
- [13] Mishra, B.B., Gautam, S. and Sharma, A. (2013) Free Phenolics and Polyphenol Oxidase (PPO): The Factors Affecting Post-Cut Browning in Eggplant (*Solanum melongena*). *Food Chemistry*, **139**, 105-114. <https://doi.org/10.1016/j.foodchem.2013.01.074>
- [14] Druzynska, B. (2007) The Influence of Time and Type of Solvent on Efficiency of the Extraction of Polyphenols from Green Tea and Antioxidant Properties Obtained Extracts. *Acta Scientiarum Polonorum, Technologia Alimentaria*, **6**, 27-36.
- [15] Fu, Z.-F., Tu, Z.-C., Zhang, L., Wang, H., Wen, Q.-H. and Huang, T. (2016) Antioxidant Activities and Polyphenols of Sweet Potato (*Ipomoea batatas* L.) Leaves Extracted with Solvents of Various Polarities. *Food Bioscience*, **15**, 11-18. <https://doi.org/10.1016/j.fbio.2016.04.004>
- [16] Truong, D.-H., Nguyen, D.H., Ta, N.T.A., Bui, A.V., Do, T.H. and Nguyen, H.C. (2019) Evaluation of the Use of Different Solvents for Phytochemical Constituents, Antioxidants, and in Vitro Anti-Inflammatory Activities of *Severinia buxifolia*. *Journal of Food Quality*, **2019**, Article ID: 8178294. <https://doi.org/10.1155/2019/8178294>
- [17] Athanasiadis, V., Grigorakis, S., Lalas, S. and Makris, D.P. (2018) Highly Efficient Extraction of Antioxidant Polyphenols from *Olea europaea* Leaves Using an Eco-Friendly Glycerol/Glycine Deep Eutectic Solvent. *Waste and Biomass Valorization*, **9**, 1985-1992. <https://doi.org/10.1007/s12649-017-9997-7>
- [18] Pintač, D., *et al.* (2018) Solvent Selection for Efficient Extraction of Bioactive Compounds from Grape Pomace. *Industrial Crops and Products*, **111**, 379-390. <https://doi.org/10.1016/j.indcrop.2017.10.038>
- [19] Qasim, M., *et al.* (2016) Effect of Extraction Solvents on Polyphenols and Antioxidant Activity of Medicinal Halophytes. *Pakistan Journal of Botany*, **48**, 621-627.
- [20] Maldonado, A.F.S., *et al.* (2014) Extraction and Fractionation of Phenolic Acids and Glycoalkaloids from Potato Peels Using Acidified Water/Ethanol-Based Solvents. *Food Research International*, **65**, 27-34. <https://doi.org/10.1016/j.foodres.2014.06.018>
- [21] Gajula, D., *et al.* (2009) Determination of Total Phenolics, Flavonoids and Antioxidant and Chemopreventive Potential of Basil (*Ocimum basilicum* L. and *Ocimum tenuiflorum* L.). *International Journal of Cancer Research*, **5**, 130-143. <https://doi.org/10.3923/ijcr.2009.130.143>
- [22] Martynenko, A. and Chen, Y.G. (2016) Degradation Kinetics of Total Anthocyanins and Formation of Polymeric Color in Blueberry Hydrothermodynamic (HTD) Processing. *Journal of Food Engineering*, **171**, 44-51. <https://doi.org/10.1016/j.jfoodeng.2015.10.008>
- [23] Złotek, U., *et al.* (2016) The Effect of Different Solvents and Number of Extraction Steps on the Polyphenol Content and Antioxidant Capacity of Basil Leaves (*Oci-*

- mum basilicum* L.) Extracts. *Saudi Journal of Biological Sciences*, **23**, 628-633. <https://doi.org/10.1016/j.sjbs.2015.08.002>
- [24] Boeing, J.S., *et al.* (2014) Evaluation of Solvent Effect on the Extraction of Phenolic Compounds and Antioxidant Capacities from the Berries: Application of Principal Component Analysis. *Chemistry Central Journal*, **8**, 48-48. <https://doi.org/10.1186/s13065-014-0048-1>
- [25] Zhong, L., *et al.* (2019) An Optimized Method for Extraction and Characterization of Phenolic Compounds in *Dendranthema indicum* var. *aromaticum* Flower. *Scientific Reports*, **9**, Article No. 7745. <https://doi.org/10.1038/s41598-019-44102-9>
- [26] Hosseini, S., *et al.* (2016) Evaluation the Organic Acids Ability for Extraction of Anthocyanins and Phenolic Compounds from Different Sources and Their Degradation Kinetics during Cold Storage. *Polish Journal of Food and Nutrition Sciences*, **66**, 261-269. <https://doi.org/10.1515/pjfn-2015-0057>
- [27] Lao, F. and Giusti, M.M. (2018) Extraction of Purple Corn (*Zea Mays* L.) Cob Pigments and Phenolic Compounds Using Food-Friendly Solvents. *Journal of Cereal Science*, **80**, 87-93. <https://doi.org/10.1016/j.jcs.2018.01.001>
- [28] Sipahli, S., Mohanlall, V. and Mellem, J.J. (2017) Stability and Degradation Kinetics of Crude Anthocyanin Extracts from *H. Sabdariffa*. *Food Science and Technology*, **37**, 209-215. <https://doi.org/10.1590/1678-457x.14216>
- [29] Espinosa-Acosta, G., *et al.* (2018) Stability Analysis of Anthocyanins Using Alcoholic Extracts from Black Carrot (*Daucus carota* ssp. *Sativus* var. *Atrorubens* alef.). *Molecules*, **23**, 2744.
- [30] Imen, T., *et al.* (2012) Phenolic Acids and Total Antioxidant Activity in *Ocimum basilicum* L. Grown under Na<sub>2</sub>SO<sub>4</sub> Medium. *Journal of Medicinal Plants Research*, **6**, 5868-5875.
- [31] Madiwale, G.P., *et al.* (2012) Combined Effects of Storage and Processing on the Bioactive Compounds and Pro-Apoptotic Properties of Color-Fleshed Potatoes in Human Colon Cancer Cells. *Journal of Agricultural and Food Chemistry*, **60**, 11088-11096. <https://doi.org/10.1021/jf303528p>
- [32] Bartoletti, S.C. (2014) Black Potatoes: The Story of the Great Irish Famine, 1845-1850. HMH Books, Boston, MA.
- [33] Jaromar, L., *et al.* (2016) Colored Potatoes. In: Singh, J. and Kaur, L., Eds., *Advances in Potato Chemistry and Technology*, 2nd Edition, Academic Press, San Diego, 249-281. <https://doi.org/10.1016/B978-0-12-800002-1.00009-1>
- [34] Ieri, F., *et al.* (2011) Rapid HPLC/DAD/MS Method to Determine Phenolic Acids, Glycoalkaloids and Anthocyanins in Pigmented Potatoes (*Solanum tuberosum* L.) and Correlations with Variety and Geographical Origin. *Food Chemistry*, **125**, 750-759. <https://doi.org/10.1016/j.foodchem.2010.09.009>
- [35] Kalita, D., Holm, D.G. and Jayanty, S.S. (2013) Role of Polyphenols in Acrylamide Formation in the Fried Products of Potato Tubers with Colored Flesh. *Food Research International*, **54**, 753-759. <https://doi.org/10.1016/j.foodres.2013.08.023>
- [36] Lee, S.H., *et al.* (2016) Antioxidant Contents and Antioxidant Activities of White and Colored Potatoes (*Solanum tuberosum* L.). *Preventive Nutrition and Food Science*, **21**, 110-116. <https://doi.org/10.3746/pnf.2016.21.2.110>
- [37] Brown, C.R. (2008) Breeding for Phytonutrient Enhancement of Potato. *American Journal of Potato Research*, **85**, Article No. 298. <https://doi.org/10.1007/s12230-008-9028-0>
- [38] Lopez-Cobo, A., *et al.* (2014) Distribution of Phenolic Compounds and Other Polar

Compounds in the Tuber of *Solanum tuberosum* L. by HPLC-DAD-Q-TOF and Study of Their Antioxidant Activity. *Journal of Food Composition and Analysis*, **36**, 1-11.

- [39] Bellumori, M., *et al.* (2017) Coloured-Fleshed Potatoes after Boiling: Promising Sources of Known Antioxidant Compounds. *Journal of Food Composition and Analysis*, **59**, 1-7. <https://doi.org/10.1016/j.jfca.2017.02.004>
- [40] Kim, J.-S. (2016) Antioxidant Activities of Selected Berries and Their Free, Esterified, and Insoluble-Bound Phenolic Acid Contents. *Preventive Nutrition and Food Science*, **23**, 35-45. <https://doi.org/10.3746/pnf.2018.23.1.35>
- [41] Marcus, J.B. (2019) Chapter 2—Nutritional and Physical Concerns in Aging. In: Marcus, J.B., Ed., *Aging, Nutrition and Taste*, Academic Press, Cambridge, 25-63. <https://doi.org/10.1016/B978-0-12-813527-3.00002-8>