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REVIEW

Fatty Acids and Bioactive Lipids of Potato Cultivars: An Overview

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Abstract: Potato tuber is a highly nutritious, wherein genotype and environmental differences are known to exist in the shape, size and nutritional value of potatoes. Owing to its high consumption, potato could be an ideal carrier of health-promoting phytochemicals. Potato cultivars contain many bioactive lipidic compounds such as fatty acids, glycolipids, phospholipids, sterols, tocols and carotenoids, which are highly desirable in diet because of their health-promoting effects. In the scientific literature, information on the content and profile of bioactive lipidic compounds in potato cultivars are few. The concentration and stability of bioactive lipids are affected by many factors such as genotype, agronomic factors, postharvest storage, cooking and processing conditions. In this review levels and composition of bioactive lipids in terms of lipid classes, fatty acids, phytosterols, tocopherols, and caroteinoids distribution in different potato cultivars including genetically modified potato (GMP) were highlighted and discussed. In addition, factors affecting bioactive lipids levels, stability and health benefits are reviewed. In consideration of potential nutritional value, detailed knowledge on lipids of potato cultivars is of major importance.

Key words: *Solanum tuberosum*, glycolipids, phospholipids, tocopherols, sterols, caroteinoids

1 Introduction

Potato (*Solanum tuberosum*) is an herbaceous annual crop that grows under broad geographical distributions and climatic conditions[1]. It is the fourth most important crop of the world, exceeded only by wheat, rice and maize, with annual production approaching 365 million tons in 2012 according to Food and Agriculture Organization of the United Nations Statistical Database[2]. In addition, potatoes have become the third most widely consumed plant product by humans after wheat and rice[3].

Apart from being a rich source of starch, potatoes contain good quantity of small molecules and secondary metabolites which play an important biological and functional role[4, 5]. Many of the bioactive compounds in potato are important because of their health promoting effects, therefore, are highly desirable in the human diet[5]. Since potato is highly valued as a source of complex carbohydrates and vitamins with an added value of low fat content, it is being considered as a solution to meet the increasing food demand around the world[1, 6].

2 Chemical composition of potato tuber

Potato is one of the staples in the human diet and it is considered an important raw material in the starch industry as well. Tubers, the most important part of the plant, are an excellent source of carbohydrates, proteins, and vitamins. They are valued for their high starch content [up to 30.4% of fresh weight (FW)] and digestibility[7]. Tuber proteins (up to 2%) are very valuable for amino acids. The biological value (BV) of the tuber is ranged between 90 and 100 compared with eggs (100), soybeans (84) and beans (73)[8]. BV is a measure of the proportion of absorbed protein from a food which becomes incorporated into the proteins of the organism's body. There are two scales on which BV is measured; percentage utilization and relative utilization. Potatoes are also rich in vitamins and minerals,

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such as vitamin C (0.20 mg/g FW), vitamin B6 (2.5 μg/g FW), potassium (5.64 mg/g FW), phosphorus (0.30-0.60 mg/g FW), and calcium (0.06-0.18 mg/g FW)[9]. The health-oriented character of potatoes not only is a result of the high level of vitamin C but also is for the presence of different antioxidant phenolic compounds, such as phenolic acids and flavonoids[3].

The carotenoids' levels in potatoes determine whether the tuber flesh is white (low carotenoids content), yellow (moderate content), or orange (high content). Despite the fact that white and yellow-fleshed potatoes are similar in the carotenoids level; the yellow ones have higher levels of xanthophylls, which made it more favorable in the world production[10-12]. In addition to the above antioxidants, potatoes also contain high level of vitamin E predominantly represented by α-tocopherol. Moderate levels of lipophilic tocopherols have been reported in the staple potato[12, 13]. Dietary antioxidants including tocopherols are believed to play a key role in the body's defense system against reactive oxygen species (ROS), which are known to be involved in the pathogenesis of aging and many degenerative diseases such as cardiovascular diseases and cancers. Therefore, potatoes may significantly contribute to the antioxidant dietary intake and are likely to provide health benefits[14].

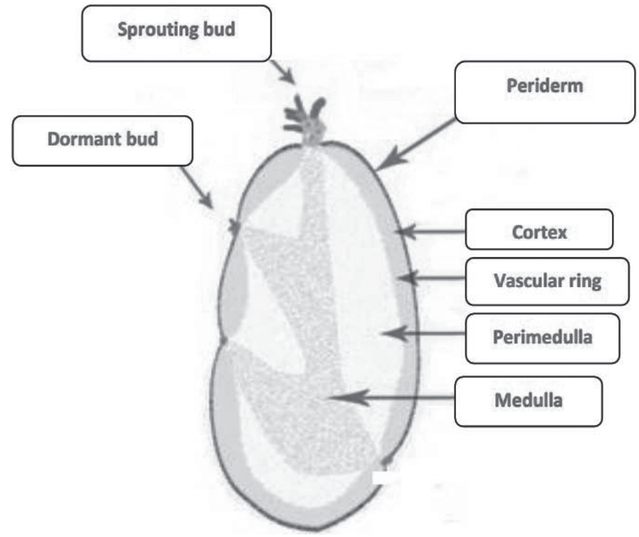


Fig. 1 Anatomy of potato tuber.

3 Lipids of potato tuber and potato starch

Total lipids (TL) in potatoes represent approximately 0.1-0.5% of potato tuber FW. Most of the lipids are located in the region between the peel and vascular ring of the tuber (Fig. 1). Therefore, in the thickly peeled potatoes the content of this nutritional component is even smaller. Also, TL of potato tubers consists mainly of phospholipids (PL, 47%), glycol- and glactolipids (GL, 22%), which are structural elements of biological membranes as well as neutral lipids (NL, 21%) such as acylglycerols and free fatty acids.

More than 94% of tuber lipids are in forms containing esterified fatty acids. Galliard[15] reported that tuber lipids consist of 47.4% PL, 21.6% galactolipid, 6.4% esterified steryl glucoside, 1.3% sulpholipid, 2.4% cerebroside and 15.4% triglyceride. Major lipids and a portion of the triacylglycerol (TAG) are associated with tuber membranes. While lipid bodies can occasionally be found within the cytoplasm, it is unlikely that tubers contain appreciable amounts of lipid reserves. Therefore, fatty acid composition of potato tubers should primarily reflect the composition of cell membranes[16]. The composition of the fatty acids of TL isolated from potato tubers is nutritionally advantageous. The essential part is formed by the relatively reactive polyunsaturated fatty acids (PUFA) with one to three double bonds, mainly linoleic and linolenic acid (70-75%), precursors of a wide range of volatile compounds[15].

Lipid-saccharide interactions predominantly involve interactions between lipids and starches. The formation of such complexes is the goal of numerous technological procedures. Lipid-starch interactions can both hamper and facilitate processing and can affect the properties of both starch and lipids.

In potato starch, lipids, phosphates and low-molecular weight (LMW) proteins are present in the interior of the granules at relatively low levels. Their presence and interaction within starch granules strongly influence starch behavior towards gelatinization, retrogradation, swelling, viscosity and leaching of soluble carbohydrates during different technological processing (i.e. cooking, baking and extrusion)[17, 18].

Normally, lipids are extracted from potato starch (PSt) granules using *n*-propanol-water (3:1, v/v) using cold and hot extractions into surface and internal lipid fractions. PSt lipids (0.53 g/100 g) were characterized by having high level of surface lipids (0.32 g/ 100 g) while internal lipids accounted for 0.21 g/100g[19]. Dhital, Shrestha, Hasjim and Gidley (2011) separated PSt granules into very small (PSt-VS), small (PSt-S), medium (PSt-M), large (PSt-L), and very large (PSt-VL) fractions and the TL was found to be higher in the small PSt ones. Also, fatty acids of PSt were found to be in the following order C16:0 > Cl8:2 > C18:3 > C18:l. The fatty acid profile from the cold extract indicated that it contained high level of saturated fatty acids (SFA, 42.1%). When the hot solvent mixture was employed, the fatty acid percentages for C16:O (49.9%), C18:l (13.6%) and C18:O (7.35%) were increased. Similar results were reported by Vasanthan and Hoover[20].

In sweet potato, there is also a small amount of lipids in the PSt[21, 22] and the characteristic fatty acids for sweet PSt were $CH3-(CH2)_{13}-COOH$ + Lys + Glucose and $CH3-(CH-CH)_4-(CH2)_4-COOH$ + glucose[23]. Since the presence of amylose/lipid complexes in food formulations has great effects on starch texture in the solid state, therefore the chemical features of lipid in sweet PSt were investigated by comparing their IR and NMR spectra before and after hydrolysis by lipase[24]. The results showed that the absence of C–H stretching vibration near 2930 cm^{1} in IR spectra of sweet PSt hydrolyzed by lipase was probably due to an interaction of amylose and amylopectin without lipids. The results of ^{13}C NMR showed that lipids and proteins were attached to each other and only lipid connected directly with sweet PSt. Thus, lipids probably inhibit crystal formation of starches.

4 Lipids in transgenic potatoes

4.1 Total lipids and lipid classes

Potato is an important target crop for biotechnological applications and a valuable model system for studying signaling processes. Although the intake of potato lipids is minimal due to its small content, the large portion of potatoes in the daily food rations in many countries significantly increased the daily consumption of unsaturated fatty acids such as linoleic (32.1 mg/100 g) and linolenic acids (22.7 mg/100 g)[25, 26]. Thus, the cultivation of potato species, which accumulates more lipids in their tubers, would be an interesting task. Genetic engineering has been actively involved in the carbohydrate metabolism improvement of potato, which provides a carbon skeleton for the synthesis of amino acids and other organic compounds.

Prescha *et al.*[27] overexpressed the heterologous 14-3-3 gene of pumpkin and obtained plants with blocked synthesis of isoforms a and b of the protein. Proteins belonging to the 14-3-3 family participate in the vegetative cycle of the plants and have an influence on the synthesis of catecholamines. The results showed that the highest amount of lipids was in the tubers of the transgenic line J2 (approximately 69% higher than the wild type) with the *cis*-a-linoleic acid as the main fatty acid. Lipids were separated into polar and nonpolar fractions. A comparison of the percentage of polar and non-polar lipids revealed higher ratios of the non-polar fraction in all transgenic lines (an almost three times higher content in line J2) compared with control. Determination of polar lipids showed higher differences between this fraction in control and transgenic potato. All transgenic lines (except G1) contained higher levels of polar lipids in the tuber dry matter. There was only little change (up to 10%) in the NL content in all transgenic lines in comparison to the control. The mechanism by which the changes in lipid content and fatty acids composition in transgenic plants occurred is as yet unknown but the results obtained strongly suggest the involvement of the 14-3-3 isoforms in the regulation of lipid metabolism.

Genetically modified potato (GMP) genotypes with overexpressed or underexpressed P14-3-3a (29G) and P14-3-3c (20R) isoforms of 14-3-3 protein were field-trialled[27]. The contents of protein, starch, sugars and lipids were determined. An increase was recorded in TL overexpressing 14-3-3 protein from *Cucurbita pepo*[28]. Analysis of plants suggested that the function of the isolated 14-3-3 isoform is in the control of carbohydrate and lipid metabolism. Overexpression of the 14-3-3 protein does not affect protein synthesis and vitamin C content, but it does affect TL amount. GMP tubers showed changes in TL amount and composition. They contained 69% more TL compared with the wild-type potato. Separation of lipids into polar and non-polar fractions revealed that the GMP contained almost 3 times more non-polar lipids than the control. Fatty acid profiling showed that linoleic acid was the main fatty acid of both GMP and non-genetically modified potato (NGMP). In the non-polar fraction of lipids from GMP, the unsaturated fatty acids were found in higher levels[26, 27].

Ramadan and El-Sanhoty[13] compared fatty acids, sterols, tocopherols distribution and lipid classes [(neutral lipids (NL), glycolipids (GL) and phospholipids (PL)] as well as unsaponifiable levels in GMP Spunta G2, G3 (developed with resistance to potato tuber moth (PTM) with a Cry V gene) and NGMP. GMP lines G2 and G3 contained 0.59%, 0.75 and 0.72% TL, respectively. Among the lipids present in NGMP (Fig. 2), the level of PL was the highest (53%), followed by NL (24%) and GL (23%). In GMP G2 and G3 lines, levels of NL increased to be 40% and 39% of TL, respectively, while the levels of total polar lipids (PL and GL) decreased. Significant decrease in PL levels was measured in both lines (from 53% in NGMP to 40% in GMP), while the levels of GL decreased from 23% in NGMP to ca. 20% in GMP.

The proportion of NL classes presented in GMP and

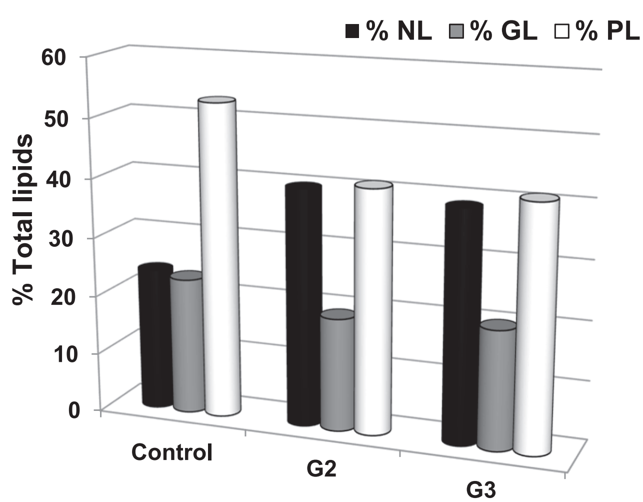


Fig. 2 Percentages of non-polar and polar lipids in GMP and NGMP Spunta.

Table 1 Neutral lipid classes (g/100 g of TL) in GMP and NGMP Spunta.

Lipid class	NGMP	GMP G2	GMP G3
Monoacylglycerols	0.96	1.52	1.32
Diacylglycerols	1.32	2.00	2.18
Free fatty acids	0.91	1.20	1.24
Triacylglycerols	20.2	33.9	33.1
Sterol esters	0.55	1.32	1.05

NGMP are shown in Table 1. Total NL in NGMP accounted for 240 g/kg, whereas NL measured in higher amounts in GMP G2 and G3 (400 and 390 g/kg, respectively). Classes of NL in GMP and NGMP contained triacylglycerol (TAG), diacylglycerol (DAG), monoacylglycerol (MAG), free fatty acids (FFA) and esterified sterols (STE) in a decreasing order. Significant amount of TAG was found (*ca.* 85% of total NL) followed by a low level of DAG (5-5.6% of total NL), while FFA, MAG and STE were recovered in lower amounts.

GL are amphiphilic components of cell membranes, composed of a hydrophilic polar sugar head group and a hydrophobic a polar lipid moiety anchoring the molecule in the membrane. The sugar moiety may vary from small saccharide units to very large polysaccharide chains. According to their chemical structure, these compounds may fulfill a variety of biological functions important for many biological processes[29]. Classes of GL presented in GMP and NGMP Spunta were sulfoquinovosyldiacylglycerol (SQD), digalactosyldiacylglycerol (DGD), cerebrosides (CER), steryl glucoside (SG), monogalactosyldiacylglycerol (MGD) and esterified steryl glucoside (ESG) (Figs. 3 and 4). Total GL measured in the highest amounts in NGMP (230 g/kg) followed be GMP G3 (200 g/kg) and GMP G2 (190 g/kg), respectively. DGD, MGD, ESG and SQD were the main components and made up approximately 90% of the total GL. CER and SG were measured in lower amounts in NGMP and GMP Spunta. The average daily intake of GL in human has been reported to be 140 mg of ESG, 65 mg of SG, 50 mg of CER, 90 mg of MGD and 220 mg of DGD[30].

PL are the main component of all cell membranes that form lipid bilayers because of their amphiphilic traits. PL molecule consists of two hydrophobic fatty acid and a hydrophilic consisting of a phosphate group, wherein the two components are joined together by a glycerol molecule. PL are used to formulate liposomal and other nanoformulations of drugs to improve bioavailability and increase penetration. In food systems PL can act as an emulsifier, enabling oils to form a colloid with water. PL classes in GMP and NGMP were separated into four major fractions using HPLC[13]. PL classes (Fig. 5) revealed that the predominant PL classes in NGMP and GMP were phosphatidylcholine (PC) followed by phosphatidylethanolamine (PE), phosphatidylserine and phosphatidylinositol (PI). About 43-46% of total PL was PC followed by PE (31-33%), while phosphatidylserine (16-19% of total PL) and PI (5-7% of total PL) were found in lower levels. Based on results of this study, it can be concluded that the compositions of GM potato Spunta G2 and G3 with Cry V gene are considerably equivalent to that of the wild type control with no toxicological effects.

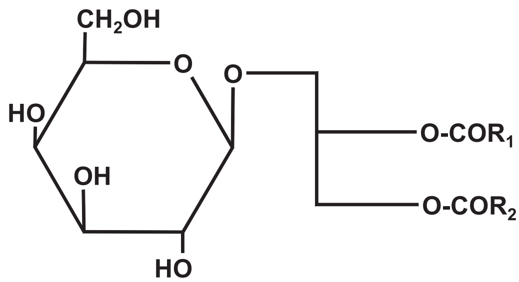
After feeding GM potato Spunta for 30 days, no differences were found in food intake, daily body weight gain and feed efficiency in albino rates. GM and non-GM potato Spunta DNA survival was comparable during feed passage in the rat gastrointestinal tract. In GM potato Spunta, modified constructs from DNA were not detectable in tissue samples[31].

4.2 Fatty acid composition

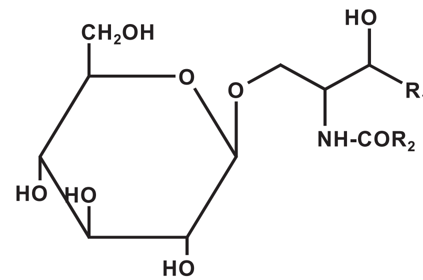
The result of the fatty acid analysis of TL extracted from wild type (D) and GMP with overexpression of 14-3-3 protein (J2)[26] showed that the percentage of oleic, linoleic and linolenic acids is in great agreement with the published reports of Kolbe *et al.*[32] and Trevini *et al.*[33]. The content of linoleic acid, the main fatty acid of potato, was approximately 49%. TL from the control tubers contained a large amount of palmitic and linolenic acids (10 and 14%, respectively). Fatty acids found in TL of transgenic J2 tubers were present in proportions similar to those in the control plants. The exception was a 55% increase in oleic acid, but the content of this acid was 4.5% of fatty acids in J2 potato. It was found that the main fatty acids of non-polar fraction were palmitic, linoleic, and linolenic acids. In the case of the control plants, the contents of palmitic, linoleic, and linolenic acids were 40, 21, and 13%, respectively. In the GMP, a significant elevation of the unsaturated fatty acid component of the non-polar fraction of tuber TL was revealed. The linoleic acid content increased by 48% wherein linolenic acid increased by 33%. A significant 71% increase of oleic acid was also reported, whereas the palmitic acid content decreased by 43%.

The percentage contribution of the polar lipids to the TL was more than twice the contribution of the non-polar lipids. Moreover, in the non-polar fractions the participation of palmitic acid was observed to be twice as high. In the case of the transgenic tubers (J2), the increase of the non-polar lipids was accompanied by a significant increase in the unsaturated fatty acids in this fraction. The lipids from both GMP and control potato revealed a nutritionally valuable profile of fatty acids, with a high content of unsaturated acids.

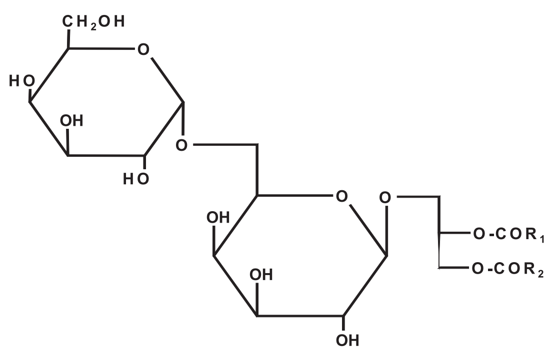
The fatty acids composition in lipids of GMP and NGMP from potato Spunta[13], shown in Table 2, revealed that oleic and cis-α-linoleic acid were the main fatty acid in different potato Spunta lines. In addition, TL contained high levels of palmitic and *cis*-α-linolenic acids. The content of oleic



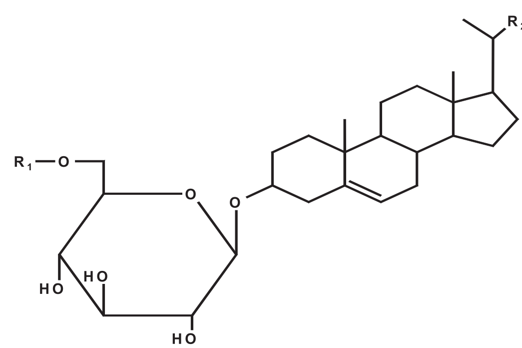
Monogalactosyldiacylglycerol (MGDG)



Cerebroside (CER)

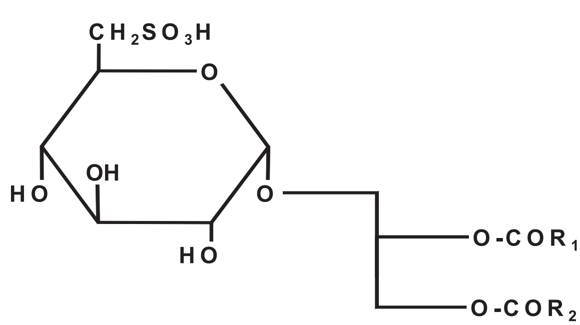


Digalactosyldiacylglycerol (DGDG)



R_1= H, Steryl glucoside (SG)

R_1= acyl, Acylated steryl glucoside (ASG)



Sulfoquinovosyldiacylglycerol (SQD)

Fig. 3 Chemical structures of glycolipids found in potato lipids.

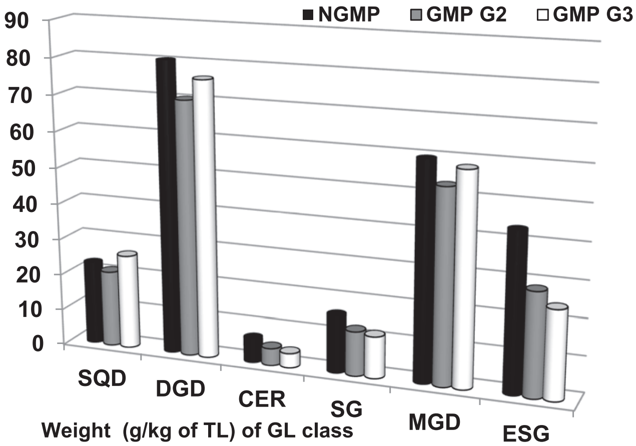


Fig. 4 Glycolipid classes (g/kg of TL) in GMP and NGMP Spunta.
Abbreviations: SQD, sulphoquinovosyldiacylglycerol; DGD, digalactosyldiacylglycerol; CER, cerebrosides; SG, steryl glucoside; MGD, monogalactosyldiacylglycerol and ESG, esterified steryl glucoside.

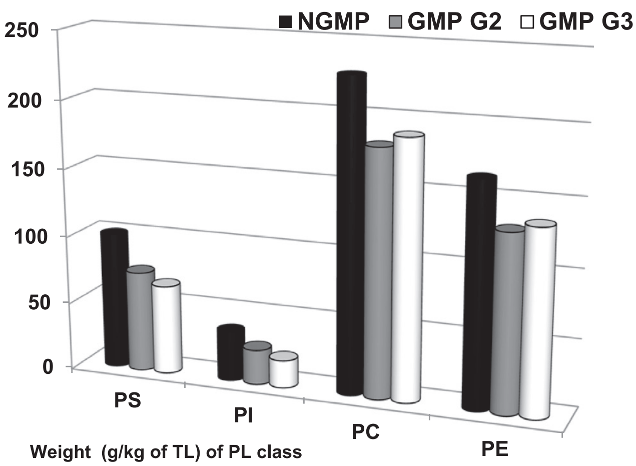


Fig. 5 Phospholipid classes (g/kg of TL) in GMP and NGMP Spunta.
Abbreviations: PS, phosphatidylserine; PI, phosphatidylinositol; PC, phosphatidylcholine and PE, phosphatidylethanolamine.

and linoleic acids, which are the main fatty acid of potato, were about 62.5-64.5% of all acids. Fatty acids levels in lipids of transgenic potato Spunta G2 and G3 tubers were relatively different to those in the control plants. Significant changes in the content of main unsaturated fatty acids in lipids were observed between GMP lines and the control. PUFA were found in higher levels in GMP (31.5-31.9%) than in NGMP (31%). On the other hand, SFA and monounsaturated fatty acids (MUFA) were found in to be less in GMP than in control. These results showed that the percentage of these acids is in agreement with the results published by El-Sanhoty *et al.*[34] and Dobson *et al.*[35].

MUFA can help lower cholesterol levels, reduce inflammation and regulate the insulin and blood sugar levels. PUFA, like MUFA, help lower bad cholesterol level (LDL). A specific kind of PUFA, *omega*-3 fatty acids, is beneficial to the heart by protecting against high blood pressure and might also reduce your risk of Type 2 diabetes. The profile of the fatty acids in lipids from potatoes revealed the consistent changes in composition of fatty acids in the transgenic lines. The mechanism by which the changes in fatty acids profile in transgenic plants occurred is yet unknown.

Table 2 Fatty acids composition (%) of GMP and NGMP Spunta.

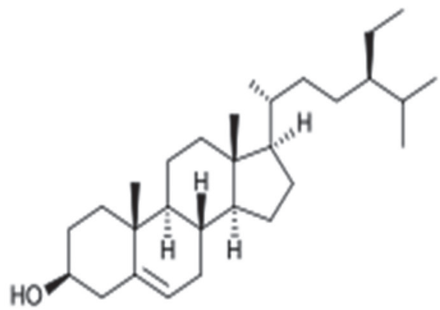
Fatty acid	NGMP	GMP G2	GMP G3
C16:0	11.0	10.5	10.7
C18:0	4.00	4.00	3.90
C18:1*n*-9	45.0	44.5	43.9
C18:2*n*-6	19.5	20.0	20.6
C18:3*n*-3	11.5	11.5	11.3
Other acids	9.00	9.50	9.60

4.3 Sterols (ST) composition

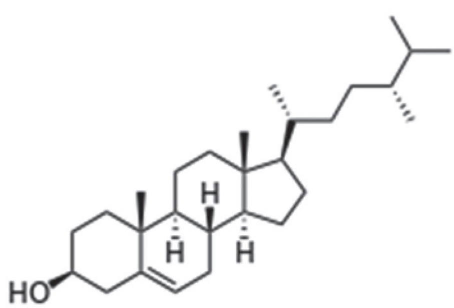
Unsaponifiables are the products contained in the fatty substance that, after saponification of oil or fat, are not volatile in the operating conditions. Unsaponifiables usually composed of bioactive compounds including tocols, sterols and hydrocarbons. Total unsaponifiables in potato Spunta lines recorded the highest level in GMP G3 (4% of lipids), followed by GMP G2 (3.9% of lipids) and NGMP (3.9% of lipids), respectively[13]. GMP G3 line contained the highest amounts of total ST (29 g/kg oil), followed by GMP G2 (26 g/kg oil) and NGMP (25 g/kg oil). The results pointed to a similarity between the percentage proportions of the most abundant ST in the tuber from GMP and NGMP Spunta (Table 3). β-Sitosterol (Fig. 6) was the main compound and comprised 43.1-43.7% of total ST content in the potato lines. The next major components were campesterol (*ca.* 26% of total ST) and Δ5-avenasterol (*ca.* 20% of total ST). Other components, e.g., brassicasterol, Δ7-avenasterol and stigmasterol were presented at lower levels and comprising about 10% of total ST. Lanosterol, sitostanol and Δ5,

Table 3 Levels of phytosterols (g/100 g of TL) in GMP and NGMP Spunta.

Compound	NGMP	GMP G2	GMP G3
Brassicasterol	0.103	0.129	0.134
Campesterol	0.670	0.679	0.754
Stigmasterol	0.056	0.025	0.024
β-Sitosterol	1.080	1.180	1.260
Δ5-Avenasterol	0.500	0.551	0.574
Δ7-Avenasterol	0.093	0.135	0.153



***β*-Sitosterol**



Campesterol

Fig. 6 Chemical structures of the main sterols found in potato lipids.

24-stigmastadinol were not detected in GMP and NGMP Spunta unsaponifiables[13]. Among different ST, β-sitosterol has been the most intensively investigated with respect to its physiological and beneficial effects in humans.

4.4 Tocopherols composition

Levels and profile of tocopherols in GMP and NGMP from Spunta cultivar are shown in Table 4. Data revealed that GMP G3 contained the highest amounts of total tocopherols (5 g/kg oil), followed by GMP G2 (4.5 g/kg oil) and NGMP (3.5 g/kg oil), respectively[13]. α-Tocopherol was the main compound (77.5-80% of total tocopherols) in GMP and NGMP Spunta followed by β-tocopherol (16.2-19% of total tocopherols). δ- and γ-Tocopherol were detected in lower amounts. The levels of α-tocopherol observed in the Andean potato tubers, ranging from 2.73 to 20.80 mg/kg, were above the quantities reported in the literature for commercial varieties [0.6-3 mg/kg, recalculated from Chun *et al.*[36] and Spychalla and Desborough[16]]. The levels observed for Nicola, with a brownish skin and a pale yellow flesh as well as Vitelotte with a purple skin and a partly purple flesh, were 0.8 and 2.3 mg of α-tocopherol kg, respectively[37]. It is generally assumed that increasing α-tocopherol in the diet can contribute to a decreased risk of chronic diseases. Therefore, increasing tocopherols content in potatoes is of an interest.

Table 4 Levels of tocopherols (g/100 g of TL) in GMP and NGMP Spunta.

Compound	NGMP	GMP G2	GMP G3
α-Tocopherol	0.271	0.356	0.400
β-Tocopherol	0.067	0.077	0.081
γ-Tocopherol	0.009	0.013	0.015
δ-Tocopherol	0.004	0.004	0.005

5 Caroteinoids

Potatoes are known as one of the richest sources of antioxidant compounds in the human diet. The main antioxidants are phenols, ascorbic acid, tocols and carotenoids[38]. Carotenoids are a widespread family of lipophilic pigments[39]. Carotenoids are tetraterpenoids with a long conjugated double bond system and a near bilateral symmetry around the central double bond[40]. There are over 750 known carotenoids with their color ranging from pale yellow to deep red[41]. Based on epidemiological studies a positive link is suggested between higher dietary intake and tissue concentrations of carotenoids and lower risk of chronic diseases[42].

Potatoes are a good source of carotenoids, which are lipophilic compounds synthesized in plastids from isoprenoids[43]. Lutein, zeaxanthin, violaxanthin and neoxanthin are the major carotenoids present in potatoes and β-carotene is present in trace amounts. The orange and yellow color of the tuber flesh is due to zeaxanthin and lutein, respectively. Cultivated diploid potatoes derived from *Solanum stenotonum* Juz. & Bukasov and *Solanum phureja* Juz. & Bukasov have been reported to be a great source of zeaxanthin and lutein[44].

Carotenoids and their derivative xanthophylls are diverse lipid-soluble pigments. In potato, xanthophylls are abundant carotenoids[45]. Two of these pigments, present in low concentration in potato (β-carotene and lutein), have an important role to play in eye health. The most potent dietary source of vitamin A (pro-vitamin A) is β-carotene. Lutein is an oxygenated xanthophyll that protects against macular degeneration, the leading cause of visual impairment and blindness in older North American adults[46].

Potatoes with yellow flesh contain primarily lutein, with a trace of β-carotene and other pigments including violaxanthin, zeaxanthin, and others[45]. Carotenoids content ranges from 57–750 μg/150 g FW and there are more carotenoids in yellow than white-fleshed cultivars[9]. The orange-fleshed potatoes contain zeaxanthin in addition to lutein[47]. Breeding may increase carotenoids content, as wild species may contain these pigments in higher levels[45].

Van Eck *et al.*[48] enhanced β-carotene content by RNAi-mediated silencing of the β-carotene hydroxylase gene that converts β-carotene to the less useful zeaxanthin. However, β-carotene to retinol conversion efficiency (21 μg of β-carotene per 1 μg retinol) proposed for developing countries suggests that a combination of strategies will be necessary to sufficiently improve the pro-vitamin A content of potato for populations at risk of vitamin A deficiency.

White- and yellow-fleshed potatoes are very familiar to people around the world. The intensity of yellow-fleshed varies greatly and those at the far end of the continuum may be described as orange. Despite the common belief in earlier studies that the most intensely colored yellow-fleshed potatoes contained β-carotene, it may be true that there is no β-carotene or just a trace[10]. Rather, *Solanum* potato, in contrast to the sweet potato (Ipomoea spp.), contains xanthophylls of various sorts. Total carotenoids measurement exists in the literature since the mid-20th century. Caldwell *et al.*[49] reported 14 to 54 and 110 to 187 μg/100 g FW for white- and yellow-fleshed potatoes, respectively. Kasim[50] reported values for total carotenoids between 199 and 560 μg, identifying lutein, violaxanthin and lutein 5,6 epoxide.

Granado *et al.*[51] reported 17 and 65 μg in raw and cooked potato, respectively. Tevini *et al.*[52] and Tevin and Schonecker[53] reported a range of 102 to 219 μg in yellow-fleshed potato, including lutein, β-carotene, neoxanthin, violaxanthin and lutein 5,6 epoxide as components. Iwanzik *et al.*[54] compared potatoes with various degrees of yellow intensity founding a range of total carotenoids from 27 to 329 μg. They reported lutein, neoxanthin, violaxanthin and lutein 5,6 epoxide as components and found a strong correlation between carotenoids concentration and colorimetric measurements of yellowness. Heinonan *et al.*[55] reported 13 and 60 μg from summer and spring potatoes, respectively. Studies have measured levels in potato with intensely yellow flesh that derive these high levels from *S. phureja*, a diploid cultivated species endemic to the Andean Cordillera. Brown *et al.*[47] found levels exceeding 2000 μg in breeding materials segregating for orange-, yellow-, and white-fleshed phenotypes derived from a diploid population originating from *S. phureja* and *S. stenotomum*. The orange-fleshed types contained predominantly zeaxanthin, which is redder in color than lutein, conferring a dark yellow to orange appearance depending on concentration in the flesh. Hale[56] found a range of 97 to 536 μg/100g FW in a series of cultivars and breeding lines. Brown *et al.*[57] divided cultivars into white, yellow, and dark yellow categories on the basis of color which corresponded to 50 to 100, 150 to 250 and 500 to 700 μg/100 g FW.

Römer *et al.*[58] increased the level of zeaxanthin in yellow-fleshed potato by transformation of sense and antisense constructs of neoxanthin epoxidase. This inhibited conversion of zeaxanthin into violaxanthin. Increases in zeaxanthin over wild type ranged between four- and 130-fold. The highest levels of zeaxanthin reached 40 μg/g DW. Lu *et al.*[59] found high levels, in their most highly pigmented materials, 1435 and 2200 of total carotenoids, respectively, listing lutein, zeaxanthin, neoxanthin, violaxanthin and lutein 5,6 epoxide as components. Breithaupt and Bamedi[60] reported values of 58-175 and 38-62 μg for yellow and white flesh, respectively, indicating that esterified xanthophylls made up a substantial portion of total carotenoids. Nesterenko and Sink[61] reported the carotenoids level and xanthophyll identities of white-, yellow-, and orange-fleshed potato. They reported values ranging from 48 to 879 μg of the yellow-fleshed types, the highest values were 265 μg while the single orange-fleshed type had 879 μg. Beside the ubiquitous lutein, which is always present in white-fleshed potato, violaxanthin was the second most common xanthophyll reported in abundance in yellow-fleshed potatoes.

Brown *et al.*[57] reported that antioxidant values attributable to a chloroform soluble fraction of the tuber. The ORAC values ranged from 2 to 7 μg/100 g FW α-tocopherol equivalents. Total carotenoids concentration was correlated with the antioxidant values and also had a statistically significant positive regression coefficient. Studies have compared purified samples of carotenoids for antioxidant values. There is agreement that lycopene displays the highest value while lutein and zeaxanthin are approximately haft as effective[62, 63]. Clevidence *et al.*[64] reported that consumption of dietarily realistic amounts of carotenoid-rich vegetables raised plasma and colon cell levels of several carotenoids by significant amounts.

Potato cultivars with white flesh contained less carotenoids as compared to cultivars with yellow or orange flesh. Total carotenoids content was reported in the range of 50–350 μg/100 g FW and 800–2000 μg/100 g FW, respectively, in white- and yellow-fleshed potato cultivars[45]. The carotenoid profiles and concentrations in tubers of *Solanum phureja* Juz. & Bukasov have been correlated with the intensity of yellow flesh color, and zeaxanthin and antheraxanthin were found as the predominant carotenoids in deep yellow-fleshed varieties while violaxanthin, antheraxanthin, lutein and zeaxanthin constituted the main carotenoid profile of yellow potatoes, and violaxanthin, lutein and β-carotene in cream-fleshed potatoes[65]. Hejtmankova *et al.*[66] studied the main carotenoids in 15 varieties of *Solanum tuberosum* with different flesh color including white, yellow, red and purple and two varieties of *Solanum phureja*. Content of carotenoids was affected by variety, locality and the growing year. Content of total carotenoids ranged from 0.779 to 13.3 mg/kg dry matter (DM). The main carotenoid was lutein in all varieties (54–93%). In addition, violaxanthin, neoxanthin, zeaxanthin and β-carotene were identified in most of the analyzed samples. The highest carotenoid content was found in *S. phureja* varieties. The pigmented varieties Blaue Anneliese, Violetta, Olivia (all purple) and H.B. Red (red) showed comparable carotenoid amount with the yellow-fleshed variety Agria; other pigmented varieties contained similar carotenoid levels as white-fleshed varieties. Tubers of a hybrid population of the diploid cultivated potatoes *Solanum phureja* contain zeaxanthin levels higher than any previously reported for potatoes[66].

Tierno *et al.*[67] reported variations in the carotenoid concentrations in some colored potato cultivars. There was a six-fold variation in total carotenoids, which ranged from 0.00915 to 0.0590 g/kg FW. Levels of carotenoids were higher in the cultivars Morada, Highland Burgundy Red, Rouge de Flandes and Rosa Roter, whereas Bleu de La Manche, Fenton and Blue Congo showed the lowest carotenoids amount. Relatively low total carotenoid values were found in most of the medium or deep purple cultivars. According to Kotíková *et al.*[68] deep purple potato cultivars generally have lower ability to synthesize and accumulate carotenoids when compared to yellow-fleshed potato cultivars.

Researchers have been able to increase carotenoids content considerably using transgenic approaches. Ducreux *et al.*[69] were able to increase tuber carotenoids content from 5.6 to 35 μg/g DW (cv. Desiree) by overexpressing a bacterial phytoene synthase. They also observed large increase in the levels of individual carotenoids, β-carotene (more than 11 fold) and lutein (19 fold). Diretto *et al.*[70] claimed that 50% of the Recommended Dietary Allowance (RDA) of vitamin A can be met by consuming 250 g of carotenoids enriched genetically engineered potatoes.

6 Conclusion

The research in potato chemistry has established the fact that there is a lot more in potatoes than starch. Although total lipids amount of potato tubers is low; potato tuber lipids contain high levels of bioactive constituencies in terms of lipid classes, fatty acids, phytosterols, tocols, and caroteinoids. Levels of bioactive lipids in potatoe cultivars can be improved by developing new varieties from available germplasm high in these compounds. The large portion of potatoes in the daily food rations worldwide may significantly increase the daily intake of essential polyunsaturated fatty acids (i.e., linoleic and linolenic acids). Natural colorant and antioxidants present in colored-flesh potatoes can be used for developing functional foods and nutraceuticals. Considering the large quantities in which potatoes are consumed throughout the world, potatoes could be a very good vehicle for addressing some health related problems. Therefore, cultivation of potato species, which accumulates more lipids, would be an interesting task.

7 Conflict of interest

None.

7.1 Compliance with Ethics Requirements

This article does not contain any studies with human or animal subjects.

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