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Study Review

Nutritional and functional components of non centrifugal cane sugar: A compilation of the data from the analytical literature

Walter R. Jaffé *

Innovaciones Alimentarias INNOVAL, Calle Paguey, Qta. Irazu, La Trinidad, Caracas, Venezuela

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ABSTRACT

Non-centrifugal cane sugar (NCS) (panela, jaggery, kokuto, etc.) is a traditional sweetener of increasingly economic importance after a long process of displacement by refined sugar. By searching the analytical literature with the different local names of NCS (jaggery, gur, kokuto, panela, chancaca, piloncillo, rapadura, muscovado, unrefined sugar, black sugar) as key-words, this review identified the published data on its content of 7 proximate, 14 minerals, and 13 vitamins so to calculate its average and median values, as well as list its contents of potentially relevant functional components like phenolics, amino acids, complex sugars and others. The forty-two publications on chemical content and properties found to show that NCS has nutritionally and functionally significant quantities of minerals, vitamins and phenolics, among other constituents, as well as antioxidant capacities. This justifies its inclusion in food composition databases and in reviews of antioxidant properties and phenolic contents of foods. Higher awareness of the nutritional and functional properties of NCS could increase scientific, nutritional and health interest in this food.

Contents

* Tel.: +58 2129453827.
E-mail address: wjaffecar@gmail.com

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1. Introduction

Non-centrifugal cane sugar (NCS), the technical denomination used by the Food and Agriculture Organization of the United Nations (FAO), is a solid unrefined product obtained by evaporating sugarcane juice (FAO, 1994). It has been traditionally consumed as a sweetener in most sugarcane growing regions of the world where it is known by many different names, the most common ones being jaggery and gur (South Asia), panela (Latin America), muscovado (Philippines), rapadura and azucar mascavo (Brazil) and kokuto (Japan) (Jaffé, 2012a). In 1961 NCS represented 16% of total per capita caloric sweetener consumption worldwide. This share has been falling reaching 3% in 2009. Today, it is a marginal food on the world market but still important in some of the producing countries. This is shown by its share in the daily consumption of caloric sweeteners (g/person/day) for 2007 of the following countries: Myanmar 46%; Bangladesh 20%; Colombia 19%; India 10%; Pakistan 10% (Own calculations based on Faostat data).

However, whilst production of NCS has been declining in Asia it has been rising, even if only slowly, in Latin America according to the International Sugar Organization (2013). There it reached an all-time high in 2011 surpassing the 2,000,000 metric ton level for the first time. There are growing efforts to increasingly market NCS alongside other types of niche market sugars overcoming the negative view that the traditional sugar industry has had of non-centrifugal sugar (International Sugar Organization, 2013).

But the growth of the international importance of NCS is hampered by the widespread confusion over its product identity caused by its many names. Many of the publications on chemical and food science aspects of NCS are in Japanese, Spanish or Portuguese and most use its local name. As a result of this dispersion and difficulty of access of the available information NCS is not recognized as an important food and therefore not included in most of the nutritional content of foods databases as, for example, in the US, France and Switzerland (ANSES, 2012; FFS and VOS, 2014; USDA, 2013). The "brown sugar" and "turbinado sugar" included in some of them are coated sugars, that is, refined crystallized saccharose mixed with some level of sugarcane molasses. Also, databases of antioxidant components in foods, like the Phenol Explorer (Neveu et al., 2010) and the U.S. databases on proanthocyanidins, isoflavones and flavonoids (USDA, 2004; Bhagwat et al., 2008, 2013;) do not include NCS, the same as reviews on antioxidant capacity and phenolic contents of foods, with one exception (Sreeramulu and Raghunath, 2011), as the following publications show (Blomhoff, 2005; Devasagayan et al., 2004; Dimitrios, 2006; Halvorsen et al., 2002; Petti and Scully, 2009; Shahidi and Naczk, 2006). This review purposes to identify and facilitate the use of the available analytical data of acceptable quality on the nutritional and functional properties of NCS, focusing on its content of minerals, vitamins, antioxidants and other potentially relevant components and its health effects. In this way the recognition of NCS as a promising functional food will be advanced, hopefully increasing research efforts to extend its use.

2. Methodology

Papers published in scientific journals, as well as food composition tables and databases recognized by INFOODS, the international network organized by the FAO, published before April 2015, have been the sources of the data. Posters or conference presentations have not been included. The Google search engine and Google Scholar have been the main tools used to identify relevant publications. Searches were done in English, Spanish and Portuguese covering 20 pages of search results. The keywords used have been "non centrifugal cane sugar" and the different local names of NCS (jaggery, gur, kokuto, panela, chancaca, piloncillo, rapadura, muscovado, unrefined sugar, black sugar) combined with keywords relevant to the purpose of the article such as "chemical composition", "nutrients", "antioxidants", "vitamins", etc. In the case of the food composition data the information provided by INFOODS for each country in the world has been examined to identify the data on NCS composition accessible through the Internet, in English, German, French, Spanish or Portuguese (INFOODS, 2014).

In all, forty-two publications containing relevant analytical data on NCS composition were obtained, fourteen on proximate, minerals and vitamins, sixteen on antioxidant properties and phenolics content and twelve on other potentially functional components. Additionally twelve publications on antioxidant capacity and content in parts of the sugarcane plant, sugarcane juice and sugarcane molasses were identified.

Each identified publication was abstracted and data points taken to be each reported analytical value, usually a mean of duplicate or triplicate values. Data points described as "non detected" were assigned a value of zero. Statistics were calculated using Microsoft Excel.

3. Nutritional content of NCS

NCS is essentially dried sugar cane juice. The juice is extracted from the cane, cleaned, clarified and then concentrated by evaporation of its water content. Depending on the manufacturing process it is either presented in solid form, known as lump sugar, or in granulated form. Given the high sucrose content of cane juice it is, therefore, crystals of sucrose mixed with molasses, the additional constituents of cane juice. The World Customs Organization (WCO) (2010) defines it as follows: "The product contains only natural anhedral microcrystals, of irregular shape, not visible to the naked eye, which are surrounded by residues of molasses and other constituents of sugar cane".

These additional constituents are reducing sugars (glucose and fructose), minerals, vitamins, organic acids, amino acids, complex or rare sugars, and other trace substances, many probably still unknown.

3.1. Proximate composition

The published proximate composition of NCS, presented in Table 1, is surprisingly scarce as only thirteen publications were identified. Six of these are research papers and seven are official national food composition tables (Bangladesh, Brazil, Central America, Colombia, Japan, Peru, and UK).

Sucrose is the most important component, between 76.55 and 89.48%, followed by reducing sugars (3.69–10.5%) and water (1.5–15.8%). The relatively large range of moisture content is caused by differences in the manufacturing process conditions of this mainly artisanal product. The mineral content (ashes) is relatively high (0.3–3.6%). Protein content ranges between

Table 1
Proximate composition of NCS.[a]

Component %	Mean	SD	Median	Range Min	Range Max	N	References
Carbohydrates	91.28	4.54	91.20	83.90	97.2	6	1, 3, 4, 5, 11, 12
Total sugars	92.08	3.22	92.45	87.5	95.4	6	1, 6, 7, 8, 9, 13
Sucrose	84.49	5.83	85.96	76.55	89.48	4	6, 7, 8, 13
Reducing sugars	7.33	2.81	7.57	3.69	10.5	4	6, 7, 8, 13
Fiber	0.00	0.00	0.00			3	4, 9, 12
Protein	0.64	0.42	0.60	0.37	1.7	11	1, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13
Fats	0.13	0.19	0.10	0.00	0.10	6	1, 3, 4, 9, 11, 12
Moisture	5.00	3.92	3.40	1.5	15.8	11	1, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13
Ash	1.47	0.89	1.35	0.3	3.6	10	3, 4, 5, 6, 7, 8, 9, 11, 12, 13

References: [1]FSA (2002), [2]Guerra and Mujica (2010), [3]ICBF (2014), [4]INCAP (2007), [5]INS (2009), [6]Rodríguez and Segura (2004), [7]Romo et al. (2008), [8]Sahu and Saxena (1994), [9]Shaheen et al. (2013), [10]Singh et al. (2013), [11]Sugiyama University (2004), [12]Unicamp and NEPA (2011), [13]Waheed and Ahmad (2008).
[a] Products identified as un-refined sugar, lump brown sugar, jaggery, panela, rapadura or chancaca

0.37 and 1.7% and fats between 0 and 0.1%. No fiber has been reported. The basic difference between NCS and refined sugar is the presence in the first of reducing sugars and of significant quantities of minerals and other minor constituents. The nutritional and functional difference will then primarily depend on these minor constituents.

The range of values for the components presumably reflect differences between sugarcane varieties, agronomical and process conditions. The relationship of genotype and yield and quality of NCS has been recognized many years ago leading to the creation of collections of sugarcane cultivars for NCS production by agricultural research institutes in countries like Colombia and Venezuela, for example. But these varieties have generally being evaluated only for yield and agro ecological parameters.

3.2. Minerals

The published data on mineral content of NCS, seven scientific papers and seven national food composition tables (Bangladesh, Brazil, Central America, Colombia, Japan, Peru, UK), are presented in Table 2.

There is again relatively wide dispersion of the data in practically all measured elements as shown by large standard deviations. Again, this probably reflects the influence on mineral content of NCS of agronomic conditions such as sugarcane varieties, soil types, fertilization practices, harvesting condition, as well as manufacturing process conditions. Differing analytical methodologies could also play a role. So, for example, the wide range of values for calcium probably reflect the variable use of lime for the clarification of the sugarcane juice in the manufacturing process of NCS. The determination of chromium in NCS calls for special analytical precautions to avoid its loss in the analytical process (Wolf et al., 1974).

The following general conclusions can be drawn. Calcium, chloride and potassium are present in the order of 100 mg/100 g, followed by phosphorus, sodium and magnesium (order of 10 mg/100 g), copper and iron (order of 1 mg/100 g), manganese and zinc (order of 0.1 mg/100 g), and chromium and cobalt (order of 0.01–0.001 mg/100).

3.3. Vitamins

Three scientific publications as well as seven national food composition tables (Bangladesh, Brazil, Colombia, Central America, Japan, Peru, UK) report data on vitamin content of NCS, which is shown in Table 3.

The number of reports on vitamin content of NCS is small leading to large SDs. Eight vitamins are reported in total, three of them by only one source, six by two and five by four or more. There are solid data for the presence of thiamin, riboflavin, niacin, vitamin B5, B6 and for the lack of vitamin B12. The data for vitamin A, folic acid, vitamin C and vitamin D are contradictory and there are insufficient data on vitamin E and K.

3.4. Nutritional significance of mineral and vitamin content of NCS

The nutritional significance of the mineral and vitamin content of NCS is commonly expressed by the proportion of the nutrients required for an adequate diet that is provided by its daily consumption in a given population. The following example is developed for the USA using its Reference Daily Intake (RDI) or Daily Reference Values (DRV) values legally required for food

Table 2
Minerals in NCS[a] (per 100 g).

Mineral	Quantity × 100 g	Mean	SD	Median	Range Min	Range Max	N	References
Calcium	mg	102.62	76.00	92.00	13.70	240.00	13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
Chloride	mg	125.48	127.16	123.30	5.30	250.00	4	1, 8, 10, 13
Cobalt	μg	9.90		9.90	9.90	9.90	1	13
Copper	mg	1.47	2.85	0.52	0.17	8.50	8	1, 2, 7, 8, 9, 10, 11, 12
Chromium	μg	13.95	2.90	13.95	11.90	16.00	2	13, 14
Iodine	μg	0.01		0.01	0.01	0.01	1	3
Iron	mg	4.98	3.48	4.30	1.60	12.50	12	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13,
Magnesium	mg	65.51	30.02	56.50	31.00	120.00	11	1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13
Manganese	mg	0.80	0.54	0.50	0.35	1.66	5	1, 2, 10, 12, 13
Phosphorus	mg	57.54	35.43	72.00	2.00	125.00	11	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12
Potassium	mg	531.26	370.33	479.50	14.05	1100.00	12	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13
Selenium	μg	Tr			0.00	0.00	1	1
Sodium	mg	37.31	20.48	30.88	15.50	79.00	12	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13
Zinc	mg	0.61	0.52	0.49	0.10	1.76	12	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13

References: [1]FSA (2002), [2]Guerra and Mujica (2010), [3]ICBF (2014), [4]INCAP (2007), [5]INS (2009), [6]Rodríguez and Segura (2004), [7]Romo et al. (2008), [8]Sahu and Saxena (1994), [9]Shaheen et al. (2013), [10]Singh et al. (2013), [11]Sugiyama University (2004), [12]Unicamp and NEPA (2011), [13]Waheed and Ahmad (2008), [14]Wolf et al. (1974).
[a] Products identified as un-refined sugar, lump brown sugar, jaggery, panela, rapadura or chancaca.

Table 3
Vitamin content of NCS[a] (in 100 g).

Vitamin	Quantity × 100 g	Mean	SD	Median	Range Min	Range Max	*N*	References
Vit A ER	ER	0.24	0.42	0.00	0.00	0.72	3	3, 5, 7
Vit A	mg	1.90	2.69	1.90	0.00	3.8	2	7, 8,
Beta Carotene	μg	80.75	114.20	80.75	0.00	161.5	2	6, 7
B1 (Thiamin)	mg	0.03	0.02	0.02	0.01	0.05	5	2, 3, 6, 8, 9
B2 (Riboflavin)	mg	0.07	0.03	0.07	0.04	0.11	8	1, 2, 3, 4, 6, 7, 8, 9
B3 (Niacin)	mg	2.14	2.83	0.63	0.08	7	6	2, 3, 4, 6, 8, 9
B5 (Pantothenic acid)	mg	0.70	0.97	0.70	0.01	1.38	2	8, 9
B6 (Pyridoxine)	mg	0.21	0.30	0.04	0.01	0.72	5	2, 3, 8, 9, 10
B9 (Folic acid)	μg	3.33	5.77	0.00	0.00	10.00	3	3, 5, 9
B12 (Cobalamin)	μg	0.00		0.00			2	3, 9
Vit C	mg	4.23	6.41	2.00	0.00	17.6	7	2, 3, 5, 6, 7, 8, 9
Vit D2	mg	2.17	3.75	0.00	0.00	6.5	3	7, 8, 9
Vit E	mg	55.65		55.65	0.00	55.65	2	8, 9
Vit K	μg	0.00		0.00			1	9

References: [1]FSA (2002), [2]ICBF (2014), [3]INCAP (2007), [4]INS (2009), [5]Romo et al. (2008), [6]Sahu and Saxena (1994), [7]Shaheen et al. (2013), [8]Singh et al. (2013), [9]Sugiyama University (2004), [10]Unicamp and NEPA (2011).

[a] Products identified as un-refined sugar, lump brown sugar, jaggery, panela, rapadura or chancaca

labeling purposes in this country (FDA, 2008a). The daily consumption normally used for calculating these requirements in the USA is the "reference amount customarily consumed" (RACC) established for many common foods (FDA, 2008b). Since NCS is little consumed in the USA, no RACC has been determined for it. Instead, the maximum recommended value for added sugar consumption based on a 2000 kcal diet, which is 50 g per day according to Drewnowski (2010), has been used to analyze the nutritional impact of a hypothetical substitution of added refined sugar (sucrose) by NCS. The results of this exercise and its comparison with refined sugar are presented in Table 4.

These results show that NCS could be claimed to be a high source for copper (more than 20% of the RDI) and a good source for iron and manganese (between 10 and 19% of the RDI) according to the U.S. Food and Drugs Administration (FDA) regulations on health claims on food (FDA, 2008b). Additionally, chromium, magnesium, potassium, niacin and vitamin B6 in NCS supply between 5 and 9% of the RDI for these nutrients. In contrast refined sugar practically does not contain minerals and vitamins.

To be considered "healthy" by the FDA a food must not only meet the criteria of not exceeding predefined levels of total fat, saturated fat, cholesterol and sodium, but also provide 10% or more of the DRV of protein, fiber, vitamin A, vitamin C, calcium or iron (Fulgoni et al., 2009). In this sense, NCS is healthy as it does not exceed the above levels and provides more than 10% of daily iron requirements.

4. Antioxidants in NCS

The first reference found on antioxidants in sugarcane and its products is a 1981 paper in Japanese by Yamaguchi and Yamada reporting antioxidant effects in kokuto, the Okinawan NCS, as cited in Nakasone et al. (1996). Since then at least four reports on antioxidant capacity in NCS have been published.

Table 4
Effect of refined sugar and NCS consumption on DRVs of minerals and vitamins.

Components	RDI or DRV[1]	Granulated (refined) sugar		NCS	
		Quantity[2] × 50 g	% of RDI[3]	Quantity[2] × 50 g	% of RDI[3]
Minerals					
Calcium, mg	1000	0.50	0.05	53.46	5.35
Chloride, mg	3400	0.00	0.00	62.66	1.84
Chromium, μg	120	0.00	0.00	6.98	5.81
Copper, mg	**2**	**0.00**	**0.00**	**0.74**	**36.82**
Iodine, μg	150	0.00	0.00	0.01	0.00
Iron, mg	**18**	**0.03**	**0.14**	**2.53**	**14.04**
Magnesium, mg	400	0.00	0.00	32.76	8.19
Manganese, mg	**2**	**0.00**	**0.00**	**0.40**	**19.88**
Phosphorus, mg	1000	0.00	0.00	29.45	2.94
Potassium	3500	1.00	0.03	274.05	7.83
Selenium, μg	70	0.00	0.00		
Sodium	2400	0.50	0.02	18.58	0.77
Zinc, mg	15	0.01	0.03	0.32	2.16
Vitamins					
Folate, μg	400	0.00	0.00	2.50	0.63
Niacin, mg	20	0.00	0.00	1.25	6.27
Pantothenic acid, mg	10	0.00	0.00	0.35	3.48
Riboflavin, mg	1.7	0.01	0.56	0.03	1.82
Thiamin, mg	1.5	0.00	0.00	0.02	1.03
Vitamin A IU	5000	0.00	0.00	0.18	0.00
Vitamin B12, μg	6	0.00	0.00	0.00	0.00
Vitamin B6, mg	2	0.00	0.00	0.13	6.44
Vitamin C, mg	60	0.00	0.00	2.30	3.83
Vitamin K, μg	80	0.00	0.00	0.00	0.00

References: [1]FDA (2008a), [2]Calculated from USDA (2014), [3]Calculated from Tables 2 and 3.

Table 5
Total antioxidant capacity (TAC) of NCS.

Reference	Harish Nayaka et al. (2009)	Inafuku et al. (2007)	Okabe et al. (2009)	Payet et al. (2005)		Phillips et al. (2009)
NCS	Jaggery	Kokuto	Kokuto	Raw brown sugar		Raw Cane Sugar
Method	DPPH	DPPH	DPPH	DPPH	ABTS	FRAP
Measure	μg/ml EC50	μmol Trolox Equivalent/100 g	μmol Trolox Equivalent/100 g	% inhibition		mmol/100 g
Samples	1	3	7	2	2	1
TAC	7.81	396.4	935.67	22.1	47.1–51.3	0.204

4.1. Antioxidant capacity

The antioxidant activity in NCS has been quantified by free radical scavenging assays in five NCS, as shown in Table 5.

Even as these measurements are difficult to compare because of differing methodologies and measuring units it is clear that NCS presents significant antioxidant capacities.

This property of NCS has been attributed to its polyphenols content based on the significant correlation between the total phenolics content of NCS and its antioxidant activity. A correlation coefficient of 0.894 between total phenolics content and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity was found by Payet et al. (2005). Harish Nayaka et al. (2009) calculated the following correlation coefficients between total polyphenols content and bioactivity: Cytoprotective activity ($r = 0.9809$), DPPH radical scavenging activity ($r = 0.9187$); reducing power ($r = 0.9978$); and protection against DNA damage ($r = 0.9814$).

The relative importance of this antioxidant capability has been partially addressed by Phillips et al. (2009), who calculated that the increase in antioxidant content that would result from direct substitution of refined sugar by raw cane sugar, which is centrifuged, or turbinado sugar, which is a coated sugar, for an amount equivalent to the sweetening power of 130 g refined sugar, which was the average daily per capita consumption in the USA for the early 2000s, would be 0.1–0.2 mmol per day. On an absolute basis, this potential increased antioxidant intake would be similar to the contribution of tea or fruit, which are considered high in antioxidants (Phillips et al., 2009). The increase would be much higher if NCS is used rather than raw sugar or turbinado given that these have lost significant amounts of the molasses content. It is clear that replacing refined sugar with NCS can add significantly to the cumulative antioxidant content of the diet.

4.2. Phenolics in NCS

Only three total phenolics content for NCS are reported in the identified literature. Payet et al. determined 25.96 gallic acid equivalent (GAE) mg/100 g of NCS (2005) and Harish Nayaka et al. (2009) 3873 GAE mg/100 g, the difference between them being two orders of magnitude. Inafuku et al. with a different methodology measured 382.3 (+) catechin mg/100 g (Inafuku et al., 2007). These differences probably reflect the use of different methodologies as well as variations between the NCS analyzed.

Since the first report of antioxidant phenolic glycosidic compounds in kokuto (the Okinawan NCS) by Kimura in 1984 (Nakasone et al., 1996), 15 phenolic aglycones in NCS have been reported to date by five groups (Galvez et al., 2008; Harish Nayaka et al., 2009; Nakasone et al., 1996; Payet et al., 2005; Singh et al., 2015), listed in Table 6. Only five of these phenolics have been reported by two or more groups clearly showing the preliminary character of the current knowledge on the micro-composition of NCS.

The same can be said on glycosides. Nineteen phenolic glycosides have been detected in NCS, reported in five publications. The isolation of these compounds has been done with liquid chromatography (LC), mostly HPLC, and the identification using libraries of phenolics or NMR.

4.3. Antioxidants in sugarcane and its products

Phenolic compounds in sugarcane have been traditionally of interest to sugar technologists as one of the causes of color in sugarcane products. Low color in raw sugar, the input for the process to obtain white refined sugar, is a crucial quality criterion for this widely traded product. A large variety of plant pigments and natural colorants have been identified in sugarcane leaves and juice (Paton and Doung, 1992). The cane plant itself supplies primarily low molecular weight plant pigments (flavonoids, chlorophylls, carotenes, xanthophylls and phenolic compounds) which contribute approximately 30% of all raw-sugar color. The rest is provided by high molecular weight colorants many of them product of chemical transformations during sugar processing (Lindeman and O'Shea, 2004).

Interest in the constituents of sugarcane and its product has been rekindled by the recognition that sugarcane juice and some of its products, particularly un-refined sugars, less-refined sugars and molasses, have antioxidant capacities. Since 2006, at least eight reports have been published on antioxidant activity in sugarcane leaves, other parts of the plant, sugarcane juice and molasses (Abbas et al., 2013, 2014; Colombo et al., 2009; Duarte-Almeida et al., 2011; Feng et al., 2014; Harish Nayaka et al., 2008; Payet et al., 2006; Vila et al., 2008). This activity has been quantified by radical scavenging activity assays and others, like DPPH, ferric reducing ability of plasma (FRAP), b-carotene/linoleic acid and phosphomolybdenum reduction. All of these studies agree on the relatively high antioxidant activity of sugarcane, sugarcane juice and molasses and on their potential functional importance. Antioxidant activity is significantly correlated with total phenolic content as measured by the Folin-Ciocalteu assay (Harish Nayaka et al., 2009; Payet et al., 2006). Other studies identify individual phenolic antioxidant compounds in the sugarcane plant and sugarcane juice (Abbas et al., 2013, 2014; Duarte-Almeida et al., 2011; Payet et al., 2006; Vila et al., 2008).

The origin of the phenolic compounds in NCS is its presence in the leaves, stalks and juice of the sugarcane plant both in free or bonded forms, as well as in the manufacturing process of sugarcane juice and NCS (Manohar et al., 2014). Enzymatic browning due to polyphenol oxidase, action of glucosidases and Maillard reactions plays all a role in the generation of phenolics.

Nakasone et al. reported that phenolic compounds isolated from sugarcane juice were glycosides and not the free phenolic compounds corresponding to aglycones, concluding that phenolic compounds in NCS were derived from the phenolic glycosides present in sugarcane juice (Nakasone et al., 2005). Payet et al. (2005) postulate that some of the phenolic acids they found in NCS, and some also found by Harish Nayaka et al. (2009), are the products of the degradation of hydroxycinnamic acids derivatives in sugarcane juice. Duarte-Almeida et al. (2011) compared the content of phenolic acids in culms and sugarcane juice concluding that enzymatic processes during the extraction of the juice promote the methylation of caffeic acid giving rise to ferulic acid

Table 6
List of phenolics detected in NCS (number of reports).

Name	No. of reports	References
Flavone aglycones		
3-Hydroxy-1-(4-hydroxy-3.5-dimethoxyphenyl)-1-propanol	1	Nakasone et al. (1996)
4-Hydroxyphenylacetic acid	1	Harish Nayaka et al. (2009)
Benzoic acid	1	Payet et al. (2005)
Chlorogenic acid	1	Galvez et al. (2008)
Coniferyl alcohol	1	Nakasone et al. (1996)
Ferulic acid	2	Payet et al. (2005), Singh et al. (2015)
Gallic acid	1	Harish Nayaka et al. (2009)
Gentisic acid	1	Harish Nayaka et al. (2009)
p-Coumaric acid	3	Harish Nayaka et al. (2009), Payet et al. (2005), Singh et al. (2015)
p-Hydroxy benzoic acid	2	Payet et al. (2005), Singh et al. (2015)
Protocatechuic acid	1	Harish Nayaka et al. (2009)
Synapil alcohol	1	Nakasone et al. (1996)
Syringaresinol	1	Nakasone et al. (1996)
Syringic acid	3	Harish Nayaka et al. (2009), Payet et al. (2005), Singh et al. (2015)
Vanillic acid–vanillin	3	Harish Nayaka et al. (2009), Payet et al. (2005), Singh et al. (2015)
Glycosides		
Medioresinol	1	Nakasone et al. (1996)
3-Hydroxy-4,5-dimethoxyphenyl-β-D-glucopyranoside	1	Takara et al. (2002)
β-D-Fructofuranosyl-α-D-(6-vanilloyl)-glucopyranoside	1	Takara et al. (2002)
β-D-Fructofuranosyl-α-D-(6-syringil)-glucopyranoside	1	Takara et al. (2002)
3-Hydroxy-1-(4-hydroxy-3-methoxyphenil)-2-[4-(3-hydroxy-1(E)propenyl)2-methoxy phenoxy]propyl-β-D-glucopyranoside	1	Takara et al. (2002)
3-Hydroxy-1-(4-hydroxy-3-methoxyphenyl)-2-[4-(3-hydroxy-(E)-propenyl)2,6-dimethoxyphenoxy]propyl-β-D-glucopyranoside	1	Takara et al. (2002)
Dehydrodiconiferyl alcohol-9′-β-D-glucopyranoside	1	Takara et al. (2002)
4-[Ethane-2-[3-(4-hydroxy-3-methoxyphenyl)-2-propen]oxy]-2-dimethoxy-phenyl-β-D-glucopyranoside	1	Takara et al. (2002)
4-[Ethane-2-[3-(4-hydroxy-3-methoxyphenyl)-2-propen]oxy]-2-methoxy-phenyl-β-D-glucopyranoside	1	Takara et al. (2002)
4-(β-D-Glucopyranosyloxy)-3,5-dimethoxyphenyl-propanone	1	Takara et al. (2003)
3-[5-[(Threo)2,3-dihydro-2-(4-hydroxy-3-methoxyphenyl)-3-hydroxymethyl-7-methoxybenzofurany]]-propanoic acid	1	Takara et al. (2003)
2-[4-(3-Hydroxy-1-propenyl)-2,6-dimethoxyphenoxy]-3-hydroxy-3-(4-hydroxy-3,5-dimethoxyphenyl)propyl-β-D-glucopyranoside	1	Takara et al. (2003)
4-[(Erythro)2,3-dihydro-3(hydroxymethyl)-5-(3-hydropropyl)-7-methoxy-2-benzofuranyl]-2,6-dimethoxyphenyl-β-glucopyranoside	1	Takara et al. (2003)
9-O-β-D-Xylopyranoside of icariol A_2	1	Takara et al. (2003)
3-Hydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)-2-[4-(3-hydroxy-1-(E)-propenyl)-2,6-dimethoxyphenyl]propyl-β-D-glucopyranoside3-hydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)-2-[4-(3-hydroxy-1-(E)-propenyl)-2,6-dimethoxyphenyl]propyl-β-D-glucopyranoside	1	Takara et al. (2002)
3,4-Dimethoxyphenyl-β-D-glucoside	2	Kimura et al. (1984), Matsuura et al. (1990)
3,4,6-Trimethoxyphenyl-β-D-glucoside	1	Kimura et al. (1984)
3,4-Methoxy-4-hydroxyphenil-β-D-glucopyranoside (tachioside)	1	Matsuura et al. (1990)
4-Hydroxy-phenil-β-D-glucopyranoside (arbutin)	1	Matsuura et al. (1990)

in the juice. This is confirmed by the fact that no caffeic acid has been found by the authors analyzing phenolics content in NCS (see Table 6).

Polyphenols are highly unstable species that undergo numerous reactions in the course of food processing and storage principally because of enzymatic oxidation (Cheynier, 2005). But their presence in NCS shows that many are stable, probably because of the inactivation of enzymes by the heat treatment used in its manufacture.

5. Other relevant components

Other components reported in NCS are organic acids, amino acids, aldehydes, alcohols and various volatile compounds.

5.1. Organic acids

Six to seven organic acids were found by Wada (1993) in NCS, 32–37% of their total quantity being aconitic acid. Succinic and acetic acid decreased greatly during the manufacturing process of NCS. Aconitic acid and malic acid were also reported in NCS kokuto by Nakasone et al. (2000) and Nakasone (2004). Aconitic acid was detected as a mayor fraction of the nondialyzable components in raw cane sugars by Godshall et al. (2001).

5.2. Amino acids

More than twenty amino acids have been identified in NCS kokuto, 70–80% of them being Asp, Asn, Glu and Gln (Nakasone et al., 1990). It is suggested that amino acids play an important role in the formation of aroma in kokuto. This agrees with the work by Wada (1993) who found that all amino acids, with exception of Glu, decreased during the manufacturing process. The presence of amino acids has been confirmed indirectly when acrylamide was detected in NCS (Hoenicke and Gatermann, 2005). This substance is suspected to be carcinogenic and forms when carbohydrates and the amino acid asparagine are subjected to high temperatures as during baking, frying and roasting (Dybing et al., 2005).

5.3. Rare or complex sugars

At least two rare or complex sugars with potential functional roles have been identified in NCS. D-Psicose, a C-3 epimer of D-fructose, is one of them, present in small quantities in commercial carbohydrate foods or agricultural products. It has 70% of the sweetness of sucrose but no calories (Cheung et al., 2012). NCS has been found to contain relatively high amounts of it, the same as in traditional Japanese food prepared with NCS kokuto. The quantities are closely related to NCS concentration, heating times and temperature during manufacturing process suggesting this sugar is formed by a non-enzymatic reaction (Oshima et al., 2006). In animal models it has been claimed that D-psicose has anti-hyperglycemic and anti-atherosclerosis effects (Cheung et al., 2012). This is controversial as other research has reported that supplemental D-psicose has no anti-diabetic effects in rats (Matsuo and Izumori, 2004).

Cycloisomaltooligosaccharides or cyclodextrans are water soluble oligosaccharides which have been found to strongly inhibit glucansucrase activity of mutant streptococci, therefore expected to have cariostatic activity (Funane et al., 2007). At least three cyclodextrans have been detected in NCS kokuto, suggesting that they are safe for humans as they have been exposed to them for a long time (Tokasiki et al., 2007).

5.4. Alcohols – waxes

Long-chain alcohols (mainly octacosanol) and aldehydes were found in organic solvent extracts of NCS kokuto (Asikin et al., 2008), their content depending on the manufacturing process of the NCS. Open-pan boiling yielded high octacosanol and low aldehydes content, the latter being heat labile. Filtering and vacuum pan concentration produced lower amounts of waxes. These compounds have been credited with blood lipid lowering activity giving rise to commercial offers of sugar cane derived food supplements, claims that have not been independently replicated (Berthold et al., 2000).

5.5. Volatile compounds

Thirty volatile compounds have been identified in NCS by gas chromatography coupled to a mass spectrometer (GC–MS), most being furans, furanones, 2-acetylpyrrole or 5-(hydroxymethyl) furfural, produced by the thermal degradation of carbohydrates via caramelization or Maillard reactions during the manufacturing process (Payet et al., 2005). 5-(Hydroxymethyl) furfural, together with 5-hydroxymethyl-2-furoic acid and an unidentified third component, have been found to be bioactive low-molecular-weight Maillard reaction product (MRP) in model glucose-lysine systems, with marked intracellular antioxidant activity and nitric oxide and interleukin-8 (IL-8) inhibitory activities compared to other MRPs (Kitts et al., 2012). Glucose-amino acids Maillard reactions also produce different aromas depending on the amino acid present (Wong et al., 2008).

5.6. Nanoparticles

The presence of carbon nanoparticles (CNP) in different carbohydrate based food caramels, and also in NCS jaggery, has been reported. Excitation tunable photoluminescence was observed. This suggests potential usefulness of these CNP for various biological applications as the sources of extraction are common food items and therefore can be considered safe for human consumption (Md Palashuddin et al., 2012).

5.7. Contaminants and toxins

Toxic trace elements arsenic, bromine, mercury, antimony and selenium have been detected with high performance anion exchange chromatography with conductivity detector (HPAEC-CD) in NCS jaggery in Pakistan (Waheed et al., 2009). Their content is well within human tolerance levels. Also polycyclic aromatic hydrocarbons (PAHs), contaminants produced in the burning and/or processing of sugarcane, have been found in 80% of examined samples of NCS in Brazil using HPLC-FL (Silva et al., 2011). The level ranged from 0.07 to 4.03 $\mu g\ kg^{-1}$ (no safety levels have been established for PAHs). On the other hand, HPAEC-CD showed that the content of some inorganic anions and organic acids may be used as an important criterion of the quality of commercial NCS (Wojtczak et al., 2013).

As pointed out before, acrylamide has been found in NCS (Hoenicke and Gatermann, 2005). It is a product of the manufacturing process and its formation can be reduced or avoided by controlling some process parameters (Dybing et al., 2005).

6. Health effects of NCS

A previous review identified 27 reports of a wide range of health effects of NCS or its extracts in in vitro or animal research models (Jaffé, 2012b). Only two papers report trials with humans. The bioactive compounds proposed as possible causes are minerals (Fe, Cr and P in the form of phosphates) and phenolic compounds. In two cases specific bioactive polyphenols have been identified.

The strongest evidence for a health effect of NCS to date is the increased formation of hemoglobin and red blood cells caused by its iron content, reported in humans by at least two papers. The cause and effect relationship between iron consumption and hemoglobin and red blood cells increase has been accepted by the European Food Safety Agency and therefore claims in this sense are permitted in Europe (EFSA, 2014). The statistically significant increase in hemoglobin in preschool children after consumption of a NCS fortified beverage has been demonstrated by a Brazilian group (Arcanjo et al., 2009) leading them to propose to consider NCS a food fortificant (Arcanjo et al., 2013).

7. Concluding remarks

The data reviewed above permit to conclude that NCS is a complex food in terms of the wide variety of bioactive components it contains. These are present in relatively high quantities, to be expected because of the 100-fold concentration factor between the sugarcane plant and the final product.

The content of the components of NCS presents large variations within the same product in one country or region and between differently named products of different countries. It is important that the reasons of these variations are better understood so to permit standardization and optimization for specific components. Particularly important outstanding issues in the better characterization of NCS are the presence and content of vitamins and antioxidants given their potential health effects. Another weakness is the understanding of the origins of the bioactive compounds in NCS and its chemical changes during manufacturing and storage which is currently sketchy and incomplete.

The combination of many bioactive compounds in relatively high quantities in NCS should have sparked much higher scientific, nutritional and technological interest than the current scarcity of publications on its chemical composition and physiological effects suggests. The wider recognition and acceptance of the nutritional and functional potential of NCS will need the full characterization of its nutritional and antioxidant capabilities and effects. This could turn this currently marginal food into a mainstream natural sweetener, a widely used food ingredient and a base for a range of nutraceutical and medicinal products.

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