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Thermal treatments affected to quality attributes of *Solanum procumbens* Lour.

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Abstract

Solanum procumbens Lour. has been distributed in many places of Vietnam and tropical regions. Its extract includes numerous therapeutic properties in pharmacopeia. This research evaluates the possibility of dried herbal tea production from this valuable phytochemical source. Different variables of vapor steaming, convective drying, and roasting are verified to monitor the degradation of total phenolic content, total flavonoid content, diphenylpicrylhydrazyl (DPPH) free radical scavenging, ferric reducing antioxidant power (FRAP) and overall acceptance in *S. procumbens*. Results show that *S. procumbens* should be blanched by steaming within 45 s as primary treatment, dehydrated at 45/7.0 °C/hrs, roasted at 150/20 °C/min to preserve the most antioxidant constituents with total phenolic content, total flavonoid content, half inhibitory concentration (IC50) of DPPH, FRAP as well as the highest organoleptic value. High retention of total phenolic content, total flavonoid content, antioxidant power as well as high sensory score of the dried *S. procumbens* herbal tea plays an important decision in consumer preference and acceptance. All these processing steps can be performed in simple handling with universal available equipments like steaming oven, convective drier and roasting oven. Findings in this study will be useful data for house-hold scale production.

Keywords

antioxidant, drying, herbal tea, roasting, steaming, *Solanum procumbens*

Introduction

Solanum procumbens Lour. Is a well-known in folk medicine against different chronic ailments due to its diversified phytochemical constituents like phenolics, flavonoids, glycoalkaloids and coumarins (1). Different biological properties such as antimicrobial, anti-inflammatory, cytotoxic, antifungal, antiviral and antioxidant potential has been reported on *Solanum* sp. (2). It has been especially demonstrated to be effective in treating arthritis, cancer and hepatitis (3). Numerous chemical substances have been discovered in this valuable plant including indole-3-carbaldehyde, ziganein, vanillic acid, benzoic acid, 4-hydroxybenzaldehyde and salicylic acid (4). The most important compound has been investigated namely solacanin with excellent α-glucosidase inhibitory capacity (5). Apart from natural collection, it has also been propagated via seedling production to satisfy planting and processing demands.

Pretreatment before dehydration is very necessary to high-quality dehydrated plants, limited drying duration and minimal energy requirement

(6). Steaming has shown numerous advantages for herbal dehydration. The most advantage of steaming is limitation of discoloration. The steamed parsley gives 30% more quickly dehydrating speed and 72% energy consuming reduction. The dehydrated parsley has better lutein content and excellent color sustain (7). Thermal pre-treatment induces higher chlorophyll sustain and better rehydration power of the dehydrated coriander leaves compared to control ones (8). However, steaming induces a great reduction of antioxidant potentials in herbal plants (9). Convective drying is one of the most basic, simple and efficient methods in food processing and preservation. It has been commonly utilized in non-tropical regions where sunlight is not enough. Dehydrating temperature, dehydrating duration and air speed have been totally controlled (10). Dehydration of herb by convective drying is mostly affected by different drying variables like air speed, temperature and moisture gradient (11). To achieve the best processing efficiency and capacity, they should be optimal with high drying load in short processing time with minor impact to the thermal sensitive constituents in medicinal plants. It is very important to preserve value-added substances and sensory quality attributes in raw medicinal material during drying (12). There has been a positive correlation between air drying temperature and volatile removal, especially with lower boiling point (13). Under thermal treatment, moisture is removed out of fresh materials inducing to solid-dehydrated products (14). There have been two types of moisture including unbounded and bound water. Unbounded water is easily escaped from food matrix by diffusion, migration and evaporation (15). Moisture removal out of fresh materials will facilitate for inhibition of microbial growth and proliferation; enzyme activity decreased; overall acceptance either increased or decreased leading to extension of product stability (16). High temperature of convective dehydration results to major decomposition of herbal flavors and pigments (17). High shrinkage on the finished product is one of the main restrictions of convective drying (10). Dehydration will be a smart strategy to decrease weight and volume thus facilitating for packaging, preservation and distribution. Due to low moisture content, the dried plant has better resistance to microbial invasion and enzymatic reaction with an extended shelf life (18). Low energy consumption during convective drying is also very important to reduce production cost towards sustainable production with minor environmental impact.

Green tea has been obtained from drying and roasting meanwhile black tea has been normally achieved from fermentation (19). Roasting has been also an important step to accomplish the dried herbal tea production. Roasting has been commonly applied in herbal tea dehydration to avoid any excess pharmacological reactions, mild side effects, alter functional characteristics and cover bad behaviors (20). Roasting greatly improves the specific flavors of herbal tea (21). Maillard reaction products have been formed via roasting (22). Roasting strongly contributes to consumer's acceptance apart from physicochemical and antioxidant attributes of herbal tea (23). Roasting creates a significant impact to bioactive components like phenolics, flavonoids, vitamins. Roasting has been demonstrated causing partially loss of chlorogenic acids (24). The bioactive degradation by thermal roasting is totally relied on temperature, time and heating ways (25). Herbal tea production can be processed from various thermal treatments in different ways from pilot model by simple techniques to huge industrial scale by innovative technologies. Modern treatment methods like steam explosion, shockwave have drawn a great attention. An investigation enable to produce underwater high-voltage discharges (3.5 kV) combined with aqueous plasma expansion has been conducted. The degree of phytomass demolition induced by infusion of the pressure shockwaves (50–60 MPa) accompanied by this extension has been evaluated applying gas adsorption method. The kinetics of the outer layer region and the micropore dimension on different pretreatment periods of corn silage and sunflower seeds has been verified with reliable analytical procedures. The multiple accelerates on the reaction layer have scaled up to a 15% rising in amassed methane emission, which has itself evolved in the overall increment of the anaerobic fermentation. Exploitation of the sunflower seeds permits up to 45% higher oil volume applying the similar active pressure (26). Innovation of new methods taking by-product without any supplemental power or minimal catalysts is a beginning basic for inducing sustainable. The intricate application of greenhouse balances has been examined on an industrial scale. Minimal power manufactured by the process has been utilized to perform the technology, due to diversified thermal recirculation and abundant methane volume. Propagation of labile carbon in relation to available nitrogen, methane volume and the production of preventers have been examined thoroughly. These findings have eliminated different negative behaviors about the proportion of carbon to nitrogen and emphasize the function of the availability of carbon in phyto-mass usage (27).

The antioxidant activity participates in retardation of chain initiation, degradation of peroxides and limitation of ongoing hydrogen abstraction, free radical scavenging, reducing capacity and capturing of transition-metal ion catalysts. DPPH is the free radical and collected an electron or hydrogen radical to form a sustainable diamagnetic molecule. FRAP serves reducing power as a key indicator of its antioxidant activity. In order to utilize raw *Solanum procumbens* as a valuable material for herbal tea production at house-hold scale, purpose of our study focuses on the impact of different thermal treatments such as vapor steaming, convective drying and roasting to antioxidant and organoleptic properties of herbal tea from *Solanum procumbens*. Adaptable experiments with universal available equipments like steaming oven, convective drier and roasting oven were applicable in this research. Therefore, it is absolutely feasible to implement at small and medium scale production; there is no need to rely on hi-tech equipments or high capital investment that will be a promising potential for start-up. This research finding will better preserve phytochemical constituents in *Solanum procumbens*.

Materials and Methods

Solanum procumbens has been planted and collected since 2019 in Binh Phuoc province, Vietnam. Before planting, put the seeds in water for about 40 °C and soak for 15 min, the purpose of soaking in warm water is to quickly germinate. The seeds that float to the surface of the water are removed because these are flat seeds. The trees are planted in the rainy season. The density of row size is 50 × 50 cm, plant spacing is 50 × 50 cm. When planting, remove the potting bag to reach the tree in the middle of the hole, straighten the tree, fill it with soil and compact the soil at the base, after planting, water the plants a little to avoid water withdrawal. Water is necessary to provide enough water for the tree, especially in the dry season, when the fruit is growing and when the fruit is ready to ripen. The trees with good care after only 4 months can be harvested by collecting the stem, roots. It is free from insect, disease and pesticide. It was washed under clean water to remove foreign matters. Chemical reagents such as Folin-Ciocalteu phenol, DPPH (2, 2-Diphenyl picrylhydrazyl) reagent, FRAP reagent, gallic acid, catechin reagent, sodium carbonate, methanol $FeCl_3.3H_2O$ are all analytical grade purchased from Fluka (Switzerland) and Sigma Aldrich (USA). Lab apparatus and equipments include test tube, cylinder, beaker, Erlenmeyer flask, vortex mixer, steaming oven, convective drier, roasting oven, UV-Vis spectrophotometer.

Researching method

Solanum procumbens is steam-blanched at 110 °C in different duration (15, 30, 45, 60 and 75s), dehydrated by convective drying (35/8.0, 40/7.5, 45/7.0, 50/6.5 and 55/6.0 °C/hrs), roasting (140/30, 145/25, 150/20, 155/15 and 160/10 °C/min). In each experiment, samples have been taken to determine total phenolic content, total flavonoid content, DPPH free radical scavenging, FRAP ferric reducing antioxidant and overall acceptance (28).

Total phenolic content or TPC (mg GAE/100 g) is estimated by Folin-Ciocalteu reagent assay (29). Aluminum chloride colorimetric method is applied for quantification of total flavonoid content or TFC (mg QE/100 g) (30). DPPH free radical scavenging (IC_{50}, µg/ml) is estimated using UV-VIS spectrophotometric method at wavelength 517 nm (31). FRAP (mg ascorbic acid equivalents/ml) ferric reducing antioxidant has been defined as power inreducing of Fe^{+3} to Fe^{+2} by an antioxidant using the method described by Benzie and Strain (32). Overall acceptance is determined by a group of specialists using 9-point Hedonic scale.

Statistical analysis

The experiments are run in triplicate with different groups of samples. The data are presented as mean±standard deviation. Statistical analysis is performed by the Statgraphics Centurion version XVI.

Results and Discussion

The effect of steaming at 110 °C in different times (s) to antioxidant and organoleptic properties of raw and steamed *Solanum procumbens* is clearly presented in Table 1. It's obviously noticed that the raw *S. procumbens* contains a great amount of total phenolic content (243.18±0.24 mg GAE/100 g) and total flavonoid content (169.73±0.09 mg QE/100 g) contributing to an excellent antioxidant power with IC_{50} of DPPH (11.52±0.04 µg/ml), FRAP (0.97±0.03 mg AAE/ml). The steaming at 110 °C for 15 -45s causes a slight decomposition of total phenolic content (194.53±0.15 down to 141.12±0.23 mg GAE/100 g), total flavonoid content (112.08±0.10 down to 79.42±0.06 mg QE/100 g), IC_{50} of DPPH (17.84±0.03 up to 19.04±0.03 µg/ml), FRAP (0.73±0.01 down to 0.51±0.04 mg AAE/ml). However, extension of steaming time from 60-75s causes a significant reduction of total phenolic content (80.09±0.12 down to 47.84±0.09 mg GAE/100 g), total flavonoid content (31.03±0.13 down to 12.08±0.05 mg QE/100 g), IC_{50} of DPPH (25.19±0.02 up to 33.79±0.00 µg/ml), FRAP (0.23±0.01 down to 0.09±0.03 mg AAE/ml). The highest overall acceptance (7.07±0.02) is noticed at sample steamed at 110°C for 45 s while the lowest sensory score (4.32±0.02) is recorded at sample steamed at 110 °C for 75 s. Therefore steaming at 110 °C for 45 s is selected for further experiments. Blanching/steaming has been recommended as pre-treatment for pepper before convective drying to control enzymatic browning and reduce drying duration. Dried pepper will obtain better pungency, flavor and color by this steaming in advance of the official convective dehydration (33). Asparagus blanched in hot water before convective drying results tobetter reconstitution and fine structure (34). The steamed dehydrated basil leaves reveal higher color retention (35). Roselle calyx steamed at 115 °C for 30 seconds preserves the highest total phenolic and flavonoid content (20). *Polyscias fruticosa* steamed in vapor for 30 seconds results to better retention of total phenolic, total flavonoid, DPPHradical-scavenging ability and FRAP ferric reducing antioxidant power (36).

The effect of convective drying at different conditions (35/8.0, 40/7.5, 45/7.0, 50/6.5 and 55/6.0, °C/hrs) to antioxidant and organoleptic properties of steamed and dried *S. procumbens* has been thoroughly elaborated in Table 2. It's clearly realized that the steamed *S. procumbens* contains a remarkable amount of total phenolic content (141.12±0.23 mg GAE/100 g) and total flavonoid content (79.42±0.06 mg QE/100 g) contributing to a high antioxidant power with IC_{50} of DPPH (19.04±0.03 µg/ml), FRAP (0.51±0.04 mg AAE/ml) as well as overall acceptance (7.07±0.02). The convective drying at 45/7.0 (°C/hrs) causes a slight degradation of total phenolic content (132.41±0.06 mg GAE/100 g), total flavonoid content (71.24±0.02 mg QE/100 g), IC_{50} of DPPH (19.67±0.01 µg/ml), FRAP (0.46±0.01 mg AAE/ml) and overall acceptance (8.12±0.03). Therefore convective drying at 45/7.0 (°C/hrs) is selected for further experiments. In another report, inhibitory capacity of *S. procumbens* has been noticed at IC_{50} values of 221.5 µM (5). The long-standing duration of hot air contact the more color depression is (14). Temperature at 50 °C has been recommended for convective drying of okra to maintain nutritional proximate, preserve bioactive ingredients and stabilize organoleptic attributes (37). Convec-

Table 1. Effect of steaming at 110 °C in different times (s) to antioxidant and organoleptic properties of raw and steamed *Solanum procumbens.*

Steaming time (s)	Raw	15	30	45	60	75
TPC (mg GAE/100 g)	243.18±0.24[a]	194.53±0.15[b]	167.41±0.18[bc]	141.12±0.23[c]	80.09±0.12[d]	47.84±0.09[e]
TFC (mg QE/100 g)	169.73±0.09[a]	112.08±0.10[b]	93.59±0.07[bc]	79.42±0.06[c]	31.03±0.13[d]	12.08±0.05[e]
DPPH (IC_{50}, µg/ml)	11.52±0.04[e]	17.84±0.03[d]	18.65±0.01[cd]	19.04±0.03[c]	25.19±0.02[b]	33.79±0.00[a]
FRAP (mg AAE/ml)	0.97±0.03[a]	0.73±0.01[b]	0.65±0.02[bc]	0.51±0.04[c]	0.23±0.01[d]	0.09±0.03[e]
Overall acceptance (score)	6.51±0.01[b]	5.30±0.00[d]	5.63±0.03[c]	7.07±0.02[a]	5.49±0.01[cd]	4.32±0.02[e]

tive dehydration with a quick drying speed at the initial of the dehydration may induce to rigid structure and inferior reconstitution ability (34). For herbal tea, overall acceptance is also an important quality criteria as it's greatly affected to consumer demand (11). A remarkable change of color has been clearly noticed on *S. officinalis* when air drying temperature accelerated 50-55 °C (38). A low air drying temperature around 30 °C has not been encouraged owing to slow drying rate leading to low production capacity and more chance of fungi proliferation (39). Convective dehydration is used hot air as drying agent to exchange moisture between sample and hot air current in the drying cabinet. The most advantages of convective dehydration can be easily recognized as simple equipment, easy manipulation, adequate expense and long stability. However, this drying method also reveals several backwards such as long drying duration, oxidation of bioactive components, darkening color, off flavor and rough surface on the dehydrated products (40). Convective drying creates finished samples with modified structural characteristics such as high hardening, high bulk density, more shrinkage, dense structure, low porosity. A great degradation of antioxidant activity, volatile removal and an accumulation of more yield of essential oil have been noticed on this dehydration method. Convective drying temperatures have been recommended at 50–70 °C to protect flavonoid and ascorbic acid in jujube (41); 65–73 °C to maintain flavonoids and phenolics in avocado (42); 50–70 °C for pomegranate (43), 50–60 °C for strawberry (44), 55–65 °C for cauliflower (45) to stabilize anthocyanin and ascorbic acid contents. In convective dehydration, the damage of antioxidant property derives from the raw material contact to oxygen. In an oxygen-limited space, degradation of phenolic substances and antioxidant attributes can be minimized by low temperature in convective drying (46). In order to preserve the highest total polyphenolic content, DPPH and FRAP, the convective drying temperatures have been recommended at 40 °C for date fiber (47), 50–70 °C for pomegranate (48), 50–90 °C forblackcurrant (49), 50–70 °C for jujube (41), 40–60 °C for cacao bean (50). Low dehydrating temperatures (40–60 °C) have been highly recommended for the protection of thermal-bioactive substances in the dehydrated herbs (51). Dehydrating temperature over 60 °C induces a major damage to almost volatile constituents in the dehydrated herbs (52). Moringa oleifera leaves should be dehydrated by convective drying at 40 °C to keep its pigment (53). Accelerating the dehydrating temperature results to lower antioxidant power in rosemary, meadowsweet, motherwort, willow and peppermint (54, 55). Roselle calyx dried at 35 °C under pressure -0.6 bar effectively preserves the highest total phenolic and flavonoid content (20). Polyscias fruticosa dried by convective drying at 45 °C for 6 hrs results to better retention of total phenolic, total flavonoid, DPPH radical-scavenging ability and FRAP ferric reducing antioxidant power (36).

Table 2. Effect of convective drying in different condition (°C/hrs) to antioxidant and organoleptic properties of steamed and dried *S. procumbens.*

Drying (°C/hrs)	Steamed	35/8.0	40/7.5	45/7.0	50/6.5	55/6.0
TPC (mg GAE/100 g)	141.12±0.23[a]	111.54±0.07[c]	128.13±0.05[b]	132.41±0.06[ab]	120.08±0.04[bc]	93.15±0.05[d]
TFC (mg QE/100 g)	79.42±0.06[a]	51.04±0.03[c]	65.23±0.04[b]	71.24±0.02[ab]	59.82±0.03[bc]	30.74±0.02[d]
DPPH (IC_{50}, µg/ml)	19.04±0.03[d]	21.89±0.01[b]	20.58±0.00[c]	19.67±0.01[cd]	21.05±0.00[bc]	24.72±0.03[a]
FRAP (mg AAE/ml)	0.51±0.04[a]	0.31±0.00[c]	0.41±0.03[b]	0.46±0.01[ab]	0.36±0.02[bc]	0.16±0.01[d]
Overall acceptance (score)	7.07±0.02[c]	7.31±0.02[bc]	7.84±0.01[ab]	8.12±0.03[a]	7.57±0.02[b]	6.11±0.00[d]

The effect of roasting at different conditions (140/30, 145/25, 150/20, 155/15 and 160/10 °C/min) to antioxidant and organoleptic properties of dried and roasted Solanum procumbens has been definitely shown in Table 3. It is rather easily found that roasting causes significant difference of antioxidant and organoleptic attributes of herbal tea. The dried Solanum procumbens contains a fair amount of total phenolic content (132.41±0.06 mg GAE/100 g) and total flavonoid content (71.24±0.02 mg QE/100 g) contributing to a proper antioxidant power with IC_{50} of DPPH (19.67±0.01 µg/ml), FRAP (0.46±0.01 mg AAE/ml) and overall acceptance (8.12±0.03). The roasting at 150/20 (°C/min) causes a slight degradation of total phenolic content (124.15±0.04 mg GAE/100 g), total flavonoid content (54.12±0.03 mg QE/100 g), IC_{50} of DPPH (20.14±0.02 µg/ml), FRAP (0.40±0.00 mg AAE/ml); meanwhile overall acceptance has a great improvement (8.96±0.01). Therefore roasting at 150/20 (°C/min) can be applied for processing herbal tea from Solanum procumbens. Retention of bioactive components in

Table 3. Effect of roasting in different condition (°C/min) to antioxidant and organoleptic properties of dried and roasted *Solanum procumbens*.

Roasting (°C/min)	Dried	140/30	145/25	150/20	155/15	160/10
TPC (mg GAE/100 g)	132.41±0.06[a]	100.13±0.04[c]	117.22±0.03[b]	124.15±0.04[ab]	108.41±0.03[bc]	73.18±0.02[d]
TFC (mg QE/100 g)	71.24±0.02[a]	30.42±0.04[c]	48.38±0.01[b]	54.12±0.03[ab]	39.17±0.02[bc]	18.47±0.01[d]
DPPH (IC_{50}, µg/ml)	19.67±0.01[d]	22.58±0.00[b]	20.91±0.03[c]	20.14±0.02[cd]	21.74±0.01[bc]	25.92±0.00[a]
FRAP (mg AAE/ml)	0.46±0.01[a]	0.21±0.03[c]	0.32±0.01[b]	0.40±0.00[ab]	0.27±0.03[bc]	0.09±0.02[d]
Overall acceptance (score)	8.12±0.03[c]	7.29±0.00[bc]	8.61±0.03[ab]	8.96±0.01[a]	8.42±0.00[b]	7.05±0.03[d]

Values are the mean of three replications; Mean values in row followed by the same letter/s are not differed significantly (α = P=0.05)

Solanum procumbens will also contribute to humanity healthy benefit via daily consumption of this valuable herb. Three extents of roasting involve in the flavor, color and appearance of herbal tea, including roasting until brown, charred and carbonized (56). Time and temperature of roasting strictly correlate with moisture reduction and discoloration (57). Roasting induces a mild bitter taste and a slight green properties for herbal tea. This treatment eliminates a significant amount of tannin causing astringent feeling (58). Roasting barley at 280 °C in 20s reduces 8% of phenolic content (25). DPPH of spearmint has been significantly decreased 60% after roasting (59). There is no significant difference of Ferric reducing antioxidant potential assay under roasting on black tea (60). Dried roselle calyx roasted at 135 °C for 9 min effectively preserves the highest total phenolic and flavonoid content (20). Polyscias fruticosa roasted at 135/9 (°C/min) results to better retention of total phenolic, total flavonoid, DPPH radical-scavenging ability and FRAP ferric reducing antioxidant power (36). The most advantages of this research are the exploitation of the universal available equipments, there is no need to use hi-tech equipments to save investment capital. This is particularly benefit for small and medium house-hold scale production. However, limitations in utilization of steaming oven, convective drier, roasting oven in this research are quite long time, case hardening and slight decomposition of total phenolic content, total flavonoid content, DPPH, FRAP and minor degradation of overall acceptance.

Conclusion

Solanum procumbens Lour. contains numerous bioactive ingredients beneficial to human health. This research has successfully verified the impact of steaming, drying and roasting to antioxidant and organoleptic properties of steam-dry-roasted herbal tea from *S. procumbens*. The most total phenolic content, total flavonoid content, DPPH free radical scavenging, FRAP ferric reducing antioxidant and overall acceptance will be achieved by steaming at high temperature (100 °C) in short duration (45s), drying at intermediate temperature in a proper time (45/7.0 °C/hrs), roasting at high temperature in short time (150/20 °C/min). This research suggests that vapor steaming, convective drying and roasting can be utilized for processing functional herbal tea from medicinal *S. procumbens* in small and medium-scale production. This herbal tea can be a valuable source of functional components helpful for consumers in daily consumption.

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Compliance with ethical standards

Conflict of interest: The author strongly confirms that this research is conducted with no conflict of interest.

Ethical issues: None.

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