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SHORT COMMUNICATION

Preliminary investigation on antioxidant interactions between bioactive components of *Solanum anguivi* and *Capsicum annuum*

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Abstract Evaluation of antioxidative interaction between two fruits of contra-similar characteristics belonging to same botanical family *Solanacea* namely *S. anguivi* and *Capsicum annuum* was accomplished in this study. The relative reducing power (RRP) and radical scavenging activity (RSA) of the mixture (11:0, 10:1, 5:1, 2:1, 1:1, 1:2, 1:5,1:10, 0:11) with antioxidant interaction range of 0.6958–2.4244 and 0.724–1.648 was obtained for RRP and RSA respectively for acetone–hexane derived extract. Similarly antioxidant interaction range from 1.045–1.486 to 1.0969–1.3166 was obtained for RRP and RSA respectively for ethanolic extract samples.This study demonstrated enhanced activity of *S. anguivi* and *C. annuum* when used as a mixture in comparison to when used alone. These results suggested that application of *S. anguivi* and *C. annuum as mixture* decreased intensity of undesirable sensory properties of high intensity bitterness and hot pungency associated with *S. anguivi* and *C. annuum* respectively without the use of taste masking agents.

Keywords *S. anguivi* and *C. annuum* · Extraction system · Bioactive interaction · Functional food development

Introduction

Fresh fruits and vegetables are important sources of antioxidants in human diet. Pepper fruits (*Capsicum annuum* L.) are commercially important crops that are rich in both hydrophilic antioxidants such as vitamin C and lipophilic ones such as carotenoids and vitamin E (Ilic et al. 2008) usually used as vegetable foods and spice. Hot cultivars are rich in capsaicinoids–alkaloids with pharmacological properties given the specific taste of pepper fruits (Perucka and Materska 2005). They contain some phenolic compounds specifically flavonoids. All these phytochemical compounds scavenge free radical and singlet oxygen that result to cellular damages, injure immune system and lead to a series of chronic degenerative diseases such as heart disorder, cancer, Alzheimer's disease (Prior and Wu 2013). Therefore intake of these compounds in food is an important health protecting factor because they have been recognized as being beneficial for prevention of widespread human diseases notably cancer and cardiovascular diseases, when taken daily in adequate quantity (Navarro et al. 2006). Also, *Solanum anguivi* belong to the plant family *Solanacae* and can be found as a wild plant in many places throughout the non-arid parts of Africa notably Cote de Voire, Uganda and Nigeria (Elekofehinti et al. 2012). The fruit of *S. anguivi* is used in folklore medicine in treatment of high blood pressure, ulcer and nervous disorder. Elekofehinti et al. (2012) and Daramola (2015) have reported studies on some aspects of antioxidative activity of *S. anguivi* fruits. Both *S.anguivi* and *C. annuum* shared some similarities which include; climacteric fruit, spice, being member of same botanical family: *Solanaceae*, same colourimetric change. However, they shared some differences, notably; *S. anguivi* is bitter while *C. annuum* has hot and pungent taste with different application intension in domestic cuisine.

While there are evidences that interaction occurs between some pure/isolated food components such as scavenging capacity and synergistic effects of lycopene, Vit E, Vit C and B carotene against DPPH resulted to synergistic

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interaction (Li et al. 2014) and some pure or synthetic antioxidant. Only few information exist (Li et al. 2009) about interaction between constituents of crude extracts of food plant or herb products. In food stuffs the composition of bioactive phenolics is complex and the overall antioxidant activity is due to interaction between the components. However, the interactions between the active components could be additive, synergistic or antagonistic (Gonzalex-Aguilar et al. 2012). Wang et al. (2011) defined the additive, synergistic and antagonistic effects in foods, where a food combination that provides the sum of the effects of the individual components is an additive effect, a synergistic effects occurs when the effects is greater than the sum of individual components and antagonism occurs when the sum of the effects is less than the mathematical sum that would be predicted from individual components. Interactions between bioactive components may enhance or diminish their antioxidant potential (Gliszczynsha-Swiglo and Enko 2015). Although, interaction could be synergistic, additive or antagonistic but becomes important when it is either synergistic or antagonistic and the desirability of the interaction type depends on its technological consequence. Theoretical and experimental studies have shown that drugs that exhibit synergy for a specific effect are usually not synergistic for associated side effects (Cokol et al. 2011). Therefore, in drug therapy, combining drugs has the advantage of reducing the dose that would be necessary if either drug were used alone, thus potentially decrease the incidence and severity of associated side effects (Warwick et al. 2014).

Despite established experimental evidences that *S. anguivi* has plethora of therapeutic functions, its consumption is not popular among young and old that are not under nutritional restriction based on health challenge simply as a result of its high intensity bitterness. Similarly, some tribes in Nigeria justify their restricted consumption of hot pepper based on its hot pungency even though it is of high therapeutic value. Therefore, the characteristic inherent bitterness in *S. anguivi* and hot-pungent taste of *C. annuum* have been a constraint to the unrestricted consumption and consequently led to denial from benefiting from the nutritional and therapeutic endowment of the two culinary fruits. The constraint stands as hurdle that should be addressed strategically in order to unrestrictly benefit from bioactive components of *S. anguivi* and *C. annuum.* Bioactive components interaction has been a strategy to enhanced the efficacy of some drugs and minimise associated adverse effect (Lopez-Munoz et al. 2004). In this study, exploration of the strategy of bioactive component interaction for efficacy enhancement which could lead to lower dosage and consequently lend concomitantly reduction in associated undesirable side effect without the use of sensory mask agent is accomplished. The study will be important for gaining insights about interaction between the bioactive components of *S. anguivi* and *C. annuum.*

Therefore, this study reports on evaluation of antioxidant interaction between bioactive components of *S. anguivi* and *C. annuum* with view to provide evidence for enhanced antioxidant properties of the mixture of the fruits-vegetables which could consequently provide bases towards rational design and development of functional food and nutraceuticals of *S. anguivi* and *C. annuum* origin that does not entails the use of sensory masking agents.

Materials and methods

Materials

Capsicum annuum and S. anguivi were procured from commercial market in Ado- Ekiti Ekiti State, NIgeria. Ethanol, hexane and acetone and other analytical reagents were of analytical grade. Extraction at room temperature of crude components of red pepper (*C. annuum*) and green *S. anguivi* respectively and using two solvent systems namely (1) ethanol, (2) hexane–acetone was accomplished.

Preparation of extract mixtures

Similar to the procedure of Gliszczynsha-Swiglo and Enko (2015). *C. annuum* (CA) and *S. anguivi* (SA) extracts (0.003 g) were dissolved in 5 ml of extraction solvent to make a solution for the preparation of their mixture. Mixture at weight ratio of 1.2:0, 1.1:01, 0.1:1.1, 0.0:1.2 were prepared for CA:SA. Two independent samples were prepared for each extract and for weight ratio. All mixtures were freshly prepared before RSA and RRP analyses.

Relative Reducing power

Reducing power of each sample was determined in accordance with the method of Oyaizu (1986).

Radical-scavenging activity

Radical scavenging activity (RSA) of samples on DPPH was estimated according to the method of Yamaguchi et al. (1998). Briefly, an aliquot of samples (200 µl, 0.31–2.5 mg/ml), ascorbic acid (0.04–1.25 mg/ml) was mixed with the 100 mm Tris–HCl buffer (800 µl, pH 7.4) and then added to 1 ml of 500µm DPPH in ethanol (final concentration of 250 µm). The mixture was shaken vigorously and left to stand for 20 min at room temperature in the dark. The absorbance of the resulting solution was measured spectrophotometrically at 517 nm. The

capability to scavenge the DPPH radical was calculated using the following equation.

$$\text{Scavenging effect } (\%) = [1 - (\text{absorbance of sample at } 517\ nm / absorbance of control at 517\ nm)] \times 100$$

Calculation of synergistic effects (SEs) of mixtures of CA and SA extracts

The synergistic effect of the combination of CA and SA extracts was evaluated as the ratio between the experimental antioxidant capacities of the oxidation reaction versus the theoretical antioxidant capacity. The experimental scavenging capacity of DPPH ($\%ESC_{DPPH}$) was calculated as described by Mensor et al. (2001) as follow:

$$\%ESC_{DPPH} = \frac{100 - (\text{Sample A} - \text{Blank A}) \times 100}{\text{Control A}}$$

where: Sample A = Absorbance value of the sample (crude extract antioxidant (s) plus DPPH solution). Blank A = Absorbance value of the blank (crude extract plus ethanol or extraction solvent). Control A = Absorbance value of control (DPPH solution plus ethanol or extraction solvent).

The theoretical scavenging capacity of DPPH $(\%TSC)_{DPPH}$ is the sum of the scavenging capacities of each antioxidant, calculated using the individual scavenging capacity in the following equation (Fuhrman et al. 2000).

$$\%TSC_{DPPH} = \%ESC_1 + \%ESC_2$$

ESC_{1-2} = The percentage ESC of the individual antioxidant in the mixture.

The SE of DPPH was calculated using the following equation:

$$SE\ (DPPH) = ESC_{DPPH}/TSC_{DPPH}$$

where synergism was shown when SE was greater than 1 ($SE > 1$). Likewise, the theoretical ferric reducing antioxidant power (TSC_{RRP}) was calculated using the following equation:

$$TSC_{RRP} = ESC_1 + ESC_2$$

ESC_{1-2} = The fractional percentage ESC of the individual antioxidant in the mixture.

$$SE\ (RRP) = ESC_{RRP}/TSC_{RRP}$$

where synergism was existed when SE was greater than 1 ($SE > 1$).

In overall, in order to compare the antioxidant activity of individual and combined extracts, the synergistic effect (SE) was calculated from the following equation.

$$SE = \frac{\text{Experimental value}}{\text{Theoretical value}}$$

According to Queiros et al. (2009) and Viera et al. (2012), the theoretical values were found out as the average of individual observed quantities for each one the two combined extracts, and while the experimental values coming from the observed figures for the combined extracts. $SE > 1$ is indicative of synergist effect, $SE = 1$ represents the additive effect, while $SE < 1$, stands for an antagonistic effect (Fuhrman et al. 2000; Liu et al. 2014).

Results and discussion

This study was undertaken to investigate whether binary mixture of *S. anguivi* and *C. annuum* as affected by extraction solvent could influence the antioxidant activity of the two plant foods that shared some profound similarities and differences whose consumption has been restricted by their inherent bitterness and hot-pungency associated with SA and CA respectively. Such binary interaction will obviate the use of sensory masking agents and their associated cost and other risk. Table 1 presents the values of relative reducing power (RRP) and radical scavenging activity (RSA) measured using DPPH of *S. anguivi* and *C. annuum* and their mixture as affected by two extraction solvent systems. In this study, various mixtures of CA and SA extracts (11:0,10:1, 5:1, 2:1, 1:1, 1:2, 1:5, 1:10, 0:12) were prepared to evaluate the effect of weight ratios of active components in the crude extracts in relation to their antioxidant activity, similar to the procedure of Gliszczynsha-Swiglo and Enko (2015) for the determination of interactions between tea (*Camellia sinensis*) extracts and ascorbic acid.

Examination of the result (Table 1) showed high range of value (1.7506–2.7385) RRP potential for ethanolic extract samples that contain high proportion of SA in comparison to low range of value (1.2306–1.6813) of RRP potential for ethanolic extract samples that contain low proportion of SA to CA. Also, the RSA values showed a similar trend in antioxidant activities. A cursory examination of RRP and RSA activity (Table 1) reveal that the hexane–acetone extracts of CA and SA and their mixture showed a lesser values. These results suggest that ethanolic extracts have higher antioxidant bioactive components than extracts obtained from hexane–acetone solvent system. This observation has one or both of these consequences stated afterwards. It implies that, one of the antioxidant components in either CA or SA is polar in nature. Two, non-pigment components contributed to antioxidant activity of both CA and SA. A similar result was reported by Pandey et al. (2014) in which alkanolic extract exhibited

Table 1 Antioxidant capacity of *S. annuum*, *S. anguivi* and their mixture

Weight ratio (CA:SA)	Ethanolic extract		Hexane–acetone extract	
	RRP	RSA (%)	RRP	RSA (%)
$CA_{1.2}$–$SA_{0.0}$	1.0053 ± 0.016	65.00 ± 1.00	1.5946 ± 0.06	43.75 ± 0.35
$CA_{1.1}$–$SA_{0.1}$	1.2306 ± 0.017	74.69 ± 0.31	1.0573 ± 0.017	56.125 ± 0.125
$CA_{1.0}$–$SA_{0.2}$	1.6813 ± 0.017	86.13 ± 0.13	1.5599 ± 0.035	60.50 ± 0.50
$CA_{0.8}$–$SA_{0.4}$	1.6813 ± 0.02	87.50 ± 0.00	1.9586 ± 0.0174	62.75 ± 0.25
$CA_{0.6}$–$SA_{0.6}$	1.9586 ± 0.016	87.25 ± 0.25	2.3919 ± 0.035	73.35 ± 0.35
$CA_{0.4}$–$SA_{0.8}$	1.7506 ± 0.03	74.50 ± 0.50	1.8199 ± 0.017	82.25 ± 0.25
$CA_{0.2}$–$SA_{1.0}$	2.7385 ± 0.035	84.50 ± 0.50	2.0452 ± 0.035	37.25 ± 0.25
$CA_{0.1}$–$SA_{1.1}$	2.1492 ± 0.069	84.80 ± 0.20	1.4212 ± 0.03	70.50 ± 0.5
$CA_{0.0}$–$SA_{1.2}$	2.010 ± 0.06	69.38 ± 0.40	0.6933 ± 0.00	53.00 ± 0.00

CA C. annuum, *SA S.anguivi, RSA* radical scavenging activity, *RRP* relative reducing power

higher antioxidant activity in comparison to aqueous extract.

Synergistic effect of CA in combination with SA using two extraction solvent systems

In order to investigate if synergistic interactions occurred when crude extracts of CA and SA were mixed, interaction effects were calculated. The synergistic effects (Table 2) were calculated using RSA and RRP. Based on the data obtained from individual sample extract (antioxidant endowment), the theoretical values, were calculated. If the experimental value is the same as the theoretical value, then the contribution of the individual components (antioxidant) would be additive. If the experimental value is greater than theoretical value, then an interaction exist among the additives (antioxidant), signifying synergism. And if the experimental value is lesser than theoretical value, then an antagonism exists among the additives (antioxidant), signifying negative synergism. Mathematically this is expressed thus; when the ratio of experimental antioxidant activity to theoretical antioxidant activity > 1 it indicates synergistic activity, when experimental antioxidant activity/theoretical antioxidant activity = 1, interaction is null or additive and when experimental antioxidant activity/theoretical antioxidant activity < 1, antioxidant component interaction is antagonistic or inhibitory (Liu et al. 2014).

The interaction between the constituents of extracts of CA and SA in mixtures of different weight ratios in both RRP and RSA assay showed synergism in antioxidative interaction. Although there are limited data with regard to the type of antioxidant interactions between crude extracts of natural products (spices and herbs) except in pure compounds isolated from natural product (Frum et al. 2007) or when combined with natural analogue product (Yin et al. 2012). However, this result demonstrated the wisdom in application of spices and herbs in mixture forms in folk medicine with values range from 1.045–1.486 to 1.0969–1.3166 for synergist (interaction) effects for RRP and RSA respectively for ethanolic extract samples. Similarly, the value of synergist interaction of acetone–hexane derived extracts range from 0.6958–2.4244 to 0.724–1.648 for RRP and RSA respectively. From the later data it was realized that, two of the combination showed antagonistic interaction. This non-additive effect could probably due to the fact that the bioactive components of CA and SA of the non-polar solvent extract samples formed molecular complexes resulting to reduced antioxidant activity different from the activity of individual crude components. This type of explanation was advanced by Gliszczynsha-Swiglo and Enko (2015) for the interaction between quercetin and ascorbic acid. The basic mechanism postulated by Dai et al. (2008) was that synergism was as a result of regeneration of Vitamin E from its radical form by polyphenols followed by regeneration of polyphenol by ascorbic acid. This phenomenon has high propensity of occurrence for bioactive components of crude extracts with contrast sensory properties such as RP and SG, more so that pepper is endow with ascorbic acid.

Based on these results, synergistic interactions occurred between the phenolic acids and other bioactive components in CA and SA crude extracts. The result obtained in this study suggests the phenolics/phenolic acids in the crude extracts are capable not only to donate hydrogen atoms to the radical in test-chemicals, but they are also able to donate electrons to regenerate other pro-oxidant phenols. Leopoldini et al. (2004) asserted that phenolic compounds are capable to transfer electrons to other phenolics, or antioxidant, thereby promoting their chemical regeneration which are translated to antioxidative synergistic activity.

Table 2 Interaction effects of *C. annuum* and *S. anguivi* extracts in mixture of different weight ratio

Weight ratio (CA:SA)	Ethanolic extract					
	RRP			RSA (%)		
	Exp	Theoretical	Synergist effect	Exp	Theoretical	Synergist effect
$CA_{1.1}$–$SA_{0.1}$	1.2306	1.089	1.13002	74.69	65.365	1.143
$CA_{1.0}$–$SA_{0.2}$	1.6812	1.173	1.433	86.13	65.73	1.310
$CA_{0.8}$–$SA_{0.4}$	1.6812	1.340	1.255	87.50	66.46	1.316
$CA_{0.6}$–$SA_{0.6}$	1.9586	1.5077	1.2991	87.25	67.19	1.298
$CA_{0.4}$–$SA_{0.8}$	1.7506	1.6751	1.045	74.50	67.92	1.097
$CA_{0.2}$–$SA_{1.0}$	2.7385	1.843	1.486	84.50	68.65	1.320
$CA_{0.1}$–$SA_{1.1}$	2.149	1.9263	1.1156	84.80	69.095	1.229
Weight ratio (CA:SA)	Hexane–acetone extract					
	RRP			RSA (%)		
	Exp	Theoretical	Synergist effect	Exp	Theoretical	Synergist effect
$CA_{1.1}$–$SA_{0.1}$	1.0573	1.5195	0.696	56.125	44.52	1.2607
$CA_{1.0}$–$SA_{0.2}$	1.5599	1.4443	1.08	60.50	45.29	1.3358
$CA_{0.8}$–$SA_{0.4}$	1.9586	1.2942	1.5134	62.75	46.83	1.340
$CA_{0.6}$–$SA_{0.6}$	2.3919	1.1439	2.019	73.35	48.375	1.516
$CA_{0.4}$–$SA_{0.8}$	1.8199	0.9937	1.831	82.25	49.92	1.648
$CA_{0.2}$–$SA_{1.0}$	2.045	0.8435	2.424	37.25	51.46	0.723
$CA_{0.1}$–$SA_{1.1}$	1.4212	0.7684	1.8496	70.50	52.23	1.350

CA C. annuum, *SA S.anguivi, RSA* radical scavenging activity, *RRP* relative reducing power

Conclusion

In this study, the exploration of the strategy of bioactive component interaction for efficacy enhancement which could lead to comparative low dosage and consequent concomitant reduction in undesirable sensory effects such as extreme bitterness and hot pungency associated with *S. anguivi* and *C. annuum respectively* is accomplished. Assessment showed synergistic antioxidant interaction effects between the mixture of bioactive components of *S. anguivi* and *C. annuum.* More importantly the strategy of bioactive component interaction obviates the application of bitterness and hot-pungent masking agents. Therefore, the financial cost and other risks associated with the use of such unwanted sensory masking agents are circumvented. Also, further study is needed to elucidate the mode of bioactive components interactions that lend enhanced antioxidant activity of mixture of *S. anguivi* and *C. annuum*.

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