具有重要意义[10]，为此，本研究为进一步研究 MCFA 调节 HDL 的作用提供了依据和奠定了基础。

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17 种常见蔬菜不同部位抗氧化活性的比较研究

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摘　要：目的　比较蔬菜不同部位的抗氧化活性。**方法**　采用 FRAP 法、2，4-二硝基苯肼法、Folin-Ciocaileu 法、铝离子显色法分别测定 17 种常见蔬菜不同部位的 FRAP 值及 VC、总多酚、总黄酮的含量，并分析了总抗氧化活力与抗氧化物质含量之间的相关性。**结果**　蔬菜叶子、皮的抗氧化活性高于其对应的茎和肉质部分；藕皮的总抗氧化活性最高，其次为藕肉、茴香叶、香菜叶、姜肉等，黄瓜肉的总抗氧化活性最弱；所有水提取物的总抗氧化活力均高于丙酮提取物；水提取物中，蔬菜抗氧化活性与 VC、多酚、黄酮含量的相关性具有统计学意义，多元回归分析结果显示多酚对蔬菜总抗氧化活力的贡献最大。**结论**　蔬菜不同部位的抗氧化活性差异较大，多酚类物质在蔬菜体外抗氧化活性方面可能起主要作用。

关键词：蔬菜；抗氧化活性；FRAP 值；VC；总多酚；总黄酮

过多的活性氧、活性氮自由基会引起机体内的氧化应激，并导致碳水化合物、脂类、蛋白质及核酸的氧化损伤。据报道，氧化应激会导致人类很多疾病的发生，如心血管疾病、肿瘤等[1-5]。膳食抗氧化剂被认为能够有效地保护氧化应激引起的损伤[6-8]。蔬菜水果中富含维生素、矿物质、纤维素，同时还含有天然的抗氧化物质，如类胡萝卜素、多酚、黄酮等。这些抗氧化物质能够有效地清除多种自由基、抑制链式反应的起始或者通过结合金属离子减少自由基的产生[9-12]。大量流行病学资料显示，蔬菜水果的摄入量与一些慢性疾病的发生之间呈现显著的负相关[13-16]。因此，在预防氧化应激相关疾病方面[17-19]，增加蔬菜水果的摄入量常常成为推荐的策略之一。

我们实验室之前通过测定了水果皮、果肉、种子部位的抗氧化活性，发现水果皮及种子的抗氧化活性高于果肉部分，表明水果果皮、种子部分可能是较有价值的天然抗氧化剂来源[20]。国外也有类似的报道[21,22]。然而，蔬菜不同部位抗氧化活性的研究鲜有报道[23]。在我们日常生活中，蔬菜一些部位因为卫生问题、口感不好、烹饪问题常常被丢弃，因此，可能导致蔬菜中潜在抗氧化物质及其它营养素的丢失。

本次实验中，我们采用 FRAP 法测定蔬菜不同部位抗氧活性，并分析了其与抗氧化物质 VC、多酚、黄酮含量的相关性。

1 材料与方法

1.1 材料与处理

藕、茴香、姜、香菜、菠菜、油菜、小白菜、茄子、芹菜、生菜、土豆、大白菜、青椒、韭菜、卷心菜、花菜、黄瓜、大葱共 17 种，购自天津市农贸市场。所有样品用自来水、蒸馏水反复冲洗干净，晾干表面水分，按不同部位，称取 1～5g，在研钵内按 1∶10 比例加入蒸馏水，冰浴研磨制备匀浆液，3000r/min 离心，15min 后取上清液，残渣重复提取两次，将三次上清液混合备用。水溶液提取之后，向残渣中按比例加入适量丙酮提取，室温 3000r/min 离心 15min，重复一次，将两次上清液混合备用。水溶性及脂溶性上清液用于测定蔬菜的水溶性及脂溶性抗氧化活性、VC、总多酚、水溶性及脂溶性总黄酮含量，每份样品重复测定 3 次。

1.2 方法

1.2.1 抗氧化活性

采用 FRAP 法测定。参照 Benzie 与 Strain 的方法[24]，并适当的优化。原理：在低 pH 值下，样品中的还原物质将 Fe^{3+}-三吡啶三吖嗪（tripyridy-triazine，Fe^{3+}-TPTZ）还原为二价铁形式，呈现出明显的蓝色，于 593nm 处有最大光吸收。根据吸光度大小计算样品抗氧化活性的强弱。TPTZ、Rutin，购自 Sigma 公司；其余均为国产试剂，分析纯级。

1.2.2 VC

采用 2，4-二硝基苯肼法[25]，以抗坏血酸为标准。原理：还原型抗坏血酸被活性炭将氧化为脱氢抗坏血酸，然后与 2，4-二硝基苯肼在 37℃水浴 3h 作用生成红色的脎，在浓硫酸的脱水作用下，可转变为橘红色的化合物－双－2，4-二硝基苯，在硫酸溶液中显色稳定，吸光度与总抗坏血酸含量成正比，一般根据 490nm 下的吸光度大小计算样品 VC 含量。

1.2.3 总多酚

采用 Folin-Ciocalteus 法[26]，以没食子酸为标准。原理为在碱性溶液中，酚类化合物可将钨钼酸还原（W6＋变为 W5＋），生成蓝色化合物，颜色的深浅与酚含量成正相关，在 760 nm 处有最大光吸收。

1.2.4 总黄酮

采用铝离子显色法[27]，以芦丁（Rutin，Sigma）为标准。原理：黄酮类化合物是一类具有苯骈吡喃环结构的化合物，其 3-羟基、4-羟基或 5-羟基、4-羰基及邻二位酚羟基，与铝盐进行络合反应，在碱性条件下生成红色的络合物，用于 510nm 测定其吸光度，与芦丁标准品比较进行定量。

1.3 数据处理

结果用均值±标准差表示，所有数据用 SPSS10.0 软件进行统计分析。

2 结果与讨论

2.1 蔬菜不同部位的抗氧化活性

17 种常见蔬菜不同部位结果见表 1。在测定的所有蔬菜中，藕皮的总抗氧化活力最高，达到 19.45mmol/100g；藕肉、茴香叶、香菜叶、菠菜叶、青椒肉、生姜皮、油菜叶、小白菜叶、生姜肉、芹菜叶、茄子皮、生菜叶、大葱叶、土豆皮次之，总抗氧化活力值在 3.06 到 1.11 mmol/100g；青椒肉、大白菜叶、青椒籽、卷心菜叶、花菜花、大葱茎、黄瓜皮、土豆肉、花菜茎、茴香茎、香菜茎、小白菜茎、油菜茎、卷心菜茎、茄子肉、菠菜茎、大白菜茎、生菜茎、芹菜茎、黄瓜肉等抗氧化活力值相对较低，在 0.87 mmol/100g 以下；抗氧化活力值最强与最弱的相差 216 倍。

Table 1 FRAP values of different fractions of 17 vegetables (mmol/100g wet weight)

Vegetables	Fraction		Total	Rank
	Water	Acetone		
Bok choi leaf	0. 81 ±0. 08	0. 04 ±0. 00	0. 85	16
Bok choi stem	0. 16 ±0. 01	–	0. 16	27
Cabbage leaf	0. 58 ±0. 04	0. 04 ±0. 00	0. 63	18
Cabbage stem	0. 21 ±0. 02	0. 02 ±0. 00	0. 24	25
Cauliflower flower	0. 46 ±0. 01	0. 03 ±0. 00	0. 5	19
Cauliflower stem	0. 39 ±0. 03	0. 03 ±0. 00	0. 42	21
Celery leaf	1. 02 ±0. 11	0. 86 ±0. 03	1. 88	10
Celery stem	0. 10 ±0. 02	–	0. 1	29
Coriander leaf	2. 09 ±0. 14	0. 80 ±0. 03	2. 89	4
Coriander stem	0. 23 ±0. 02	0. 05 ±0. 00	0. 28	23
Cucumber peel	0. 35 ±0. 02	0. 12 ±0. 00	0. 47	20
Cucumber pulp	0. 09 ±0. 01	–	0. 09	30
Eggplant peel	1. 30 ±0. 09	0. 03 ±0. 00	1. 33	11
Eggplant pulp	0. 24 ±0. 02	–	0. 24	25
Endive lettuce leaf	0. 85 ±0. 04	0. 44 ±0. 03	1. 28	12
Endive lettuce stem	0. 14 ±0. 00	–	0. 14	28
Fennel leaf	2. 39 ±0. 15	0. 59 ±0. 04	2. 98	3
Fennel stem	0. 26 ±0. 02	0. 14 ±0. 01	0. 4	22
Ginger peel	1. 91 ±0. 06	0. 57 ±0. 04	2. 48	6
Ginger pulp	1. 71 ±0. 08	0. 24 ±0. 05	1. 95	9
Green pepper pulp	0. 82 ±0. 01	0. 05 ±0. 01	0. 87	15
Green pepper seed	0. 73 ±0. 02	0. 08 ±0. 01	0. 81	17
Lotus root peel	17. 56 ±1. 18	1. 89 ±0. 12	19. 45	1
Lotus root pulp	2. 90 ±0. 10	0. 16 ±0. 01	3. 06	2
Pak choi leaf	1. 63 ±0. 13	0. 32 ±0. 03	1. 96	8
Pak choi stem	0. 26 ±0. 00	–	0. 26	24
Potato peel	0. 82 ±0. 03	0. 29 ±0. 01	1. 11	14
Potato pulp	0. 42 ±0. 01	–	0. 42	21
Rape leaf	1. 64 ±0. 08	0. 56 ±0. 05	2. 2	7
Rape stem	0. 21 ±0. 01	0. 02 ±0. 00	0. 24	25
Scallion leaf	1. 02 ±0. 05	0. 15 ±0. 02	1. 17	13
Scallion stem	0. 48 ±0. 05	0. 02 ±0. 00	0. 5	19
Spinach leaf	1. 67 ±0. 06	0. 87 ±0. 07	2. 54	5
Spinach stem	0. 12 ±0. 00	0. 07 ±0. 01	0. 19	26

Data are expressed as mean ± SD. Each vegetable fraction was analyzed three times.
"—", not detectable.

所有水提取物的抗氧化值高于丙酮提取物。其中大白菜茎、芹菜茎、黄瓜肉、茄子肉、生菜茎、小白菜茎及土豆肉未测得丙酮提取物的抗氧化活力值。实验结果显示,FRAP 法测得所有蔬菜的皮及叶部分高于其对应的肉及茎部分的抗氧化值,说明皮及叶子部分富含抗氧化物质,或者含有的物质具有较强的抗氧化活性。

2.2 蔬菜不同部位 VC、多酚、黄酮含量

蔬菜中含有大量的化合物发挥着抗氧化作用，如抗坏血酸、β-胡萝卜素、多酚、黄酮及其他物质[28-30]。本实验测定了 17 种蔬菜不同部位抗坏血酸、总多酚及黄酮的含量（见表 2）。本实验结果显示，芹菜叶、藕皮及茴香叶抗坏血酸含量过于 200 mg/100g；香菜叶、青椒肉、花菜花、油菜叶、花菜茎、小白菜茎及卷心菜茎抗坏血酸含量次之，在 156.55 to 103.01mg/100g；余下蔬菜不同部位的抗坏血酸含量低于 100mg/100g，土豆皮未测出抗坏血酸。对实验结果进行比较之后发现，除了土豆之外，所有蔬菜皮及叶部分抗坏血酸浓度高于其对应的肉及茎部位。

在 17 种蔬菜中，藕皮含的多酚最高，达到 228.10 mg/100g；多酚含量超过 100 mg/100g 的有茴香叶、土豆皮、香菜叶；剩余蔬菜各个部位的多酚含量低于 100 mg/100g。同样地，蔬菜皮及叶子部位多酚含量高于其对应的果肉及茎。Strack 已证实多酚在紫外线辐射、病原体及外来者入侵方面发挥着重要的保护作用[31]。

水提取物中，总黄酮含量最高的是藕皮；生姜皮、茴香叶、香菜叶、生姜肉等次之；卷心菜叶、芹菜叶和茎、黄瓜皮及果肉、茄子肉、生菜茎、土豆皮、油菜茎、大白菜叶和茎未测出水溶性黄酮含量。丙酮提取物中，青椒籽总黄酮含量最高；藕皮、生姜皮、土豆皮、花菜花、生姜肉、花菜茎、藕肉、土豆肉次之；剩余的蔬菜未测出脂溶性黄酮含量。

Table 2 The contents of VC, phenolics and flavonoids of different fractions of vegetables

Vegetables	VC (mg/100gFW)	Total phenolics (mgGA/100gFW)	Flavonoids (mgRutin/100gFW)		
			Water	Acetone	Total
Bok choy leaf	36.91 ±0.39	49.41 ±1.33	–	–	–
Bok choy stem	8.50 ±1.00	2.03 ±0.15	–	–	–
Cabbage leaf	103.01 ±7.22	37.08 ±1.60	3.64 ±0.77	–	3.64
Cabbage stem	21.96 ±1.46	12.02 ±1.91	–	–	–
Cauliflower flower	123.20 ±1.00	52.46 ±1.17	35.87 ±3.52	14.63 ±2.97	50.5
Cauliflower stem	117.27 ±3.99	22.97 ±2.70	22.09 ±1.54	7.07 ±1.12	29.16
Celery leaf	247.69 ±9.57	77.10 ±7.35	–	–	–
Celery stem	21.70 ±0.77	14.16 ±1.41	–	–	–
Coriander leaf	156.55 ±9.52	108.38 ±10.21	93.42 ±1.54	–	93.42
Coriander stem	60.61 ±2.25	19.97 ±1.04	10.67 ±1.89	–	10.67
Cucumber peel	61.63 ±5.23	43.08 ±4.04	–	–	–
Cucumber pulp	27.11 ±3.57	9.92 ±0.89	–	–	–
Eggplant peel	51.88 ±2.52	98.64 ±8.99	11.64 ±1.78	–	11.64
Eggplant pulp	12.93 ±0.93	24.28 ±2.12	–	–	–
Endive lettuce leaf	89.20 ±12.97	98.64 ±1.54	8.44 ±0.96	–	8.44
Endive lettuce stem	3.69 ±0.68	5.53 ±0.52	–	–	–
Fennel leaf	204.00 ±17.60	110.15 ±3.11	98.76 ±8.87	–	98.76
Fennel stem	27.37 ±2.77	17.59 ±1.17	8.98 ±0.77	–	8.98
Ginger peel	23.36 ±1.93	91.96 ±0.77	99.87 ±8.46	55.61 ±4.18	155.48
Ginger pulp	15.17 ±1.94	72.46 ±1.17	91.78 ±6.64	14.05 ±1.19	115.83
Green pepper pulp	124.53 ±9.92	40.44 ±3.43	22.98 ±3.35	–	22.98
Green pepper seed	26.97 ±1.08	53.77 ±1.94	34.56 ±2.54	231.79 ±13.17	266.35
Lotus root peel	241.93 ±29.89	228.10 ±4.80	147.64 ±9.64	77.70 ±7.08	225.34
Lotus root pulp	95.36 ±6.38	60.50 ±6.91	62.98 ±6.11	6.32 ±0.63	69.3
Pak choi leaf	105.20 ±2.27	71.44 ±9.18	70.76 ±6.24	–	70.76
Pak choi stem	25.50 ±4.50	16.12 ±1.89	6.77 ±1.02	–	6.77
Potato peel	–	108.50 ±3.91	–	53.70 ±1.49	53.7
Potato pulp	22.84 ±2.12	73.10 ±7.21	12.33 ±1.89	0.76 ±0.01	13.09
Rape leaf	121.91 ±3.04	78.61 ±2.47	80.98 ±8.58	–	80.98
Rape stem	31.10 ±2.16	6.55 ±0.68	–	–	–
Scallion leaf	86.54 ±2.30	91.12 ±1.78	21.20 ±2.81	–	21.2
Scallion stem	18.58 ±0.71	51.42 ±0.51	14.03 ±2.10	–	14.03
Spinach leaf	62.94 ±1.00	88.90 ±8.5	83.64 ±6.58	–	83.64
Spinach stem	14.95 ±2.87	8.60 ±1.6	4.17 ±0.51	–	4.17

Data are expressed as mean ± SD. Each vegetable fraction was analyzed three times.
"—", not detectable.

2.3 蔬菜不同部位的 FRAP 值与抗坏血酸、总多酚及黄酮含量的相关性分析

在水提取物中，蔬菜不同部位的 FRAP 值与抗坏血酸、多酚、黄酮含量之间呈显著性正相关（R^2 = 0.2983，0.4761，0.4984）；在丙酮提取物中，FRAP 值与黄酮含量之间的相关性不具有统计学意义（R^2 = 0.0341）。对本实验数据进行多元回归分析，结果显示多酚在不同部位蔬菜抗氧化力方面发挥主要作用（表 3）。我们的研究结果与 Maisuthisakul 等、杨冬梅等、陆广念等的研究一致，进一步证实蔬菜的抗氧化活性与酚类物质直接相关[32-36]。

Table 3 Results of multivariate regression analysis

Variable	β	S. E	Beta	t	*P*
constant	−1.739	0.531	−	−3.275	0.003 **
VC	7.271E−03	0.006	0.148	1.124	0.270
Phenolics	4.349E−02	0.011	0.599	3.795	0.001 **
Flavonoids	9.912E−02	0.006	0.201	1.575	0.126

Significant difference, ** $P<0.05$.

3 结论

3.1 蔬菜不同部位的抗氧化活性差异很大

蔬菜皮、叶子的抗氧活性一般高于茎和肉质，水提取物的抗氧化活性高于丙酮提取物。

3.2 蔬菜不同部位的 VC、多酚、黄酮含量差异很大

其中多酚类物质是蔬菜体外抗氧化活性的主要来源。

致谢：本项目得到了达能营养中心膳食营养研究与宣教基金（DIC2009−09）的资助。

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氧化应激对 Met 负载后大鼠肝细胞 Hcy 代谢的影响

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摘　要:目的　研究氧化应激对 Met 负载后大鼠肝细胞 Hcy 及相关氨基酸代谢的影响。**方法**　体外培养 BRL 大鼠肝细胞,选用 100μmol/L H_2O_2 诱导氧化应激,选用 50 mmol/L Met 诱导蛋氨酸负载。将大鼠肝细胞分为对照组、氧化应激组(100μmol/L H_2O_2 作用 2h)、Met 负载组(50 mmol/L Met 作用 1h)、氧化应激 + Met 负载组(100μmol/L H_2O_2 作用 2h + 50 mmol/L Met 作用 1h),实验结束收集各组培养液上清。采用高效液相法测定 Hcy、Cys 和 GSH 的含量,采用全自动氨基酸分析仪测定相关氨基酸的含量。**结果**　与对照组比较,Met 负载组 Hcy、Cys、GSH 的含量显著增加($P<0.05$),氧化应激 + Met 负载组 Hcy、Cys 的含量显著增加($P<0.05$)。与氧化应激组比较,Met 负载组和氧化应激 + Met 组的 Hcy、Cys、GSH 含量均显著增加($P<0.05$)。与对照组比较,Ser、Tau、Glu 和 Gly 的含量在氧化应激组、Met 负载组和氧化应激 + Met 组均显著减少($P<0.05$)。氧化应激组的 Ser 和 Gly 含量显著低于 Met 负载组($P<0.05$),而 Tau 含量显著高于 Met 负载组($P<0.05$);氧化应激组的 Tau 含量显著高于氧化应激 + Met 负载组($P<0.05$),而 Gly 含量显著低于氧化应激 + Met 负载组($P<0.05$)。Met 负载组的 Ser、Glu、Gly 显著高于氧化应激 + Met 负载组($P<0.05$),而 Tau 显著低于氧化应激 + Met 负载组($P<0.05$)。**结论**　氧化应激对 Met 负载后大鼠肝细胞的 Hcy 代谢可能具有一定的促进作用。

关键词:蛋氨酸负载;同型半胱氨酸;氧化应激

Effects of oxidative stress on Hcy metabolism in Met loading rat hepatocytes

Abstract: Objective　To investigate effects of oxidative stress on Hcy and related amino acids metabolism. **Methods**　100μmol/L H_2O_2 was seleted to indue oxidative stress, and 50 mmol/L Met was selected to induce Met loading. Cultured BRL rat hepatocytes was divided into control, oxidatively stressed, Met loading, and oxidatively stressed + Met loading groups. At the end of the experiment, culture fluid was collected. Hcy, Cys and GSH were measured by HPLC, amino acids were assayed by Amino Acids Analyzer. **Results**　Compared to control, the contents of Hcy, Cys and GSH significantly increased in Met loading group ($P<0.05$), and the contents of Hcy and Cys also increased in oxidatively stressed + Met laoding group ($P<0.05$). Compared to oxidatively stressed group, the concentrations of Hcy, Cys and GSH distinctively increased in Met loading and oxidatively stressed + Met loading groups ($P<0.05$). The contents of Ser, Tau, Glu and Gly decreased in oxidatively stressed, Met loading and oxidatively stressed + Met loading groups ($P<0.05$) compared to control. The concentrations of Ser and Gly in oxidatively stressed group were significantly lower, while Tau was higher than in Met loading group ($P<0.05$). The content of Tau in oxidatively stressed group was higher while Gly was lower than in oxidatively stressed + Met loading group ($P<0.05$). The concentrations of Ser, Glu, and Gly in Met loading group were higher, while Tau was lower than in oxida-