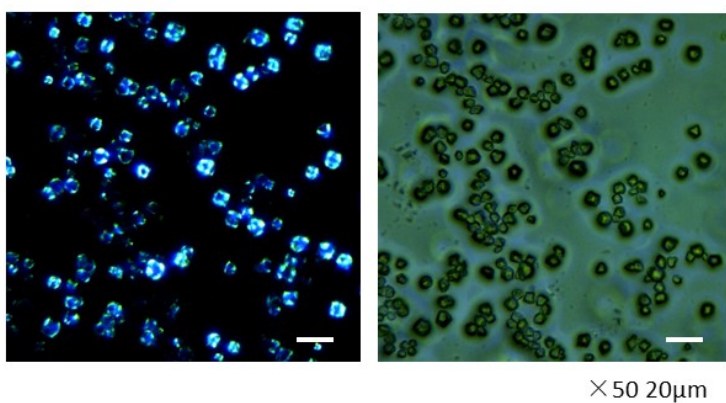


Supplementary material

Figure S1 Light micrographs (bright (left) and polarized (right)) pictures of black rice starches (A), XRD diffractograms (B) (A-F represented the samples of black rice flours with different milling degree, G represented black rice bran; H represented black rice starch).

A



B

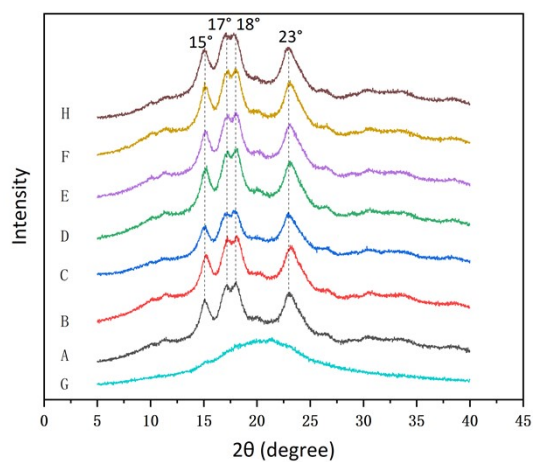


Figure S2 Scanning electron microscopy (SEM) pictures (A(1-4)-F(1-4)) and light micrographs (A5 and F5) of black rice samples. Surface section: A1-F1 (scale bar: 500 μm) and A2-F2 (scale bar: 20 μm), transverse section: A3-F3 (scale bar: 500 μm) and A4-F4 (scale bar: 20 μm); A5 and F5 (scale bar: 100 μm). Abbreviations: P, AL and EN, indicated pericarp layer, aleurone layer and endosperm region of black rice grains, respectively.

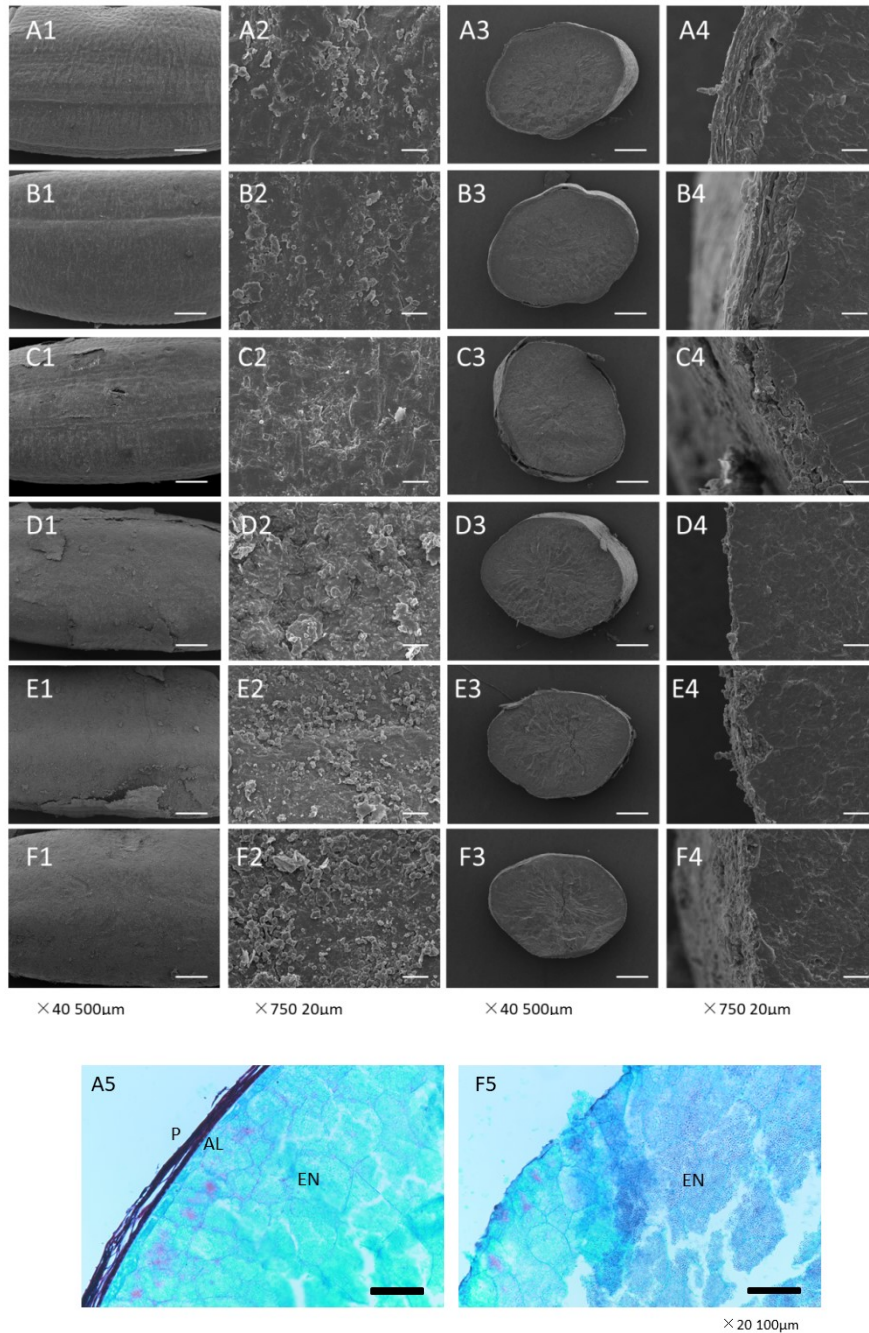


Figure S3 Starch hydrolysis curves of black rice flour (A-F) during *in vitro* digestion at 37 °C.

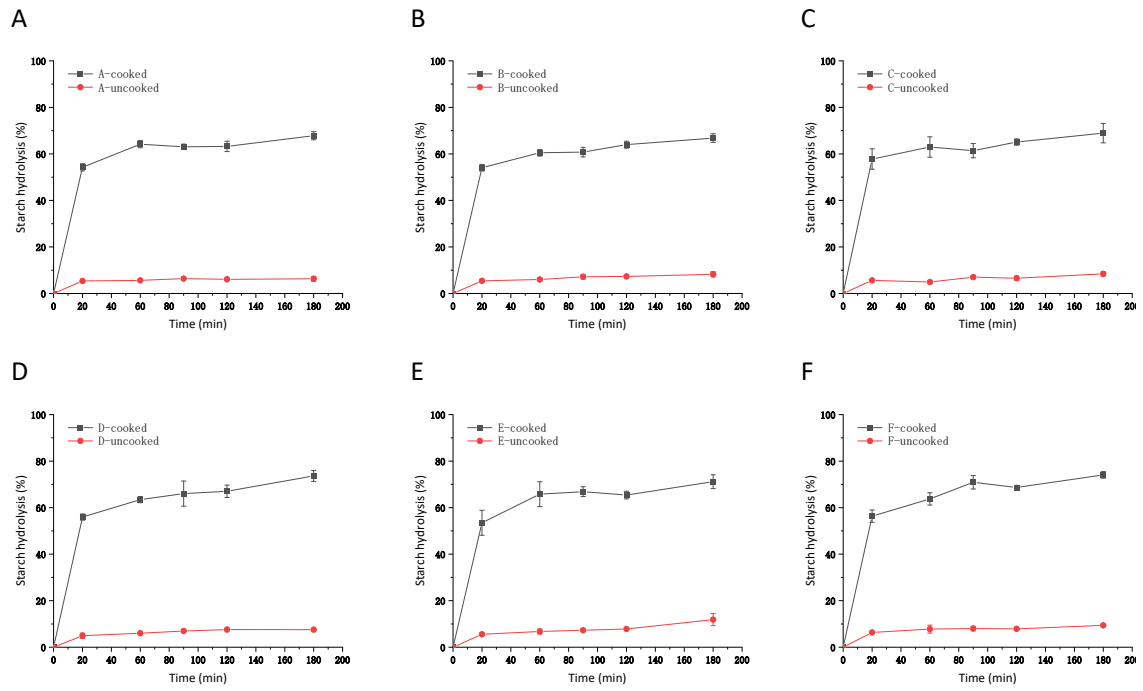


Table S1 Milling degree, bran yield, head rice yield and rice flour moisture of black rice samples.

| Rice Sample | Milling Degree (%) | Bran Yield (%) | Yield Head Rice (%) | Hundred Grain Weight (g) | Length breadth Ratio (L:B) | Rice Flour Moisture (%) |
|-------------|--------------------|----------------|---------------------|--------------------------|----------------------------|-------------------------|
| A | 0.00±0.00f | 0.00±0.00f | 95.87±0.35a | 1.91±0.05a | 2.79±0.24a | 8.70±0.24ab |
| B | 0.57±0.02e | 0.50±0.03e | 87.48±0.24ab | 1.92±0.02a | 2.68±0.22a | 8.79±0.28ab |
| C | 1.27±0.02d | 1.14±0.03d | 79.10±7.57bc | 1.91±0.04a | 2.82±0.38a | 9.20±0.34ab |
| D | 4.16±0.04c | 3.78±0.04c | 76.66±3.67bc | 1.83±0.02ab | 2.65±0.17a | 8.52±0.60b |
| E | 6.97±0.14b | 6.78±0.17b | 69.76±4.53c | 1.76±0.07b | 2.63±0.22a | 8.92±0.04ab |
| F | 10.19±0.10a | 9.88±0.14a | 68.87±3.86c | 1.75±0.01b | 2.97±0.31a | 9.46±0.16a |

Different letters in the columns represent statistically significant differences ($p < 0.05$).

Table S2 Proximate composition of black rice samples with different milling degree (g/100g DW).

| Sample | Protein (N×5.95) | Lipids | Ash | Amylose | Carbohydrate ^a |
|--------|------------------|-------------|-------------|-------------|---------------------------|
| A | 9.95±0.21a | 2.48±0.05a | 1.44±0.14a | 1.08±0.12b | 86.13 |
| B | 10.22±0.10a | 2.38±0.12a | 1.21±0.03ab | 1.00±0.04b | 86.19 |
| C | 10.19±0.15a | 1.92±0.19ab | 1.18±0.02bc | 0.95±0.17b | 86.71 |
| D | 9.85±0.23a | 1.57±0.14bc | 0.98±0.09cd | 1.23±0.54ab | 87.60 |
| E | 10.07±0.11a | 1.24±0.28c | 0.86±0.11d | 1.88±0.96ab | 87.83 |
| F | 9.88±0.10a | 0.67±0.23d | 0.51±0.06e | 2.55±0.52a | 88.94 |

^aCarbohydrate=100-protein-fat-ash

Different letters in the columns represent statistically significant differences ($p < 0.05$).

Table S3 Variation of color values of intact black rice grains, rice flour and bran.

| Intact Rice | L* | a* | b* | W | ΔE* |
|--------------------|--------------|------------|--------------|--------------|-------------|
| A | 45.71±1.75c | 0.58±0.07c | -0.93±0.19bc | 45.70±1.76c | - |
| B | 46.55±0.90bc | 0.65±0.11c | -1.16±0.17c | 46.53±0.90bc | 1.05±0.59c |
| C | 45.15±0.73c | 1.16±0.16c | -1.13±0.12c | 45.12±0.73c | 0.99±0.38c |
| D | 47.59±1.75bc | 1.96±0.54b | -1.06±0.36c | 47.54±1.77bc | 2.73±0.67bc |
| E | 51.25±3.40ab | 2.31±0.24b | -0.35±0.35b | 51.19±3.39ab | 5.91±3.22b |
| F | 55.99±2.23a | 4.60±0.31a | 0.45±0.24a | 55.75±2.20a | 11.14±2.17a |
| Rice Flour | L* | a* | b* | W | ΔE* |
| A | 64.26±0.78d | 3.56±0.07d | 0.73±0.12bc | 64.08±0.78d | - |
| B | 65.23±0.65cd | 3.58±0.05d | 0.57±0.05cd | 65.04±0.64cd | 1.00±0.61d |
| C | 65.17±1.07cd | 4.01±0.12c | 0.38±0.10de | 64.94±1.07cd | 1.21±0.82d |
| D | 66.75±0.46c | 4.70±0.10a | 0.25±0.05e | 66.42±0.47c | 2.78±0.38d |
| E | 72.50±1.08b | 4.01±0.03c | 0.88±0.10ab | 72.19±1.07b | 8.25±1.08c |
| F | 77.77±0.77a | 4.38±0.20b | 1.04±0.03a | 77.32±0.77a | 13.54±0.77b |
| G (Rice Bran) | 43.44±0.10e | 2.54±0.12e | 0.85±0.12ab | 43.37±0.10e | 20.85±0.11a |

Different letters in the columns represent statistically significant differences ($p < 0.05$).

Table S4 Pasting properties of black rice starch (H) and rice flours (A-F) with different milling degree.

| Samples | PV/cp | HS/cp | FV/cp | BD/cp | SB/cp | PT/°C |
|---------|---------------|---------------|---------------|--------------|--------------|--------------|
| A | 186.33±3.21e | 183.00±2.65e | 250.33±1.53e | 3.33±0.58d | 77.33±1.15e | 79.21±0.49a |
| B | 218.00±7.21de | 214.00±6.56d | 306.33±9.61d | 4.00±1.00d | 92.33±3.05d | 78.65±0.00ab |
| C | 249.50±0.71d | 245.00±0.00d | 341.00±0.00d | 4.50±0.71d | 96.00±0.00d | 78.65±0.00ab |
| D | 351.50±2.12c | 333.00±2.83c | 446.00±1.41c | 18.50±0.71c | 113.00±1.41c | 78.30±0.49ab |
| E | 455.00±24.04b | 418.50±21.92b | 544.00±25.46b | 36.50±2.12b | 125.50±3.54b | 77.55±0.57b |
| F | 760.00±22.63a | 626.50±16.26a | 778.50±21.92a | 133.50±6.36a | 152.00±5.65a | 77.95±0.00ab |
| H | 2385.00±52.33 | 1815.50±0.71 | 1998.50±28.99 | 569.50±51.62 | 183.00±29.70 | 75.98±0.67c |

Since each viscosity of black rice starch (H) was much higher than that of rice flour samples, the significance analysis was between black rice flour samples (A-F). Different letters in the columns represent statistically significant differences ($p < 0.05$).

Table S5 Gelatinization and retrogradation characteristics of black rice starch (H) and rice flours with different milling degree (A-F).

| Gelatinization characteristics | | | | | |
|--------------------------------|--------------|--------------|--------------|-------------|--------------|
| Samples | To(°C) | Tp(°C) | Tc(°C) | ΔH(J/g) | |
| A | 74.47±0.38a | 79.63±0.15a | 85.50±0.17a | 8.25±0.13b | |
| B | 73.95±0.21ab | 79.15±0.35ab | 84.60±0.85ab | 7.25±0.07b | |
| C | 74.05±0.35ab | 79.35±0.91ab | 85.20±0.85a | 8.29±0.35b | |
| D | 73.98±0.84ab | 78.80±0.51ab | 84.58±0.52ab | 7.02±0.97b | |
| E | 73.30±0.57ab | 78.05±0.92b | 83.50±1.13bc | 7.47±0.21b | |
| F | 72.97±0.38b | 77.80±0.87b | 84.10±0.80ab | 7.50±0.12b | |
| H | 70.33±0.31c | 75.60±0.00c | 82.03±0.50c | 11.92±1.64a | |
| Retrogradation characteristics | | | | | |
| Samples | To(°C) | Tp(°C) | Tc(°C) | ΔHr(J/g) | RD(%) |
| A | 44.27±0.31a | 53.03±0.49a | 63.23±0.31a | 4.05±0.15a | 49.08±1.97a |
| B | 44.60±0.28a | 54.05±0.78a | 63.15±0.49a | 3.78±0.51a | 52.14±7.49a |
| C | 44.75±0.35a | 53.55±0.49a | 63.85±0.35a | 3.90±0.70a | 47.26±10.52a |
| D | 44.83±1.08a | 54.20±1.11a | 63.02±0.39a | 3.53±0.64a | 54.70±11.21a |
| E | 45.20±0.53a | 54.01±0.87a | 63.15±0.45a | 3.24±0.78a | 54.61±6.96a |
| F | 45.70±0.00a | 53.87±0.40a | 62.90±0.40a | 3.66±0.80a | 48.64±10.26a |
| H | 44.93±0.42a | 54.53±0.59a | 63.10±0.26a | 4.74±0.67a | 40.74±10.98a |

Different letters in the columns represent statistically significant differences ($p < 0.05$).

Table S6 Identification results of polyphenols in whole black rice

| No. | Rt (min) | Mw (Da) | Q1 (Da) | Q3 (Da) | Compounds |
|-----|----------|----------|---------|---------|---|
| 1 | 3.45 | 287.24 | 287 | 213 | Cyanidin |
| 2 | 3.86 | 301.1 | 301.1 | 286 | Peonidin |
| 3 | 2.9 | 303.24 | 303 | 229 | Delphinidin |
| 4 | 2.58 | 433.1 | 433.1 | 271 | Pelargonidin 3-O-beta-D-glucoside (Callistephin chloride) |
| 5 | 2.45 | 449.1 | 449.1 | 287.3 | Cyanidin 3-O-glucoside (Kuromanin) |
| 6 | 3 | 463.123 | 463.1 | 301 | Peonidin O-hexoside |
| 7 | 2.3 | 465.1 | 465.1 | 303 | Delphinidin 3-O-glucoside (Mirtillin) |
| 8 | 3.22 | 477.1 | 477.1 | 315 | Rosinidin O-hexoside |
| 9 | 2.42 | 479 | 479 | 317 | Petunidin 3-O-glucoside |
| 10 | 2.81 | 493 | 493 | 331 | Malvidin 3-O-galactoside |
| 11 | 2.86 | 493.2 | 493.2 | 331 | Malvidin 3-O-glucoside (Oenin) |
| 12 | 2.81 | 535.1 | 535.1 | 287.5 | Cyanidin 3-O-malonylhexoside |
| 13 | 2.6 | 595 | 595 | 287 | Cyanidin 3-O-rutinoside (Keracyanin) |
| 14 | 2.45 | 595 | 595 | 270.9 | Pelargonin |
| 15 | 3.17 | 290.3 | 291 | 139 | L-Epicatechin |
| 16 | 2.81 | 290.079 | 291.1 | 139 | Catechin |
| 17 | 2.39 | 610.2 | 611.2 | 287.1 | Gallocatechin-gallocatechin |
| 18 | 2.5 | 322.1 | 323.1 | 177.4 | O-Feruloyl coumarin |
| 19 | 3.06 | 338.1 | 339.1 | 145.4 | O-Feruloyl 2-hydroxylcoumarin |
| 20 | 3.74 | 338.1 | 339.1 | 177.2 | O-Feruloyl 4-hydroxylcoumarin |
| 21 | 3.76 | 368.1 | 369.1 | 207.1 | N-sinapoyl hydroxycoumarin |
| 22 | 4.87 | 256.074 | 257 | 137 | Liquiritigenin |
| 23 | 5.41 | 272.0685 | 273.1 | 153 | Naringenin |
| 24 | 5.3 | 272.069 | 273.1 | 153 | Naringenin chalcone |
| 25 | 3.29 | 274.084 | 275 | 139 | Afzelechin (3,5,7,4'-Tetrahydroxyflavan) |
| 26 | 4.85 | 288.063 | 289.1 | 153 | Eriodictyol |
| 27 | 4.05 | 434.1213 | 435.1 | 273 | Naringenin 7-O-glucoside (Prunin) |
| 28 | 4.09 | 610.19 | 611.2 | 303 | Hesperetin 7-O-neohesperidoside (Neohesperidin) |
| 29 | 5.45 | 272.069 | 273.1 | 153 | Butin |
| 30 | 4.38 | 302.043 | 303 | 257 | Tricetin |
| 31 | 7.32 | 372.121 | 373.1 | 343 | Tangeretin |
| 32 | 6.84 | 402.132 | 403.1 | 373 | Nobiletin |
| 33 | 4.67 | 416.2 | 417.2 | 255.1 | Chrysin O-hexoside |
| 34 | 4.05 | 432.1 | 433.1 | 271.1 | Apigenin 7-O-glucoside (Cosmosiin) |
| 35 | 3.73 | 432.1056 | 433.1 | 271 | Apigenin 5-O-glucoside |
| 36 | 3.7 | 448.101 | 449.1 | 287.2 | Luteolin 7-O-glucoside (Cynaroside) |
| 37 | 3.96 | 462.1 | 463.1 | 301 | Chrysoeriol 5-O-hexoside |

| | | | | | |
|----|------|----------|-------|-------|---|
| 38 | 4.14 | 462.2 | 463.2 | 301.1 | Chrysoeriol 7-O-hexoside |
| 39 | 4.12 | 476.1 | 477.1 | 301.5 | Chrysoeriol O-glucuronic acid |
| 40 | 4.82 | 476.1 | 477.1 | 331.1 | Tricin O-rhamnoside |
| 41 | 5.17 | 476.1 | 477.1 | 315 | O-methylChrysoeriol 5-O-hexoside |
| 42 | 5.28 | 476.2 | 477.2 | 315 | O-methylChrysoeriol 7-O-hexoside |
| 43 | 4.13 | 492.1 | 493.1 | 331 | Tricin 7-O-hexoside |
| 44 | 5.24 | 502 | 503 | 255 | Chrysin O-malonylhexoside |
| 45 | 4.36 | 518 | 519 | 271 | Apigenin O-malonylhexoside |
| 46 | 4.43 | 548.1 | 549.1 | 301.4 | Chrysoeriol O-malonylhexoside |
| 47 | 4.55 | 550 | 551 | 303.1 | Tricetin O-malonylhexoside |
| 48 | 4.16 | 564.3 | 565.3 | 331 | Tricin O-oxalylhexoside |
| 49 | 3.89 | 578.1636 | 579.2 | 271 | Apigenin 7-O-neohesperidoside (Rhoifolin) |
| 50 | 3.82 | 578.1636 | 579.2 | 271 | Apigenin 7-rutinoside (Isorhoifolin) |
| 51 | 3.6 | 580.2 | 581.2 | 383.2 | Luteolin O-hexosyl-O-pentoside |
| 52 | 3.93 | 608.4 | 609.4 | 301 | Chrysoeriol 7-O-rutinoside |
| 53 | 3.38 | 610.1 | 611.1 | 449.3 | Luteolin 3',7-di-O-glucoside |
| 54 | 4.23 | 640.1 | 641.1 | 479.1 | Selgin O-hexosyl-O-hexoside |
| 55 | 4.49 | 654 | 655 | 207 | Luteolin O-sinapoylhexoside |
| 56 | 3.35 | 654.2 | 655.2 | 331.2 | Tricin 7-O-hexosyl-O-hexoside |
| 57 | 4.75 | 668 | 669 | 207 | Chrysoeriol O-sinapoylhexoside |
| 58 | 4.71 | 698.2 | 699.2 | 331.1 | Tricin O-sinapoylhexoside |
| 59 | 4.38 | 724.2 | 725.2 | 331.1 | Tricin O-rhamnosyl-O-malonylhexoside |
| 60 | 3.88 | 432.1 | 433.1 | 283.1 | Apigenin C-glucoside |
| 61 | 3.47 | 448.1 | 449.1 | 299.1 | Luteolin 6-C-glucoside |
| 62 | 3.32 | 448.1 | 449.1 | 299.2 | Luteolin C-hexoside |
| 63 | 3.3 | 450.1 | 451.1 | 331.1 | Eriodictyol C-hexoside |
| 64 | 3.74 | 462.1 | 463.1 | 313.2 | Chrysoeriol 8-C-hexoside |
| 65 | 4.06 | 476.1 | 477.1 | 297.2 | O-methylChrysoeriol 8-C-hexoside |
| 66 | 3.45 | 564.1 | 565.1 | 433.3 | C-hexosyl-apigenin O-pentoside |
| 67 | 3.14 | 580.1 | 581.1 | 431.3 | 6-C-hexosyl luteolin O-pentoside |
| 68 | 3.02 | 580.1 | 581.1 | 515.4 | C-hexosyl-luteolin C-pentoside |
| 69 | 3.54 | 594.1 | 595.1 | 463.1 | di-C,C-hexosyl-apigenin |
| 70 | 3.6 | 608.1 | 609.1 | 463.3 | Chrysoeriol C-hexosyl-O-rhamnoside |
| 71 | 2.9 | 610.1 | 611.1 | 431.3 | 6-C-hexosyl-luteolin O-hexoside |
| 72 | 3.64 | 610.1 | 611.1 | 317.1 | 8-C-hexosyl-luteolin O-hexoside |
| 73 | 2.8 | 610.2 | 611.2 | 473.1 | C-hexosyl-luteolin O-hexoside |
| 74 | 3.27 | 610.2 | 611.2 | 473.1 | di-C,C-hexosyl-luteolin |
| 75 | 3.67 | 610.2 | 611.2 | 465.1 | Luteolin 8-C-hexosyl-O-hexoside |
| 76 | 3.31 | 624 | 625 | 463 | 8-C-hexosyl chrysoeriol O-hexoside |
| 77 | 2.77 | 640.1 | 641.1 | 622.8 | C-hexosyl-isorhamnetin O-hexoside |
| 78 | 2.5 | 756.1 | 757.1 | 577.2 | Apigenin 6-C-hexosyl-8-C-hexosyl-O-hexoside |

| | | | | | |
|-----|------|----------|-------|-------|--|
| 79 | 2.47 | 772.1 | 773.1 | 593 | Luteolin 6-C-hexoside 8-C-hexosyl-O-hexoside |
| 80 | 3.96 | 300.1 | 301.1 | 286 | Kaempferide |
| 81 | 4.92 | 302.043 | 303 | 153 | Quercetin |
| 82 | 3.94 | 304.058 | 305.1 | 231 | Dihydroquercetin (Taxifolin) |
| 83 | 7.16 | 314.079 | 315.1 | 300 | Kumatakenin |
| 84 | 4.39 | 318.038 | 319 | 153 | Myricetin |
| 85 | 6.44 | 330.074 | 331 | 316 | 3,7-Di-O-methylquercetin |
| 86 | 4.29 | 432.106 | 433 | 287 | Kaempferol 3-O-rhamnoside (Kaempferin) |
| 87 | 3.86 | 448.101 | 449 | 287 | Kaempferol 3-O-galactoside (Trifolin) |
| 88 | 3.68 | 464.096 | 465 | 303 | Quercetin 3-O-glucoside (Isotrifoliin) |
| 89 | 4.04 | 464.096 | 465 | 303 | Quercetin 4'-O-glucoside (Spiraeoside) |
| 90 | 3.84 | 478 | 479 | 317.1 | methylQuercetin O-hexoside |
| 91 | 4.25 | 478.2 | 479.2 | 317.2 | Isorhamnetin O-hexoside |
| 92 | 3.27 | 508.1 | 509.1 | 347.2 | Syringetin 3-O-hexoside |
| 93 | 3.7 | 594.159 | 595.2 | 287 | Kaempferol 3-O-robinobioside (Biorobin) |
| 94 | 3.77 | 594.1585 | 595.2 | 287 | Kaempferol 3-O-rutinoside (Nicotiflorin) |
| 95 | 3.73 | 610.2 | 611.2 | 303.1 | Quercetin 7-O-rutinoside |
| 96 | 4.33 | 556.2 | 557.2 | 331 | Tricin 4'-O-(syringyl glyceryl)ether |
| 97 | 4.01 | 194.0579 | 195.1 | 117 | 3-Hydroxy-4-methoxycinnamic acid |
| 98 | 3.92 | 194.0579 | 195.1 | 117 | Ferulic acid |
| 99 | 2.7 | 670.2 | 671.2 | 509 | Gallic acid O-feruloyl-O-hexosyl-O-hexoside |
| 100 | 5.01 | 284.069 | 285 | 270 | Calycosin |
| 101 | 4.89 | 284.069 | 285 | 270 | Glycitein |
| 102 | 3.84 | 432.106 | 433 | 271 | Genistein 7-O-Glucoside (Genistin) |