Additional file 1. Statistical tests and distribution of 100 cowpea germplasm collections based on qualitative traits

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Trait** | **Description** | **Frequency (%)** | **Degrees of freedom** | **Chi-square** | **P-value** | **Genotypes** |
| Growth habit | Determinate | 43.0 | 198 | 469.19 | 0.00 | BB3-9-7-5, BB8-1-5-2, BB10-4-2-5, BB14-16-2-2, BBXSC13, BBSC12, Bubebe, CP1, CP2, CP6, CP11, CP414, CP418, CP732, CP753, CP2232, CP2980, CP3067, CP3422, CP3423, CP3425, Geneb, IT82-16, IT82-16E, Kapita, L10xL7, Local chipata, LT3-8-4-1, LT4-2-4-1, LT11-3-3-12, LT11-3-3-13, LT11-5-2-2, Lutechipata, Lutembwe, MS1-8-1-4,Sundan1, ZM2960, ZM2966, ZM3064, ZM3716, ZM4588, ZM4706, ZM6680. |
| Indeterminate | 39.0 | CP4,CP12, CP102,CP305, CP411, CP421, CP426,CP479,CP601,CP645,CP1769, CP2231,CP2863,CP3420,CP2XSC103, Chawa, Kapita black, Kapita north,L4XL3, L8XL9, Local kapita, LT16-7-2-5, Lute, Makulu, Mount, Namuseba, ZM308, ZM471, ZM1790, ZM2095, ZM2938, ZM2943, ZM2954, ZM2969, ZM2999, ZM3000, ZM3070, ZM4710, ZM5419. |
| Creeping | 18.0 | Bgene, CP399, CP436, CP570, CP633, CP698, CP2223, CP3413, Chiko, Chimponongo, LT4-2-4-14, Msandile, Mtilizi, Muz, ZM2081, ZM2108, ZM2939, ZM3003 |
| Leaf size  | Small | 35.0 | 198 | 404.31 | 0.00 | BBXSC13, BB8-1-5-2, CP6, CP12, CP421, CP645, CP698, CP1769, CP2232, CP2863, CP3422, Chiko, IT82-16E, L8XL9, LT4-2-4-14, LT4-2-4-14, LT11-3-3-12, Lutembwe, Lutechipata, MS1-8-1-4, Sundan1, ZM2095, ZM2108, ZM2939, ZM2943, ZM2954, ZM2966, ZM3003, ZM3064, ZM3070, ZM3716, ZM4588, ZM4706, ZM5419. |
| Medium | 26.0 | BB10-4-2-5, BB14-16-2-2, BBSC12, Bgene, Bubebe, CP2, CP4, CP11, CP414, CP418, CP436, CP753, CP2231, Chawa, Geneb, L10Xl7, Local Chipata, LT3-8-4-1, LT11-3-3-13, LT11-5-2-2, Namuseba,Makulu,ZM1790, ZM2960, ZM2969, ZM5419. |
| Big | 39.0 | BB3-9-7-5, CP1,CP102, CP399, CP411, CP426, CP479, CP570, CP601, CP633, CP732, CP2223, CP2980, CP3067, CP3413, CP3420, CP3423, CP3425, CPXSC103, Chimponongo, IT82-16, Kapita, Kapita black, Kapita north, L4XL3, Local kapita, LT16-7-2-5, Lute, Mount, Msandile, Mtilizi, Muz, ZM308, ZM471, ZM2081, ZM2938, ZM3000, ZM6680. |
| Flower colour | White | 1.0 | 198 | 387.81 | 0.00 | ZM6680. |
| Yellow | 4.0 | CP11, Namuseba, MS1-8-1-4, ZM2095. |
| Violet | 95.0 | BB3-9-7-5, BB8-1-5-2, BB10-4-2-5, BB14-16-2-2, BBXSC13, BBSC12, Bgene, Bubebe, CP1, CP4, CP2, CP6, CP11, CP12, CP102, CP305, CP399, CP411, CP414, CP418, CP421, CP426, CP436, CP479,CP601, CP633, CP645, CP698, CP732, CP753, CP421, CP426, CP479, CP570, CP601, CP645, CP1769, CP2223 CP2231, CP2232, CP2863, CP2980, CP3067, CP3413, CP3420, CP3422, CP3423, CP3425, CP2XSC103, Chawa, Chiko, Chimponongo, Geneb, IT82-16, IT82-16E, Kapita, L10xL7, Local Chipata, LT3-8-4-1, LT4-2-4-14, LT4-2-4-1, LT11-3-3-12, LT11-3-3-13, LT11-5-2-2, Kapita black, Kapita north, L4XL3, L8XL9, Local kapita, LT16-7-2-5, Lute, Lutechipata, Lutembwe, Makulu, Mount, MS1-8-1-4, Msandile, Mtilizi, Muz, Namuseba, Sundan1, ZM300, ZM308, ZM471, ZM1790, ZM2081, ZM2095, ZM2108, ZM2938, ZM2939, ZM2943, ZM2954 ZM2960, ZM2966, ZM2969, ZM2999, ZM3000 ZM3064, ZM3070, ZM3716, ZM4588, ZM4706, ZM4710, ZM5419, ZM6680. |

Additional file 1 …. Continued

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Trait** | **Description** | **Frequency (%)** | **Degrees of freedom** | **Chi-square** | **P-value** | **Genotypes** |
| Pod colour | Light green | 30.0 | 198 | 445.12 | 0.00 | BB10-4-2-5, BBSC12, BBXSC13, BB3-9-7-5,CP2,CP11, CP414, CP418,CP753, CP2231, CP2232, CP23, CP3425, IT82-16E, Kapita black, L8XL9, LT3-8-4-1, LT4-2-4-1, LT11-3-3-13, LT11-5-2-2, MS1-8-1-4, Namuseba, ZM2095, ZM2938, ZM2999, ZM3716, ZM4706, ZM4710, ZM5419. |
| Dark green | 52.0 | BB8-1-5-2, BB14-16-2-2, Bgene, CP1, CP4, CP6, CP12, CP305, CP426, CP436, CP479,CP570, CP601, CP645, CP732, CP1769, CP2863, CP2980, CP3413, CP2XSC103, Chawa, Chimponongo, Geneb, IT82-16,Kapita, Kapita north, Local chipata, Local kapita, LT4-2-4-14, LT11-3-3-12, Lutechipata, Lutembwe, Msandile, Mtilizi, Muz, Sundan1, ZM308, ZM471, ZM1790, ZM2081, ZM2108, ZM2939, ZM2954, ZM2960, ZM2969, ZM3000, ZM3003, ZM3070, ZM4588, ZM6688. |
| Purple | 18.0 | CP102, CP399, CP411, CP421, CP633, CP698, CP2223, CP3067, CP3420, CP3422, Chiko, L4Xl3, LT16-7-2-5, Lute, Makulu, Mount, ZM2943, ZM3064. |
| Leaf colour intensity | Light green | 26.0 | 198 | 588.10 | 0.00 | BB10-4-2-5, BB14-16-2-2, BBSC12, Bgene, Bubebe, CP2, CP4, CP11, CP414, CP418, CP436, CP753, CP2231, Chawa, Geneb, L10Xl7, Local Chipata, LT3-8-4-1, LT11-3-3-13, LT11-5-2-2, Namuseba,Makulu,ZM1790, ZM2960, ZM2969, ZM5419. |
| Medium green | 35.0 | BBXSC13, BB8-1-5-2, CP6, CP12, CP421, CP645, CP698, CP1769, CP2232, CP2863, CP3422, Chiko, IT82-16E, L8XL9, LT4-2-4-14, LT4-2-4-14, LT11-3-3-12, Lutembwe, Lutechipata, MS1-8-1-4, Sundan1, ZM2095, ZM2108, ZM2939, ZM2943, ZM2954, ZM2966, ZM3003, ZM3064, ZM3070, ZM3716, ZM4588, ZM4706, ZM5419. |
| Dark green | 39.0 | BB3-9-7-5, CP1,CP102, CP399, CP411, CP426, CP479, CP570, CP601, CP633, CP732, CP2223, CP2980, CP3067, CP3413, CP3420, CP3423, CP3425, CPXSC103, Chimponongo, IT82-16, Kapita, Kapita black, Kapita north, L4XL3, Local kapita, LT16-7-2-5, Lute, Mount, Msandile, Mtilizi, Muz, ZM308, ZM471, ZM2081, ZM2938, ZM3000, ZM6680. |
| Seed coat colour | Red- brown | 8. 0 | 396 | 557.10 | 0.82 | BBXSC13, CP2, CP570, CP3420, L4XL3, Msandile, MS1-8-1-4, ZM2966. |
| White | 10.0 | BB8-1-5-2, BB8-1-5-2, BB10-4-2-5, BB14-16-2-2, Bubebe, CP2XSC103, L8XL9, L10XL7, Nanuseba, ZM3716. |
| Purple- brown | 12.0 | Bgene, CP102, CP418, CP3435, Chiko, Geneb, Kapita north, LT11-3-3-13, Lute, Mtilizi, Mount, ZM2969 |
| Brown | 49.0 | BBSC12, CP1,CP6,CP11,CP305,CP399, CP411, CP414,CP421, CP436, CP466, CP633, CP645, CP668, CP753, CP1769, CP2223, CP2232, CP2863, CP3067, CP3413, CP3422, Chawa, Kapita, Local kapita,LT4-2-4-1, LT4-2-4-14, LT11-3-3-12, LT11-5-2-2, LT16-7-2-5, Lutechipata, Lutembwe, Makulu, Muz, Sundan1, ZM308, ZM471, ZM2095, ZM2938, ZM2943, ZM2954, ZM2960, ZM2999, ZM3064, ZM3067, ZM4706, ZM4710, ZM5419, ZM6680 |
| Black | 21.0 | CP4, CP12, CP479, CP601, CP732, CP2231, CP2980, CP3423, Chimponongo, IT82-16, IT82-16E, Kapita black, Local Chipata, ZM1790, ZM2081, ZM2108, ZM2929, ZM3000, ZM3003, ZM3070, ZM4588. |

Additional file 2. Correlations among phenotypic, genotypic and joint matrices based on Mantel test with 999 permutations showing the correlations (above diagonal) and p-values (below diagonal)

|  |  |  |  |
| --- | --- | --- | --- |
| Matrix | Phenotypic | Genotypic | Joint |
| Phenotypic | - | -0.025 | -0.125 |
| Genotypic | 0.69 | - | 0.99 |
| Joint | 0.7 | 0.00 | - |

Additional file 3. List, source, and description of 90 cowpea genotypes used in the study

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| No. | Genotype | Source  | Description | No. | Genotype | Source  | Description |
| 1 | CP 1 | NGB | Elite line | 46 | ZM 2081 | NGB | Elite line |
| 2 | CP 2 | NGB | Elite line | 47 | ZM 2095 | NGB | Elite line |
| 3 | CP 4 | NGB | Elite line | 48 | ZM 2108 | NGB | Elite line |
| 4 | CP 6 | NGB | Elite line | 49 | ZM 2938 | NGB | Elite line |
| 5 | CP 11 | NGB | Elite line | 50 | ZM 2943 | NGB | Elite line |
| 6 | CP 12 | NGB | Elite line | 51 | ZM 2946 | NGB | Elite line |
| 7 | CP 102 | NGB | Elite line | 52 | ZM 2954 | NGB | Elite line |
| 8 | CP 305 | Malawi | Elite line | 53 | ZM 2966 | NGB | Elite line |
| 9 | CP 399 | Malawi | Elite line | 54 | ZM 2969 | NGB | Elite line |
| 10 | CP 411 | Malawi | Elite line | 55 | ZM 2999 | NGB | Elite line |
| 11 | CP 414 | Malawi | Elite line | 56 | ZM 3003 | NGB | Elite line |
| 12 | CP 418 | Malawi | Elite line | 57 | ZM 3064 | NGB | Elite line |
| 13 | CP 421 | Malawi | Elite line | 58 | ZM 3080 | NGB | Elite line |
| 14 | CP 426 | Malawi | Elite line | 59 | ZM 4710 | NGB | Elite line |
| 15 | CP 436 | Malawi | Elite line | 60 | ZM 5419 | NGB | Elite line |
| 16 | CP 479 | Malawi | Elite line | 61 | Mtilizi | UNZA | Elite line  |
| 17 | CP 570 | Malawi | Elite line | 62 | Bgene | Farmers | Landrace |
| 18 | CP 601 | Malawi | Elite line | 63 | Chiko | Farmers | Landrace |
| 19 | CP 633 | Malawi | Elite line | 64 | Chimponongo | Farmers | Landrace |
| 20 | CP 645 | Malawi | Elite line | 65 | Geneb | Farmers | Landrace |
| 21 | CP 698 | Malawi | Elite line | 66 | Kapita | Farmers | Landrace |
| 22 | CP 732 | Malawi | Elite line | 67 | Kapita black | Farmers | Landrace |
| 23 | CP 753 | Malawi | Elite line | 68 | Kapita North | Farmers | Landrace |
| 24 | CP 1769 | Malawi | Elite line | 69 | Chiparamba | Farmers | Landrace |
| 25 | CP 2223 | Malawi | Elite line | 70 | Kapita local | Farmers | Landrace |
| 26 | CP 2231 | Malawi | Elite line | 71 | Lute | Farmers | Landrace |
| 27 | CP 2232 | Malawi | Elite line | 72 | Lutechipata | Farmers | Landrace |
| 28 | CP 2863 | Malawi | Elite line | 73 | Lutembwe chipata | Farmers | Landrace |
| 29 | CP 2980 | Malawi | Elite line | 74 | Makulu | Farmers | Landrace |
| 30 | CP 3067 | Malawi | Elite line | 75 | Mount | Farmers | Landrace |
| 31 | CP 3413 | Malawi | Elite line | 76 | Muz | Farmers | Landrace |
| 32 | CP 3420 | Malawi | Elite line | 77 | BB X SC13(1) | UNZA | Mutant line |
| 33 | CP 3422 | Malawi | Elite line | 78 | BB10-4-2-5 | UNZA | Mutant line |
| 34 | CP 3423 | Malawi | Elite line | 79 | BB14-16-2-2 | UNZA | Mutant line |
| 35 | CP 3425 | Malawi | Elite line | 80 | BB3-9-7-5 | UNZA | Mutant line |
| 36 | 82E -16 | IITA  | Elite line | 81 | BB8-1-5-2 | UNZA | Mutant line |
| 37 | Bubebe | UNZA | Elite line | 82 | CP2 X SC 103(1) | UNZA | Mutant line |
| 38 | IT82E-16 | IITA | Elite line | 83 | LT11-3-3-12 | UNZA | Mutant line |
| 39 | L4 X L3(1) | NGB | Elite line | 84 | LT16-7-2-5 | UNZA | Mutant line |
| 40 | L8 X L9 | NGB | Elite line | 85 | LT4-2-4-1 | UNZA | Mutant line |
| 41 | LIO X L7(1) | NGB | Elite line | 86 | LT3-8-4-1 | UNZA | Mutant line |
| 42 | Msandile | UNZA | Elite line | 87 | LT4-2-4-14 | UNZA | Mutant line |
| 43 | Namuseba | UNZA | Elite line | 88 | LTII-3-3-13 | UNZA | Mutant line |
| 44 | Sudan 1 | Malawi | Elite line | 89 | LTII-5-2-2 | UNZA | Mutant line |
| 45 | ZM 1790 | NGB | Elite line | 90 | MSI-8-1-4 | UNZA | Mutant line |

NGB=The National Gene Bank, UNZA=The University of Zambia, all farmers were from Zambia

Note: All accessions from smallholder farmers were from Zambia.



Additional file 4. The Mantel test between phenotypic and genotypic matrices



Additional file 5. The Mantel test between phenotypic and joint matrices



Additional file 6. The Mantel test between genotypic and joint matrices



Additional file 7. Chromosomal distribution of the 14,166 SNPs used to evaluate 90 cowpea genotypes