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# GENEALOGICAL ANALYSIS OF THE NORTH-AMERICAN SPRING WHEAT VARIETIES WITH DIFFERENT RESISTANCE TO PRE-HARVEST SPROUTING

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*A comparative analysis of genetic diversity of North American spring wheat varieties differing in resistance to pre-harvest sprouting was carried out. For identification of sources of resistance the genealogical profiles of 148 red-grained and 63 white-grained North-American spring wheat varieties with full pedigrees were calculated and estimates were made of pre-harvest sprouting. The cluster structure of the populations of red-grained and white-grained varieties was estimated. Analysis of variance revealed significant differences between the average contributions of landraces in the groups of resistant and susceptible varieties. Distribution of the putative sources of resistance in the clusters indicated that varieties having different genetic basis may have different sources of resistance. For red-grained varieties the genetic sources of resistance to pre-harvest sprouting are landraces Crimean, Hard Red Calcutta, and Iumillo, or Button, Kenya 9M-1A-3, and Kenya-U, or Red Egyptian and Kenya BF4-3B-10V1. Tracking of pedigrees showed these landraces contributed to the pedigrees, respectively, via Thatcher, Kenya-Farmer, and Kenya-58, which were likely donors of resistance for red-grained varieties. For white-grained varieties the sources of resistance were landraces Crimean, Hard Red Calcutta, Ostka Galicyjska, Iumillo, Akakomugi, Turco, Hybrid English, Rough Chaff White and Red King, and putative donors of resistance — Thatcher, RL2265, and Frontana. The genealogical profile of accession RL4137, the most important donor of resistance to pre-harvest sprouting in North American spring wheat breeding programmes, contains almost all identified sources of resistance.*

**Key words:** *wheat, genealogical profile, pre-harvest sprouting, donors of resistance.*

## INTRODUCTION

Sprouting of physiologically mature grain in the ear at a relatively high humidity during ripening and during harvesting is called pre-harvest sprouting (PHS). Precipitation during this period can lead to increased activity of $\alpha$-amylase and trigger pre-harvest sprouting. PHS dramatically affects the rheological properties of dough and baking quality. This is one of the most important limiting factors influencing the production of high quality grain. Pre-harvest sprouting occurs in almost all wheat growing regions (Dobrotvorskaya and Martynov, 2013; Chono *et al.*, 2015). Resistance to PHS is based on seed dormancy, i.e. their ability to resist sprouting, despite favourable conditions for this. The techniques of selection for resistance to PHS include tests for sprouting of threshed seed or whole ears under natural and artificial moistening and indirect assessment of resistance by measuring the falling number (Krupnov and Krupnova 2015).

Analysis of genetic diversity allows to study the genetic basis of resistant and susceptible varieties, and to identify donors and sources of resistance to PHS. In this study we use the terms “source” and “donor” (Merezhko, 1994). Sources are forms (landraces, wild relatives of cultivated species, etc.), carrying desirable traits, which may be controlled by genes with negative pleiotropic effects or by those closely linked to undesirable genes. Donors are the genetic studied sources, which can be crossed with varieties of cultivated species to produce a highly fertile hybrid progeny, and possesses no negative traits that are closely associated with the selected characters.

Different approaches based on pedigree analysis can be used to assess genetic diversity by quantitative traits and molecular and biochemical markers. The genealogical approach involves tracing pedigrees by construction of genealogical profiles and their analysis by statistical methods. The genealogical profile is the spectrum of original ancestors, i.e. landrace and accessions with unknown pedigree, which are included in the unfolded pedigree varieties. The contribution of each original ancestor to a genome of variety is estimated by summing all possible paths linking this ancestor with the considered variety (Martynov, 1998). It is assumed that the original ancestors are unrelated and characterise the genetic diversity of a set of varieties. Genealogical analysis provides estimates correlated with estimates based on marker genes (Souza and Sorrells, 1991; Cox *et al.* 1995; Martynov *et al*., 2003, Chono *et al*., 2015).

This paper presents the results of comparative analysis of genetic diversity of North-American spring wheat varieties in relation to their resistance to PHS.

## MATERIALS AND METHODS

The object of the study were varieties of spring common wheat (*Triticum aestivum* L.) with complete pedigrees and estimates of the degree of resistance to PHS using information from literature sources extracted from a database of genetic resources (Anonymous, 2013). The set of North American varieties contained 211 accessions and consisted of four groups: red-grained resistant (112 accessions), red-grained susceptible (36), white-grained resistant (24), and white-grained susceptible (39).

The group of red-grained resistant accessions included: 405-JC-3C, 5500 HR, 5600 HR, 5601 HR, 5602 HR, 5604 HR CL, AC Baltic, AC Barrie, AC Cadillac, AC Carberry, AC Cora, AC Corinne, AC Domain, AC Eatonia, AC Foremost, AC Hartland, AC Kane, AC Majestic, AC Michael, AC Minto, AC Norboro, AC Shaw, AC Splendor, AC Superb, AC Walton, Acadia, Ada, Alikat, Alsen, Alvena, Barlow, Briggs, Burnside, BW-384, BW-597, BW-608, BW-655, Cardale, CDC Abound, CDC Alsask, CDC Bounty, CDC EMDR 14, CDC EMDR 4, CDC EMDR 9, CDC Kernen, CDC Makwa, CDC Rama, CDC Utmost, CDC Walrus, Cadet, Chinook, Chris, Columbus, Conway, Cutless, Dapps, Faller, Fieldstar, Glencross, Glenn, Goodeve, Grandin, Granger, Harvest, Helios, Hope, Howard, Invader, Journey, Katepwa, Knudson, Lake, Lancer, Leader, Lillian, Line 211, Lovitt, MN-95229, McKenzie, Marquillo, Marshall, McMurachy, Minnedosa, Muchmore, N91-2071, Neepawa, Oklee, Park, Parshall, Pasqua, Pembina, Pioneer 2375, Prodigy, PT-434, PT-435, PT-559, Reeder, Renown, RL4137, RL4471, RL6082, Somerset, Steele ND, Stettler, Thatcher, Tom, Unity, Verde, Vesper, Waskada, Wildcat, and WR-859 CL.

The group of red-grained susceptible varieties included: 5700 PR, AC Abbey, AC Crystal, AC Elsa, AC Intrepied, AC Taber, AC Vesper VB, Amazon, Biggar, Bigg Red, Bluesky, CDC Go, CDC Imagine, CDC Merlin, CDC Teal, CDC Thrive, CDC VR Morris, Chester, CT 615, Cutler, Garnet, Glenlea, HY 320, Infinity, Laser, Laura, Marquis, Oslo, Peace, Prelude, Red Fife, Rescue, RL4452, Rival, Roblin, and Samson.

The group of white-grain resistant varieties included: AC 2000, AC Karma, AC Snowstar, AC Vista, DH F-72, DH H-79, Depauws Dormant White Seed Sel.1, Depauws Dormant White Seed Sel.2, Depauws Dormant White Seed Sel.3, HY 361, Kanata, Losprout, P 8810 B5-B3-A2-A2, RL4137W, RL4555, SC 8019-R1, SC 8021-V1, SC 8021-V2, Snowbird, Snowhite 475, Snowhite 476, SWS-52, W-98616, and Whitehawk.

The group of white-grained susceptible varieties was: 7722, AC Andrew, AC Reed, Argent, Cascade, ES 34, Fielder, Genesis, HY 358, Owens, AC Nanda, AC Phil, Alpowa, Alturas, Babe, Blanca, Bliss, Centennial, Challis, Clear White, Edwall, Explorer, Idaho 377S, Jubilee, Klasic, Lolo, MTHW 9420, Otis, Patwin, Penawawa, Pomerelle, Treasure, UI Cataldo, UI Pettit, Waxy Pen, Whit, Whitebird, Winsome, and Zak.

Genetic diversity of North American spring wheat varieties resistant and susceptible to PHS were studied by analysis of pedigrees and calculation of genealogical profiles of varieties using the programme GRIS 4.0 (Martynov and Dobrotvorskaya, 2009) and database (Anonymous, 2013).

The matrices of genealogical profiles were subjected to two-way analysis of variance with replications separately for red-grained and white-grained varieties. The investigated factors were resistance group (factor *A*), dominant landraces with frequency of presence in pedigrees 70–100% (factor *B*) and interaction ($A \times B$). Replications were varieties from the respective groups.

Average contributions of landrace for the analysed varieties differed greatly. For example, the average contribution of landrace Hard Red Calcutta in the set of red-grained varieties was 0.1631, Iumillo — 0.0762, Red Egyptian — 0.0085, etc. This violated an assumption of ANOVA about homogeneity (equality) of variance. To ensure homogeneity of sample variances, standardisation of contribution of landrace was carried using the formula $y_i' = (y_i - \bar{Y}) / S$, where $y_i$ – contribution of landrace in pedigree *i*-th variety $y_i'$ – standardised contribution, $\bar{Y}$ – the average contribution of landrace, *S* – standard deviation. The standardized contribution of each landrace with probability $P = 0.99$ varied in the range from –3.0 to +3.0 with a mean of zero.

## RESULTS

White-grained varieties are generally more susceptible to pre-harvest sprouting than red-grained (Gfeller and Svejda, 1960), although both wheat groups vary in this respect. Therefore, analysis of variance of ancestral contributions was carried separately for red-grained and white-grained varieties.

The pool of original ancestors of red-grained and white-grained varieties consisted of 220 and of 162 landraces and accessions, respectively, with unknown pedigree. For further statistical analysis, 41 and 36 dominant landraces were selected among original ancestors of red-grained and white-grained varieties, respectively. The last 36 landraces dominated in pedigrees of both red-grained and white-grain varieties.

Two-way analysis of variance of the standardised contributions of dominant landraces for both red-grained, and for

Table 1

ANALYSIS OF VARIANCE OF STANDARDISED CONTRIBUTIONS OF DOMINANT LANDRACES

| Sources | Red-grained varieties | | | White-grained varieties | | |
|---|---|---|---|---|---|---|
| | Df | Ms | F | Df | Ms | F |
| Total | 6067 | – | – | 2267 | – | – |
| Groups of resistance (A) | 1 | 32.90 | 34.06* | 1 | 39.09 | 44.03* |
| Landraces (B) | 40 | 1.10 | 1.14 | 35 | 0.37 | 0.42 |
| Interaction (A×B) | 40 | 4.18 | 4.33* | 35 | 6.57 | 7.40* |
| Error | 5986 | 0.97 | – | 2196 | 0.89 | – |

*Significant at the $p < 0.001$

white-grain varieties showed significant interaction ($A \times B$) between groups of resistance (factor $\grave{A}$) and landraces (factor $B$). This indicates that the contributions of the landraces are differently distributed in the groups of resistant and susceptible varieties (Table 1)

Comparison of the standardised average contributions of original ancestors of red-grained varieties showed that the resistant and susceptible groups differed significantly and eight landraces had significantly greater contribution in the resistant group — Button, Crimean, Hard Red Calcutta, Iumillo, Kenya 9M-1A-3, Kenya BF4-3B-10V1, Kenya-U, Red Egyptian and 15 landraces with a significantly greater contribution in the susceptible group — Aguilera, Akakomugi, Barleta, Carosella *et al.* (Table 2). It is likely that there are sources of resistance to PHS among landraces with higher contribution among the resistant group.

The analysed set of red-grained varieties has a cluster structure (Fig. 1). Six clusters were identified by cluster analysis of the genealogical profiles matrix (algorithm UPGMA, similarity measure — correlation coefficient) of 23 landraces. In three clusters (1, 5, and 6), which combined 44, 40, and 6 varieties, respectively, the vast majority (93%) were resistant varieties. In three other clusters (2, 3, and 4), which contained 9, 31, and 18 varieties, respectively, more than a half (52%) were susceptible varieties. The ratio of resistant and susceptible varieties in clusters 1–6 is shown in Table 3.

Two-way analysis of variance showed a highly significant interaction between landraces and identified clusters ($F$ = 19.78 for $df1$ = 110 and $df2$ = 3243). Multiple comparisons of average contributions of landraces (Table 3) showed that of the eight prospective sources of resistance, three (Crimean, Hard Red Calcutta, and Iumillo) had higher average contribution to the pedigrees of resistant varieties belonging to cluster 1. The other five landraces in this cluster had low contributions. Landraces Button, Kenya 9M-1A-3 and Kenya-U stood out in cluster 5, while contributions of the first three were low. Two landraces (Red Egyptian and Kenya BF4-3B-10V1) had the most significant contributions to the pedigrees of resistant varieties belonging to cluster 6, whereas the landraces dominant in clusters 1 and 5 had low contributions.

In the set of white-grained varieties, there were 13 landraces whose contributions were significantly higher in the group of resistant varieties, and 6 landraces with large contributions in the group of susceptible varieties (Table 4). For comparison, this table also presents landraces whose contributions differed significantly between the groups of resistant and susceptible red-grained varieties.

The set of white-grained varieties also had a cluster structure. Cluster analysis of the genealogical profiles matrix of 19 landraces identified four clusters. One cluster contained mostly resistant varieties (75%), one contained only susceptible (100%), and the remaining two were equally represented both resistant and susceptible varieties.

Two-way analysis of variance showed highly significant interaction between landraces and the identified clusters ($F$ = *2.51* for $df1 = 54$ and $df2 = 1121$). Multiple comparisons of average contributions of landrace by the Duncan test, taking

Table 2

STANDARDISED CONTRIBUTIONS OF LANDRACES IN THE GROUPS OF RESISTANT (R) AND SUSCEPTIBLE (S) TO PRE-HARVEST SPROUTING RED-GRAINED SPRING WHEAT VARIETIES

| Landrace | R | S | Landrace | R | S |
|---|---|---|---|---|---|
| Aguilera | –0.2452 | 0.7630** | Kenya 9M-1A-3 | 0.0971* | –0.3022 |
| Akakomugi | –0.1840 | 0.5724** | Kenya BF4-3B-10V1 | 0.0865* | –0.2692 |
| Barleta | –0.1881 | 0.5851** | Kenya-U | 0.0971* | –0.3022 |
| Button | 0.0867* | –0.2698 | LV-URY via Amer.44 | –0.1812 | 0.5637** |
| Carosella | –0.0857 | 0.2664* | Marroqui | –0.1630 | 0.5071** |
| Chinese 466 | –0.1767 | 0.5499** | Mediterranean | –0.1390 | 0.4323** |
| Crimean | 0.1641** | –0.5105 | Polyssu | –0.1228 | 0.3822** |
| Daruma | –0.1422 | 0.4423** | Redchaff | –0.1418 | 0.4411** |
| Etawah | –0.1085 | 0.3375** | Red Egyptian | 0.0864* | –0.2688 |
| Gehun | –0.0802 | 0.2495* | Rieti | –0.1818 | 0.5656** |
| Hard Red Calcutta | 0.0857* | –0.2666 | Turco | –0.0742 | 0.2309 |
| Iumillo | 0.1518** | –0.4722 | Zeeuwse | –0.1839 | 0.5723** |

*, ** Differences between contributions of landrace in the groups of resistant (R) and susceptible (S) to the PHS varieties are significant at the levels $p \leq 0.05$(*) and $p \leq 0.01$(**).

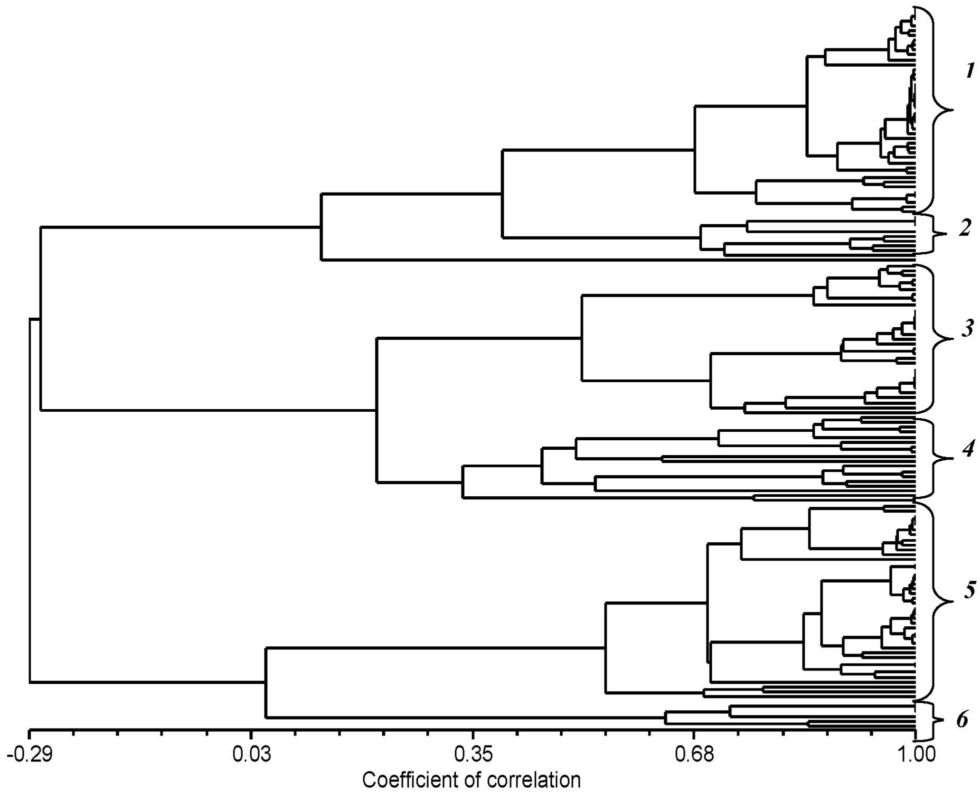


*Fig. 1.* Dendrogram of cluster analysis of red-grained wheat varieties of 23 landraces (algorithm UPGMA, similarity measure — correlation coefficient).

Table 3

STANDARDISED AVERAGE CONTRIBUTIONS OF LANDRACES* IN CLUSTERS OF RED-GRAINED VARIETIES

| Landrace | Clusters† | | | | | |
|---|---|---|---|---|---|---|
| | 1(42R:2S) | 2(5R:4S) | 3(13R:18S) | 4(10R:8S) | 5(37R:3S) | 6(5R:1S) |
| Crimean | **1.02d** | –1.68a | –0.22c | –1.01b | –0.12c | 0.17c |
| Hard Red Calcutta | **0.80c** | 1.36d | –0.47b | –1.17a | –0.27b | –0.04b |
| Iumillo | **1.09e** | –1.03a | –0.32c | –0.89a | –0.33bc | 0.23d |
| Button | –0.46a | –0.71a | –0.51a | –0.50a | **1.38b** | –0.63a |
| Kenya 9M-1A-3 | –0.49a | –0.72a | –0.55a | –0.50a | **1.44b** | –0.65a |
| Kenya-U | –0.49a | –0.72a | –0.55a | –0.50a | **1.44b** | –0.65a |
| Red Egyptian | –0.50a | –0.80a | 0.07bc | –0.47a | 0.48c | **2.65d** |
| Kenya BF4-3B-10V | –0.50a | –0.80a | 0.07bc | –0.47a | 0.48c | **2.65d** |
| Polyssu | –0.52b | –1.21a | 1.07e | –0.50b | 0.19cd | 0.30d |
| Akakomugi | –0.55b | –1.18a | 1.02d | –0.15bc | 0.12c | 0.08c |
| Aguilera | –0.60a | –0.83a | 1.02d | 0.61cd | –0.13b | –0.65a |
| Rieti | –0.55b | –1.16a | 0.94d | –0.07c | 0.15c | 0.03c |
| Barleta | –0.38a | –0.66a | 1.61b | –0.26a | –0.49a | –0.52a |
| Mediterranean | –0.47ab | –0.88a | 0.48d | 0.96e | –0.10bc | –0.01c |
| Marroqui | –0.65a | –0.79a | 0.33bcd | 0.47cd | 0.51d | –0.70a |
| Chinese 466 | –0.40a | –0.61a | 1.58b | –0.23a | –0.49a | –0.46a |
| LV-URY via Amer.44 | –0.36a | –0.62a | 1.46b | –0.24a | –0.42a | –0.50a |
| Zeeuwse | –0.55b | –1.19a | 1.02d | –0.14bc | 0.12c | 0.08c |
| Daruma | –0.52a | –0.69a | 0.24c | 0.97d | 0.09c | –0.05bc |
| Redchaff | –0.26a | –0.30a | –0.05a | 1.05b | –0.08a | –0.10a |
| Carosella | –0.17a | 1.29b | –0.14a | 0.05a | –0.00a | –0.14a |
| Etawah | –0.34a | –0.41a | –0.03ab | 1.24c | –0.10ab | 0.20b |
| Gehun | –0.17a | 1.18c | –0.14a | 0.43b | –0.15a | –0.12a |

*Values (inside a line) followed by a different letter are significantly different at $p \leq 0.05$ (Duncan range test). The sources of resistance to PHS in the clusters of resistant varieties are shown in bold.

† The ratio of resistant (R) and susceptible (S) varieties in the cluster is shown in parentheses.

Table 4

STANDARDISED CONTRIBUTIONS OF LANDRACES IN THE GROUPS OF RESISTANT (R) AND SUSCEPTIBLE (S) TO PRE-HARVEST SPROUTING OF WHITE-GRAINED SPRING WHEAT VARIETIES

| Landrace | R | S | Landrace | R | S |
|---|---|---|---|---|---|
| Akakomugi | 0.2673 | –0.1337 | Mediterranean | –0.2429 | 0.1495 |
| Button | 0.2992 | –0.1496 | Ostka Galicyjska | 0.5489** | –0.3378 |
| Carosella | –0.4319 | 0.2160** | Polyssu | 0.3900* | –0.2400 |
| Crimean | 0.3371* | –0.2075 | Redchaff | –0.2632 | 0.1316 |
| Daruma | –0.7172 | 0.3586** | Red King | 0.8614** | –0.4307 |
| Etawah | –0.6007 | 0.3003** | Red Straw | –0.4407 | 0.2204** |
| Gehun | 0.4466** | –0.2233 | Rieti | 0.3195* | –0.1966 |
| Hard Red Calcutta | 0.7976** | –0.4908 | Rough Chaff White | 0.8610** | –0.4305 |
| Hybrid English | 0.8612** | –0.4306 | *Tr. timopheevii* | –0.3196 | 0.1598* |
| Iumillo | 0.6549** | –0.3275 | Turco | 0.6281** | –0.3866 |
| Kenya 9M-1A-3 | 0.3058 | –0.1529 | Yaroslav Emmer | 0.5238** | –0.2619 |
| Kenya-U | 0.3058 | –0.1529 | Zeeuwse | 0.2030 | –0.1015 |
| Marroqui | –0.6590 | 0.4055** | Ladoga | 0.3974* | –0.1987 |

*, **Differences between contributions of landrace in the groups of resistant (R) and susceptible (S) to the PHS varieties are significant at $p \leq 0.05$(*) and $p \leq 0.01$(**).

into account the cluster structure, showed a significant predominance of contributions to the pedigrees of resistant varieties for nine landraces: Crimean, Hard Red Calcutta, Ostka Galicyjska, Iumillo, Akakomugi, Turco, Hybrid English, Rough Chaff White and Red King.

Tracking of pedigrees showed that the probable donors of resistance for white-grained varieties were Thatcher, RL2265 = McMurachy / Exchange and Frontana = Fronteira / Mentana. Comparison of the average contribution of these varieties in resistant and susceptible groups (Table 5) indicated that they are probable donors of resistance to PHS for white-grained varieties.

Table 5

AVERAGE CONTRIBUTIONS* AND FREQUENCY OF PRESENCE OF PROSPECTIVE DONORS OF RESISTANCE TO PHS IN WHITE-GRAINED VARIETIES OF SPRING WHEAT

| Prospective donor | Resistant varieties | Susceptible varieties |
|---|---|---|
| Thatcher | 0.25b (95%) | 0.09a (95%) |
| RL2265 | 0.02b (89%) | 0.00a (0%) |
| Frontana | 0.21b (95%) | 0.08a (95%) |

*Average contributions followed by a different letter inside a line are significantly different at $p \leq 0.05$.

## DISCUSSION

Distribution of prospective sources of resistance in clusters indicated that varieties having different genetic basis may have different sources of resistance to the PHS. Varieties such as AC Cora, AC Majestic, AC Michael, CDC Alsask, and other varieties of cluster 1 can have the landraces Crimean, Hard Red Calcutta, and Iumillo as sources of resistance. Tracking of pedigrees showed that a donor of resistance in these varieties is an American red-grained variety Thatcher = Marquis / (TR.DR) Iumillo // (HN-3001) Marquis / Kanred. For varieties AC Carberry, AC Domain, AC Superb, Journey and other varieties from cluster 5 the sources of resistance were Button, Kenya 9M-1A-3 and Kenya-U, whereas the donor of resistance was Kenyan white-grained variety, Kenya Farmer = Australian 27/Kenya 192. For varieties AC Eatonia, Conway, Knudson, Lancer, and Leader the sources of resistance were likely landraces Red Egyptian and Kenya BF4-3B-10V1, and the donor of resistance was Kenyan red-grained variety Kenya 58 = Red Egyptian / Kenya BF4-3B-10V1.

Thus, sources of resistance to PHS in North-American red-grained spring wheat varieties were landraces Crimean, Hard Red Calcutta, and Iumillo, or Button, Kenya 9M-1A-3, and Kenya-U, or Red Egyptian and Kenya BF4-3B-10V1. Tracking of pedigrees of red-grained varieties resistant to PHS showed that these landraces received resistance via Thatcher, Kenya-Farmer, and Kenya 58, respectively. Comparison of the average contributions of these varieties in the groups of resistant and susceptible varieties (Table 6) indicates that they were likely donors of resistance to PHS for red-grained varieties. For example, variety Thatcher was a donor of resistance for varieties belonging to the cluster 1, but not for varieties from clusters 5 and 6, and variety Kenya Farmer was a donor of resistance for varieties belonging to the cluster 5, but not for varieties from clusters 1 and 6.

Tracking of pedigrees showed that the donors of resistance for white-grain varieties were Thatcher, RL2265 = McMurachy / Exchange and Frontana = Fronteira / Mentana. Comparison of the average contributions of these varieties in the resistant and in the susceptible groups (Table 6) also showed that they were probable donors of resistance to PHS in the white-grain varieties.

Table 6

AVERAGE CONTRIBUTIONS* OF PROSPECTIVE DONORS OF RESISTANCE TO PHS IN RED-GRAINED VARIETIES OF SPRING WHEAT. FREQUENCY OF PRESENCE IN A PEDIGREE IS SHOWN IN PARENTHESES

| Prospective donors of resistance | Resistant | | | Susceptible (Clusters 2–4) |
|---|---|---|---|---|
| | Cluster 1 | Cluster 5 | Cluster 6 | |
| Thatcher | **0.680c (93%)** | 0.297a (100%) | 0.484b (100%) | 0.253a (82%) |
| Kenya Farmer | 0.004a (76%) | **0.037b (100%)** | 0.001a (40%) | 0.004a (51%) |
| Kenya 58 | 0.005a (59%) | 0.027b (97%) | **0.080c (100%)** | 0.010a (66%) |

*Average contributions followed by a different letter inside a line are significantly different at $p \leq 0.05$ (Duncan range test). Contributions of resistance donor for the varieties belonging to different clusters is shown in bold.

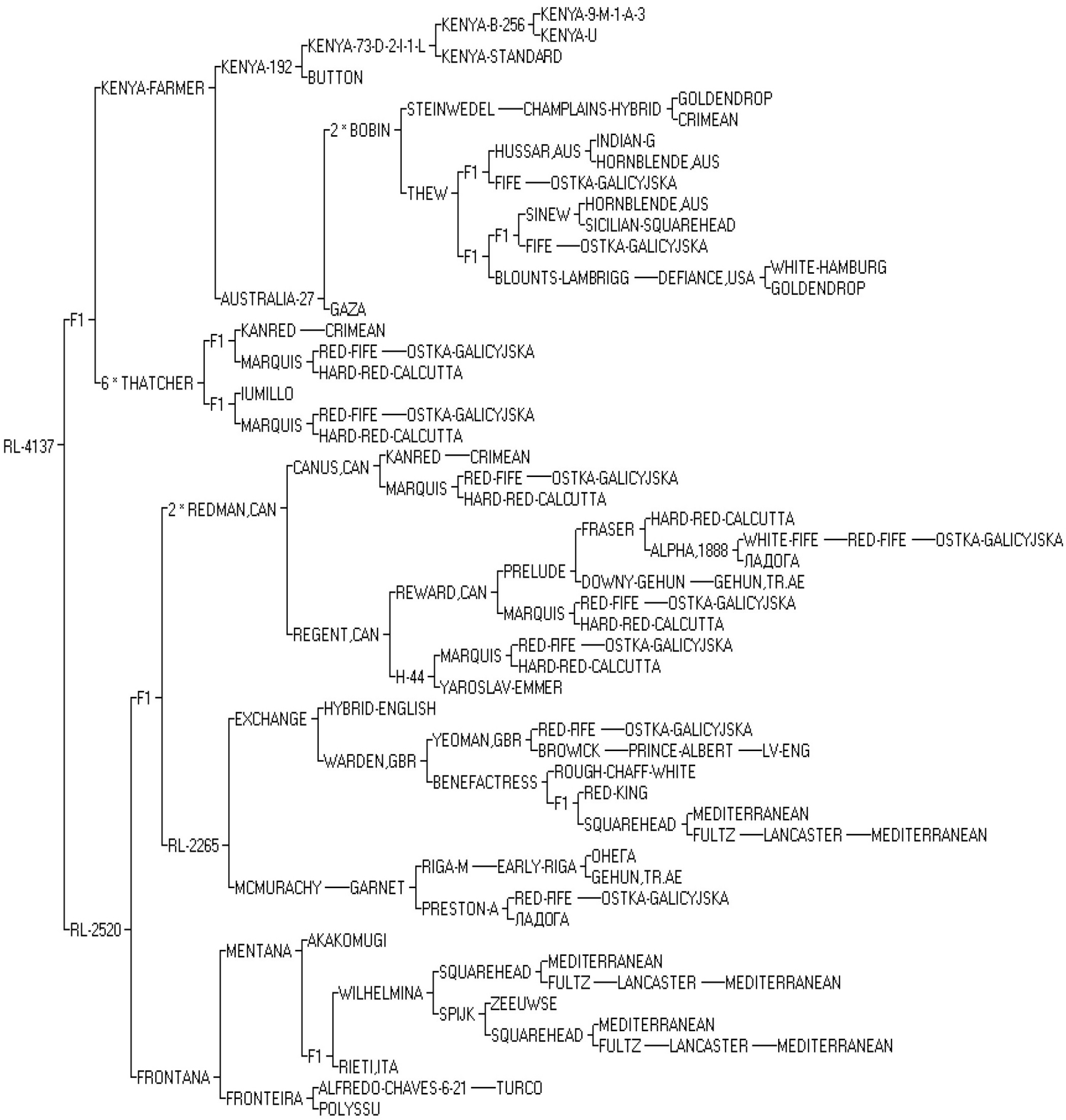


*Fig. 2.* Pedigrees of accession RL4137, donor of resistance to pre-harvest sprouting in North-American spring wheat varieties.

It is known that the most important donor of resistance to PHS for North American spring wheat varieties is accession RL4137 (Fig. 2). This accession in different conditions stably shows high resistance caused by two factors, one of which is associated with red-coloured grain, and another is not present (DePauw *et al.* 2009). In accession RL4137 = Frontana//RL2265/2*Redman(RL2520)/3/Thatcher*6/Kenya Farmer several probable donors of resistance are incorporated — Thatcher, Frontana, Kenya Farmer, RL2265. Of 18 landraces with a significantly greater contribution to groups of resistant red-grained and/or white-grained varieties (Table 2 and 5), 16 landraces were included in the genealogical profile of accession RL4137 (Table 7). Accession RL4137 is included in the pedigrees of the majority of

Table 7

GENEALOGICAL PROFILE OF ACCESSION RL4137

| Landrace* | Country | Contribution | Landrace | Country | Contribution |
|---|---|---|---|---|---|
| **Hard Red Calcutta** | IND | 0.1798 | Onega | RUS | 0.0044 |
| **Crimean** | UKR | 0.1595 | **Rough Chaff White** | ENG | 0.0039 |
| **Ostka Galicyjska** | POL | 0.1399 | LV-ENG (Prince Albert) | ENG | 0.0022 |
| **Iumillo** | ITA | 0.0812 | **Red King** | USA | 0.0020 |
| Polyssu | BRA | 0.0625 | **Button** | KEN | 0.0020 |
| **Akakomugi** | JPN | 0.0625 | Kenya Standard | KEN | 0.0010 |
| **Turco** | BRA | 0.0469 | Goldendrop | ENG | 0.0008 |
| Rieti | ITA | 0.0313 | **Kenya-U** | KEN | 0.0005 |
| Mediterranean | USA | 0.0198 | **Kenya 9-M-1-A-3** | KEN | 0.0005 |
| **Hybrid English** | ENG | 0.0156 | Gaza | EGY | 0.0004 |
| Yaroslav Emmer | RUS | 0.0155 | Hornblende | USA | 0.0003 |
| Gehun | IND | 0.0132 | Indian-G | IND | 0.0002 |
| Ladoga | RUS | 0.0088 | White Hamburg | NLD | 0.0002 |
| Zeeuwse | NLD | 0.0078 | Sicilian Squarehead | ITA | 0.0001 |

*Landraces with a significantly greater contribution to a pedigree of resistant to PHS white-grain and/or red-grained varieties are shown in bold.

resistant accessions, whereas for the susceptible accessions, its frequency of presence was very low. For example, the vast majority of resistant white-grained accessions (79%) included accession RL4137 in their pedigree, whereas all susceptible white-grain varieties lacked this accession in their pedigrees.

Pedigrees analysis using the information and analytical system GRIS4.0 confirmed the importance of accession RL4137 for North American spring wheat breeding programmes for resistance to PHS. This accession enters in the pedigrees of 390 accessions as a direct parent (AC Corinne, Columbus, Snowbird, Losprout, etc.), or as a progenitor (AC Barrie, AC Domain, McKenzie, etc.). Among the descendants of accession RL4137 are 71 released varieties and 204 advanced lines from Canada, as well as 28 released varieties and 60 advanced lines from the United States.

Thus, using comparative analysis of the genetic diversity of the set of 211 North American spring wheat varieties differing in resistance to pre-harvest sprouting a search of donors and sources of resistance was carried. The sources of resistance to PHS can be divided into two groups. The first consists of Crimean, Hard Red Calcutta, and Iumillo (donor resistance — Thatcher). Their effectiveness is not dependent on the grain colour. The second group includes specific sources Button, Kenya 9M-1A-3, and Kenya-U (donor Kenya Farmer). Kenya BF4-3B-10V1, and Red Egyptian (donor — Kenya 58), are effective for red-grain wheat; Gehun, Hybrid English, Ostka Galicyjska, and Ladoga (donor — RL2265); Polyssu, Rieti, Turco (donor — Frontana); Red King, Rough Chaff White, Yaroslav Emmer (donor — RL4137) — for white-grain wheat. Identified donors of resistance may contribute to the choice of the most favourable genetic basis in breeding programmes of spring wheat for resistance to pre-harvest sprouting.

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## ĢENEALOĢISKĀ ANALĪZE ZIEMEĻAMERIKAS VASARAS KVIEŠU ŠĶIRNĒM AR ATŠĶIRĪGU IZTURĪBU PRET GRAUDU SADĪGŠANU VĀRPĀS

Veikta salīdzinoša ģenētiskās daudzveidības analīze Ziemeļamerikas vasaras kviešu šķirnēm, kuras atšķiras ar izturību pret graudu sadīgšanu vārpās. Lai identificētu izturības avotus, tika aprēķināti ģenētiskie profili 148 sarkangraudainām un 63 baltgraudainām vasaras kviešu šķirnēm ar pilniem ciltskokiem, kurām ir zināma izturība attiecībā uz graudu sadīgšanu vārpās. Parādīts atšķirīgs vietējo formu (*landraces*) ieguldījums izturīgām un neizturīgām šķirnēm. Noteikts, ka izturības avoti sarkangraudainām un baltgraudainām vasaras kviešu šķirnēm ir bijuši atšķirīgi.