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Cytogenetic Analysis Of Sugar Beet (Beta Vulgaris L.) Varietal Samples Selected As Initial Material

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Abstract: The article presents a cytogenetic analysis of selected sugar beet (Beta vulgaris L.) varieties used as initial material for genetic research. Cytogenetic characterization and idiogram construction were performed for the sugar beet varieties Nimerchanskaya-030, Onyx, Novella, Lara, Diyor, Druzhba, and Victoria. Somatic metaphase chromosomes from two samples of each variety were analyzed, and idiograms were generated using the IdeoKar software and finalized in Adobe Photoshop. Karyotype analysis included 14 parameters, such as average chromosome length, total form percentage, centromeric index, arm ratio, and asymmetry indices (AsK%, A_1, A_2, AI). All varieties exhibited a diploid chromosome number of 2n = 18, consisting of metacentric and submetacentric chromosomes; however, significant differences were observed among the varieties in terms of chromosome length, centromere position, and arm ratio. Haploid chromosome analysis revealed structural diversity: large chromosomes were generally submetacentric, while small ones were metacentric, reflecting both intra- and inter-chromosomal variability. The idiograms visually demonstrated these differences, providing an important basis for cytogenetic identification of varieties, comparative karyotype analysis, and breeding programs. The results contribute to a deeper understanding of the sugar beet genome structure and provide valuable data for genetic improvement programs.

Keywords: Beta vulgaris, sugar beet, karyotype, cytogenetics, idiogram, chromosome morphology.

Introduction: Sugar beet (Beta vulgaris L..) belongs to

the family Chenopodiaceae and is one of the most economically important forms of Beta vulgaris. It is primarily cultivated for sucrose extraction and plays a significant role in agriculture across temperate regions such as Europe, Central Asia, and North America [1,2]. In Uzbekistan, this crop represents a key raw material for both the food industry and sugar production sectors. The plant is notable for its high sugar content, strong environmental adaptability, high yield potential, and resistance to various diseases and pests. For these reasons, sugar beet is often used as a model organism in genetic, physiological, and breeding studies.

The diploid chromosome number of sugar beet is 2n = 18, and the haploid genome size is approximately 758 Mb [3]. Its chromosomes are relatively small (around 2 µm at condensed metaphase), mostly metacentric, and show little morphological differentiation, making precise identification and numbering difficult. Karyotype analysis is a fundamental cytogenetic approach to study chromosome number, size, and morphology. However, detailed cytogenetic data on B. vulgaris, particularly regarding its chromosomal architecture, remain limited [4].

Additionally, leaf beet (Beta vulgaris L. var. cicla), a hybrid of the leaf subspecies of common sugar beet and coastal sugar beet subspecies, was artificially selected as a leaf vegetable, dating back to 2000 BC [4,5]. Leaf beet is valued for its high pigment content, yield, disease resistance, and adaptability. Sun et al. (2019) studied the karyotypes of leaf beet varieties and found that their chromosomes were composed of metacentric and submetacentric types, with each variety containing one pair of satellites. Their research indicated that the leaf beet varieties had a primitive evolutionary status, based on karyotype symmetry and average arm ratio [4].

In this study, seven varieties of sugar beet (Beta vulgaris L. var. saccharifera Alef.): Nimerchanskaya-030, Oniks, Novella, Lara, Diyor, Drujba, and Viktoriya, were subjected to comparative chromosomal analysis. The main objective was to examine their chromosome composition and structural diversity, thereby providing a cytogenetic foundation for further genetic, evolutionary, and breeding investigations of this economically important crop.

Methods

In this study, seven varieties of sugar beet (Beta vulgaris L. var. saccharifera Alef.) were investigated for chromosome analysis. The varieties studied were Nimerchanskaya-030, Oniks, Novella, Lara, Diyor, Drujba, and Viktoriya. The Novella variety was obtained from the “Zea” seed company collection, while the remaining varieties were obtained from the Institute of Plant Genetic Resources (Gene Bank Collection of the Academy of Sciences of the Republic of Uzbekistan). For cytological analysis, healthy and actively growing plants were selected, and root tips (meristematic tissues) were used for chromosome study. The biological materials were fixed and hydrolyzed using 38% orthophosphoric acid (H_3PO_4) [6]. The prepared samples were then subjected to staining, microscopic observation, and morphometric measurements, and the karyotype structure of each variety was determined.

The tips of newly developed roots, measuring 1–3 cm in length, were excised and utilized for somatic chromosome analysis. Only root tips were employed in this study. For handling the roots, 1.5 ml Eppendorf tubes were used. The roots were pretreated in a 0.1% colchicine solution at room temperature (approximately 25 °C) for 5–6 hours, followed by three washes in distilled water at room temperature, each lasting 5 minutes. For fixation and maceration (softening), phosphoric acid was applied as a hygroscopic agent and to hydrolyze cell membranes. Samples were treated at room temperature in a 38% H_3PO_4 solution (H_3PO_4: H_2O = 1:2, v/v) for 1 to 10 minutes, with the optimal time considered to be 2–3 minutes [6].

The obtained samples were stained with a 2% (w/v) orcein solution for 5–20 minutes, then transferred to a 1% (w/v) aceto-orcein solution for an additional 5–10 minutes [7]. Following staining, the roots were macerated in a 1% (w/v) aceto-orcein solution.

For microscopy preparation, stained roots were placed on glass slides. The mitotic zone, identifiable by staining, was cut with a clean razor blade and excess tissue removed. The division zone was then sectioned into several fragments of 1–2 mm, each covered with a coverslip [7]. Excess acetic acid was removed using filter paper.

Metaphase images were captured using bright-field light microscopy with a KERN OBN 132 microscope (KERN & SOHN GmbH, Germany) at 1000× magnification. At least five metaphase plates per sample were analyzed, with two metaphase plates used specifically for chromosome counting.

Morphometric measurements of chromosomes and ideogram construction were performed using Ideo-Kar 1.3 software (https://agri.uok.ac.ir/ideokar/download.html) [8]. Chromosome metaphase images were collected using KERN OPTICS S-EYE 1.10.7 software, and chromosome pairing was conducted in Adobe Photoshop CS6 (Adobe Systems, USA).

Chromosomal parameters and karyotype asymmetry

indices were calculated based on formulas incorporated into IdeoKar 1.3 [8].

Standard karyotype measurements (AR, CL, r, RL%, CI, karyotype type) and asymmetry indices (F%, HCL, TF%, AsK%, A1, A2, S%, XCI, A, xCA, CVCL, CVCI, AI) were computed; detailed definitions, formulas, and units are provided in the supplementary file.

Chromosomes were classified according to the nomenclature proposed by Levan et al. [9], based on centromere position, using arm ratio (AR = L/S) and centromeric index (CI × 100 = S/(L + S) × 100) as key criteria. Chromosomes with AR = 1.00 and CI = 50 were designated as median point (M); AR between 1.01 and 1.70 and CI between 50 and 39.5 as median region (m); AR 1.71–3.00 and CI 39.5–25 as submedian region (sm); AR 3.01–7.00 and CI 25–12.5 as subterminal region (st); AR > 7.00 and CI 12.5–0 as terminal region (t). Chromosomes with infinite AR (∞) and CI 0 were classified as terminal point (T). This classification served as the primary criterion for determining morphological chromosome types. Karyotype classification based on asymmetry degree followed the system by Stebbins [10], which evaluates two main parameters: the ratio of longest to shortest chromosome (CLmax/CLmin) and the proportion of chromosomes with arm ratio (AR) less than 2, indicating symmetrical chromosomes. Based on four length ratio categories (1.00; 0.99–0.51; 0.50–0.01; 0.00) and three classes of centromere position symmetry (A: mostly symmetrical; B: moderately asymmetrical; C: highly asymmetrical), karyotypes are classified into 12 categories from 1A to 4C. This classification was used to assess the evolutionary level of karyotype structure in the studied species.

Measurements were performed using IdeoKar 1.3 software, and mean values and standard deviations were calculated with Microsoft Excel 2016. For each parameter (arm length, total length, centromere index, arm ratio, etc.), the mean (M) and standard error of the mean (SEM) were determined.

Results

Somatic chromosomes and idiograms of seven Beta vulgaris L. var. saccharifera Alef. varieties (Nimerchanskaya-030, Oniks, Novella, Lara, Diyor, Drujba, and Viktoriya) were analyzed to assess the chromosomal morphology and karyotype structure. All varieties exhibited a diploid chromosome number of 2n = 2x = 18, consistent across all samples. Microphotographs of somatic metaphase plates (Figures 1–7) were obtained from two individuals per variety, with one metaphase plate analyzed per individual. Idiograms for each variety were constructed based on measured chromosome parameters, including chromosome length, arm ratio, and centromeric index, and were graphically arranged using Adobe Photoshop. These idiograms illustrate the relative positions and proportions of chromosomes, highlighting inter-varietal variation in chromosomal structure. Nimerchanskaya-030 (Figure 1): Chromosomes ranged from small to medium size, with a mixture of submetacentric and metacentric types. Chromosomes 1–3 were relatively longer, whereas chromosomes 8 and 9 were the smallest. Submetacentric chromosomes predominated, as indicated by higher arm ratio values. Oniks (Figure 2): This variety exhibited moderately symmetric chromosomes, with a balanced distribution of submetacentric and metacentric chromosomes. Chromosomes 1, 2, and 5 were the largest, while chromosome 9 was the smallest. The centromeric index showed slight variability, suggesting minor differences in centromere positions compared to Nimerchanskaya-030. Novella (Figure 3): Chromosomal analysis revealed a predominance of metacentric chromosomes, particularly in the middle-sized chromosomes (3–6). Larger chromosomes such as 1 and 2 displayed higher arm ratios, indicating slight asymmetry. Overall, the karyotype showed a more symmetric distribution than Nimerchanskaya-030 and Oniks. Lara (Figure 4): Chromosomes were relatively small and compact, with the majority classified as metacentric. Submetacentric chromosomes were limited to certain chromosomes (e.g., 2 and 4), reflecting minor inter-chromosomal asymmetry. The karyotype exhibited high symmetry, which may indicate stable structural features within this variety. Diyor (Figure 5): This variety demonstrated a combination of metacentric and submetacentric chromosomes, with larger chromosomes (1–3) showing higher arm

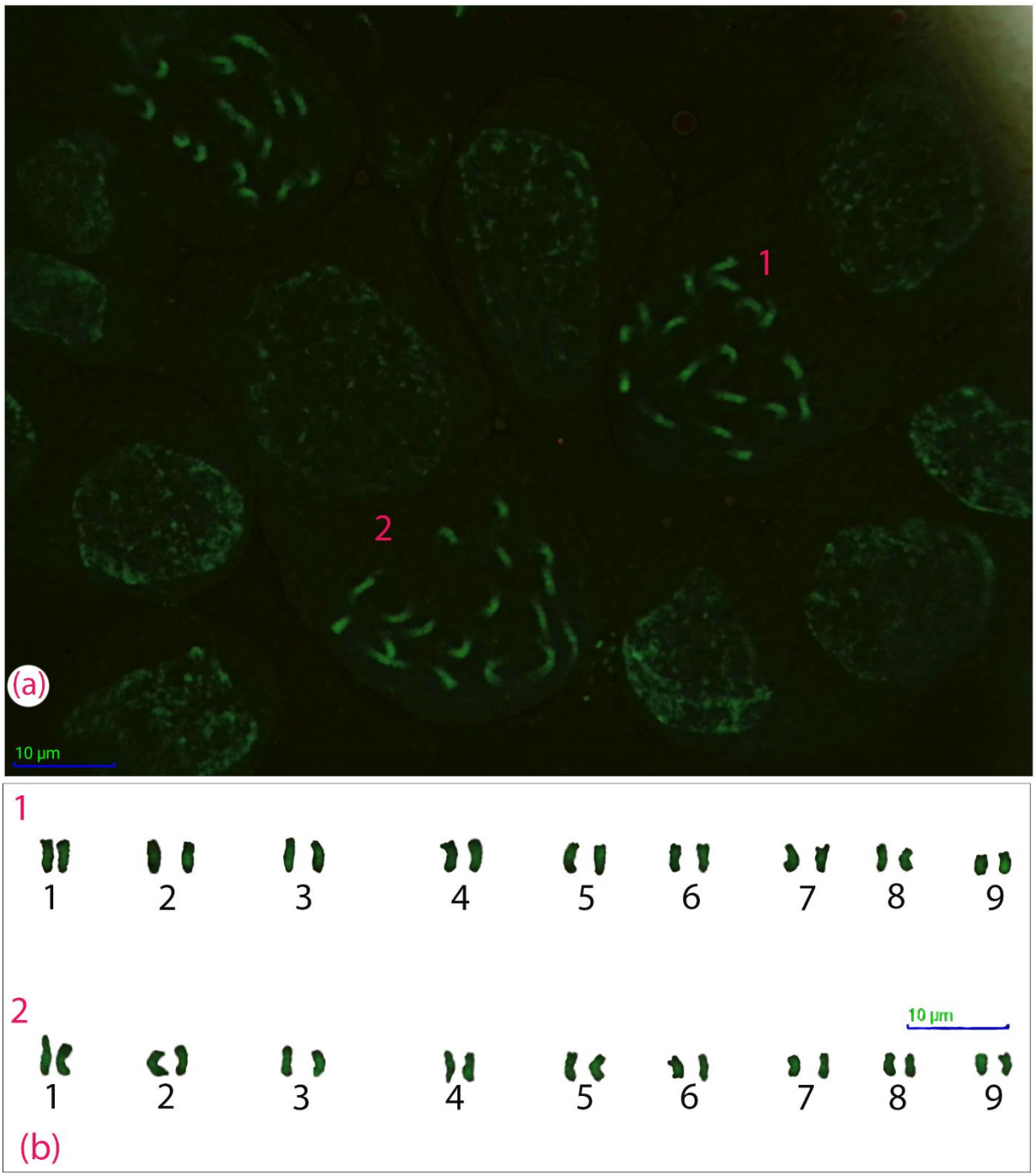

Figure 1. Somatic chromosomes and idiogram of the *Beta vulgaris* L. var. *saccharifera* Alef. variety Nimerchanskaya-030 (2n = 2x = 18). Microphotographs (a, b) represent somatic metaphase plates obtained from one of two analyzed samples of the variety. The idiogram was constructed based on measured chromosome parameters and graphically arranged using Adobe Photoshop. Scale bar = 10 µm.

ratios and relative lengths. The smallest chromosomes (8 and 9) were distinctly submetacentric, contributing to overall karyotype asymmetry. Drujba (Figure 6): Chromosomal morphology was similar to Lara, with predominance of metacentric chromosomes, though some chromosomes (1, 2, 3) showed moderate asymmetry. The idiogram reflected consistent chromosomal

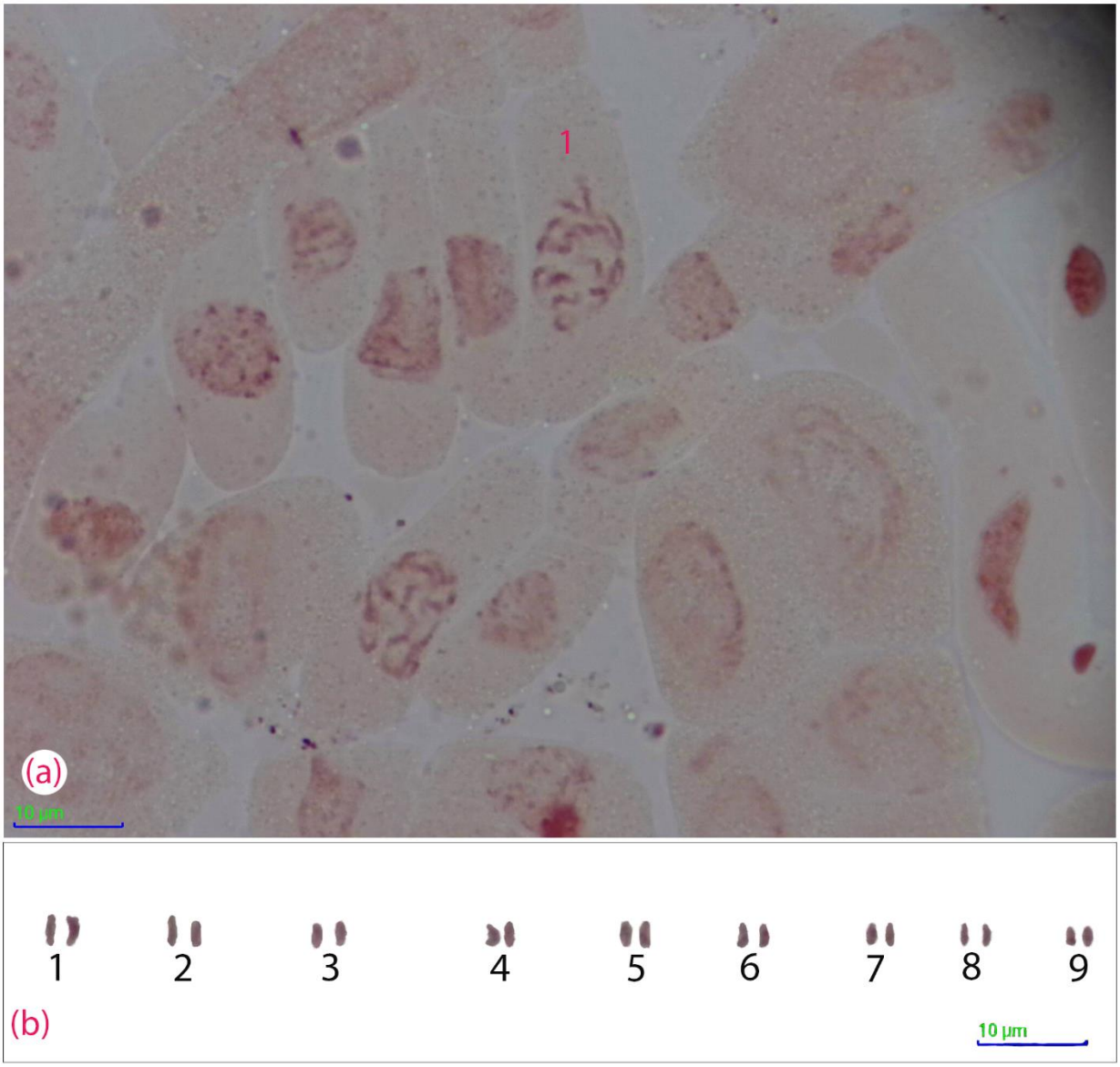

Figure 2. Somatic chromosomes and idiogram of the *Beta vulgaris* L. var. *saccharifera* Alef. variety Oniks (2n = 2x = 18). Microphotographs (a, b) represent somatic metaphase plates obtained from one of two analyzed samples of the variety. The idiogram was constructed based on measured chromosome parameters and graphically arranged using Adobe Photoshop. Scale bar = 10 µm.

organization with minor inter-varietal differences in relative length and centromeric index. Viktoriya (Figure 7): This variety displayed more submetacentric chromosomes than the others, with chromosomes 5–7 showing significant asymmetry. Chromosomes 1 and 2 were relatively longer and more symmetric. The karyotype reflected higher structural variability, suggesting potential genetic differentiation within this variety. Overall, the analysis of somatic chromosomes and idiograms demonstrated that all seven Beta vulgaris varieties maintain the same diploid number but differ in chromosome length, centromere position, and arm ratio. Submetacentric and metacentric chromosomes were distributed differently among varieties, indicating subtle karyotypic diversity. These findings provide a cytogenetic framework for identifying varietal differences and support further studies on genome organization, breeding, and selection in sugar beet.

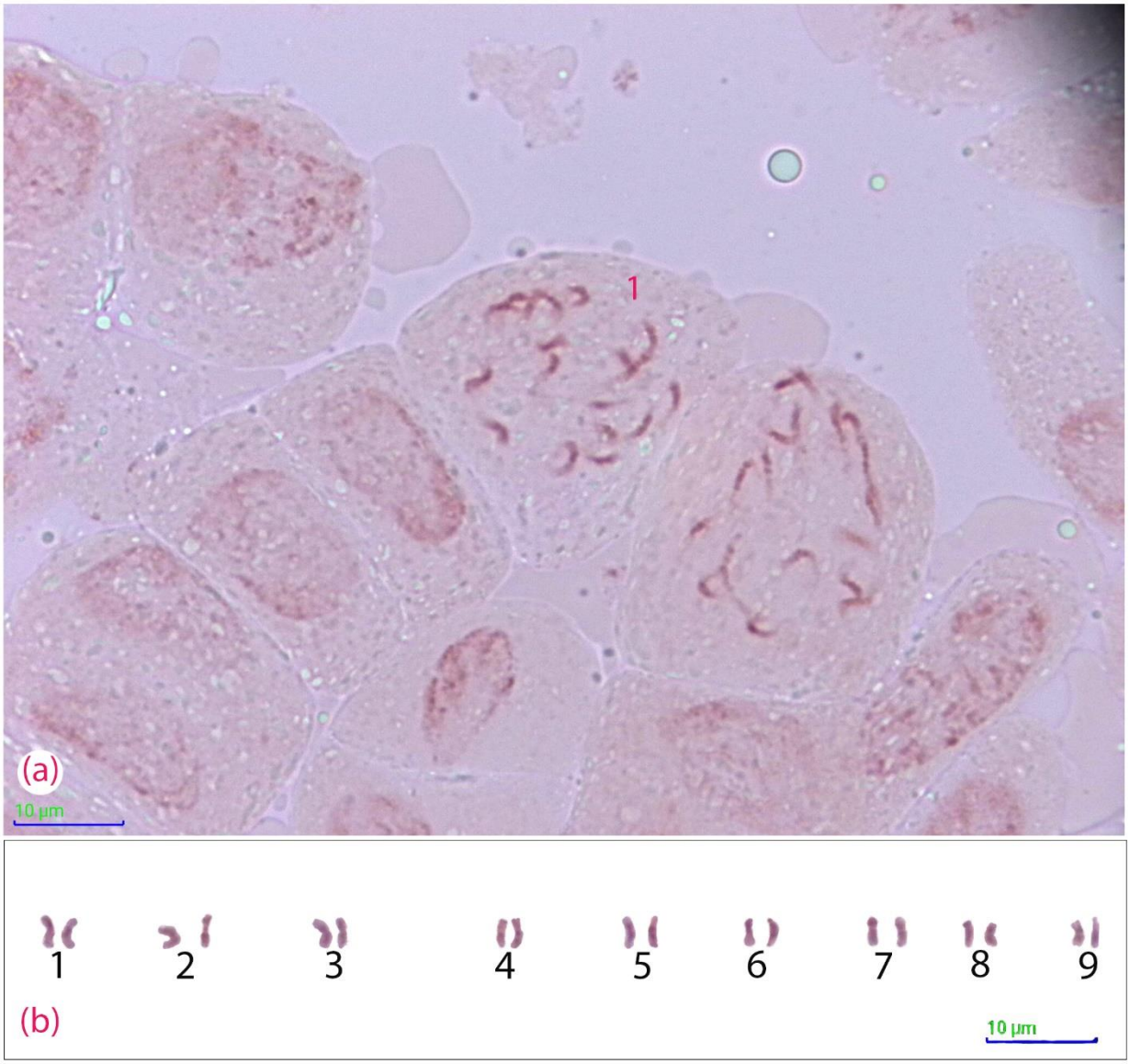

Figure 3. Somatic chromosomes and idiogram of the *Beta vulgaris* L. var. *saccharifera* Alef. variety Novella (2n = 2x = 18). Microphotographs (a, b) represent somatic metaphase plates obtained from one of two analyzed samples of the variety. The idiogram was constructed based on measured chromosome parameters and graphically arranged using Adobe Photoshop. Scale bar = 10 µm**.**

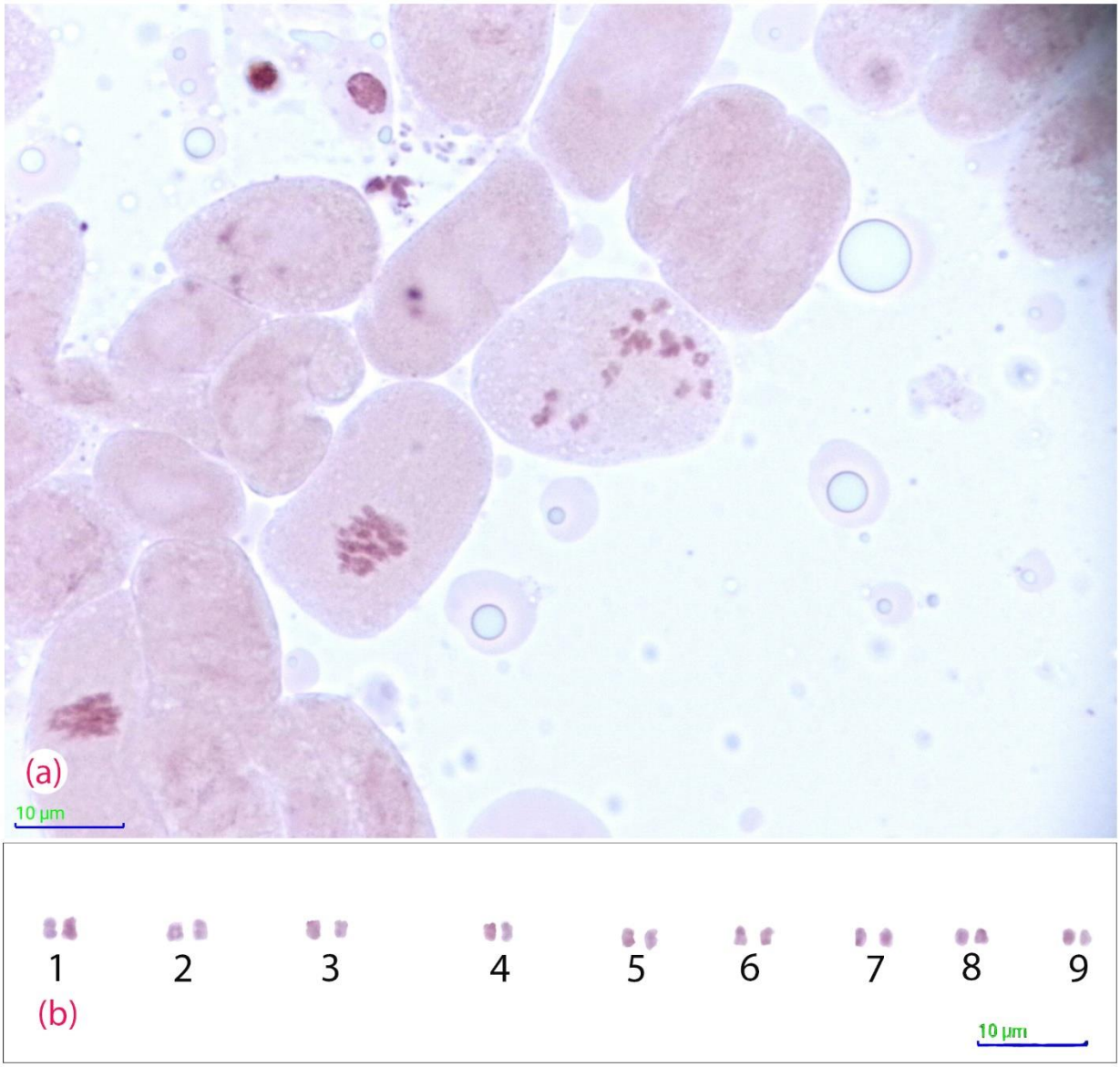

Figure 4. Somatic chromosomes and idiogram of the *Beta vulgaris* L. var. *saccharifera* Alef. variety Lara (2n = 2x = 18). Microphotographs (a, b) represent somatic metaphase plates obtained from one of two analyzed samples of the variety. The idiogram was constructed based on measured chromosome parameters and graphically arranged using Adobe Photoshop. Scale bar = 10 µm.

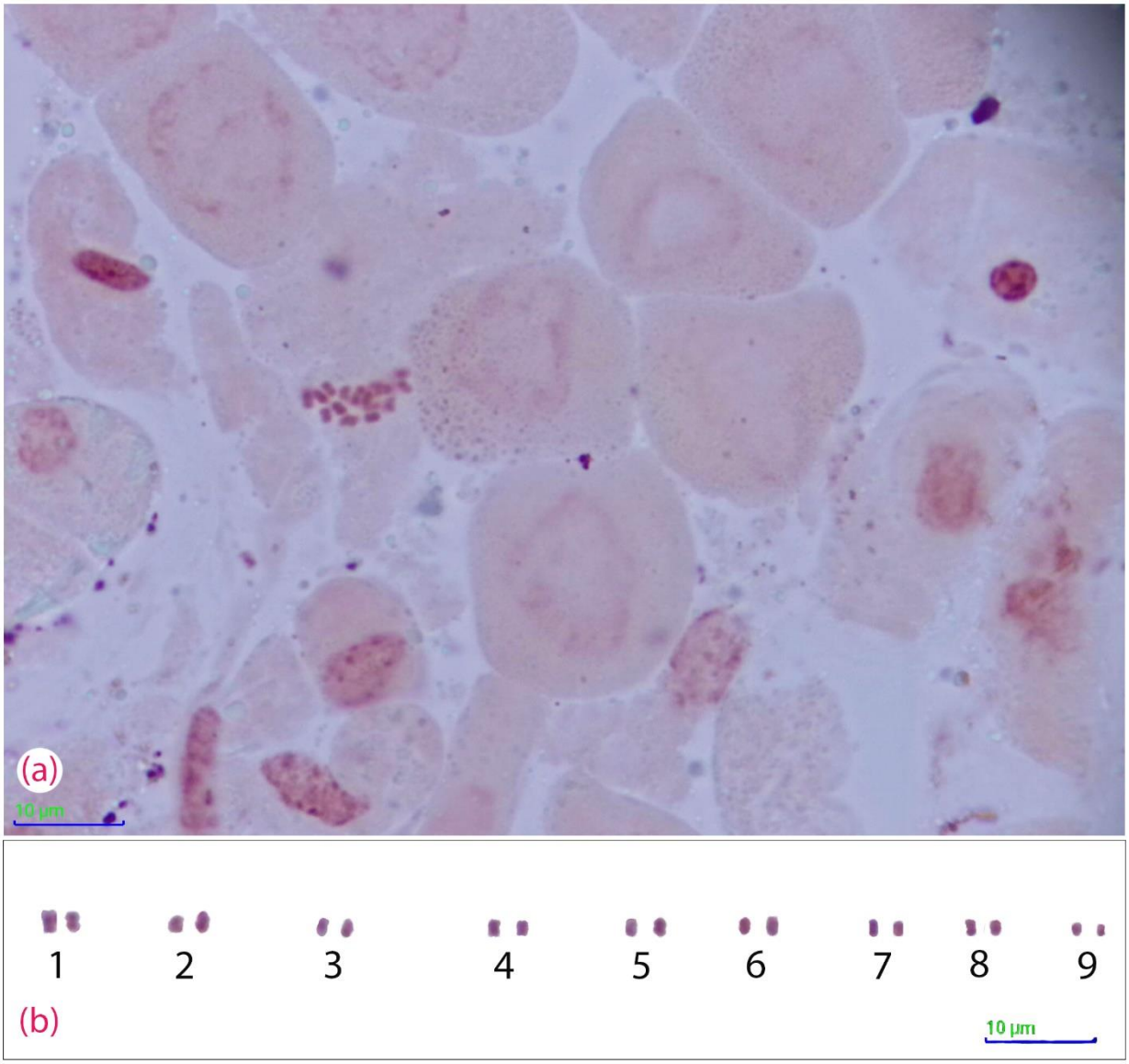

Figure 5. Somatic chromosomes and idiogram of the *Beta vulgaris* L. var. *saccharifera* Alef. variety Diyor (2n = 2x = 18). Microphotographs (a, b) represent somatic metaphase plates obtained from one of two analyzed samples of the variety. The idiogram was constructed based on measured chromosome parameters and graphically arranged using Adobe Photoshop. Scale bar = 10 µm.

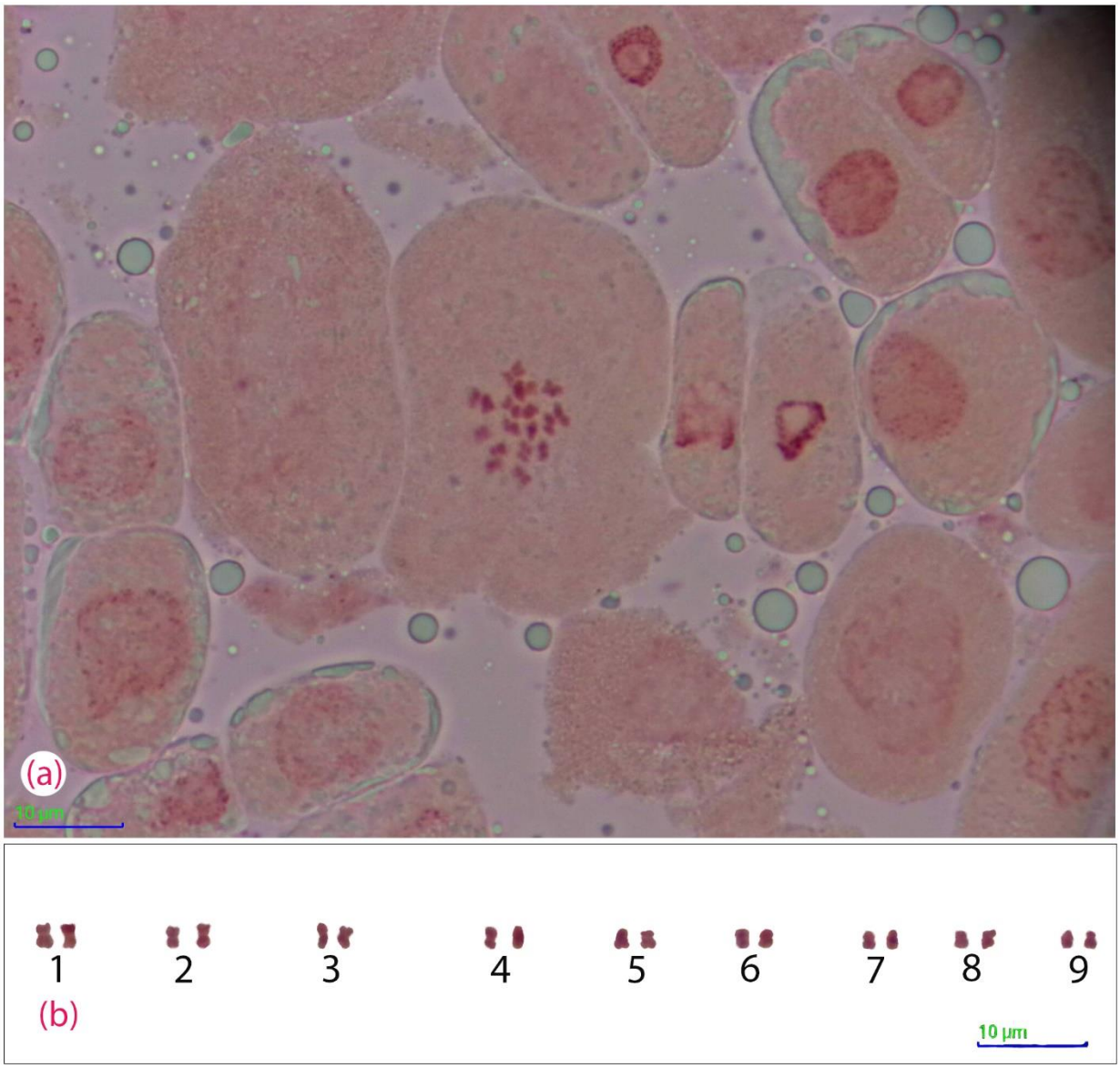

Figure 6. Somatic chromosomes and idiogram of the *Beta vulgaris* L. var. *saccharifera* Alef. variety Drujba (2n = 2x = 18). Microphotographs (a, b) represent somatic metaphase plates obtained from one of two analyzed samples of the variety. The idiogram was constructed based on measured chromosome parameters and graphically arranged using Adobe Photoshop. Scale bar = 10 µm.

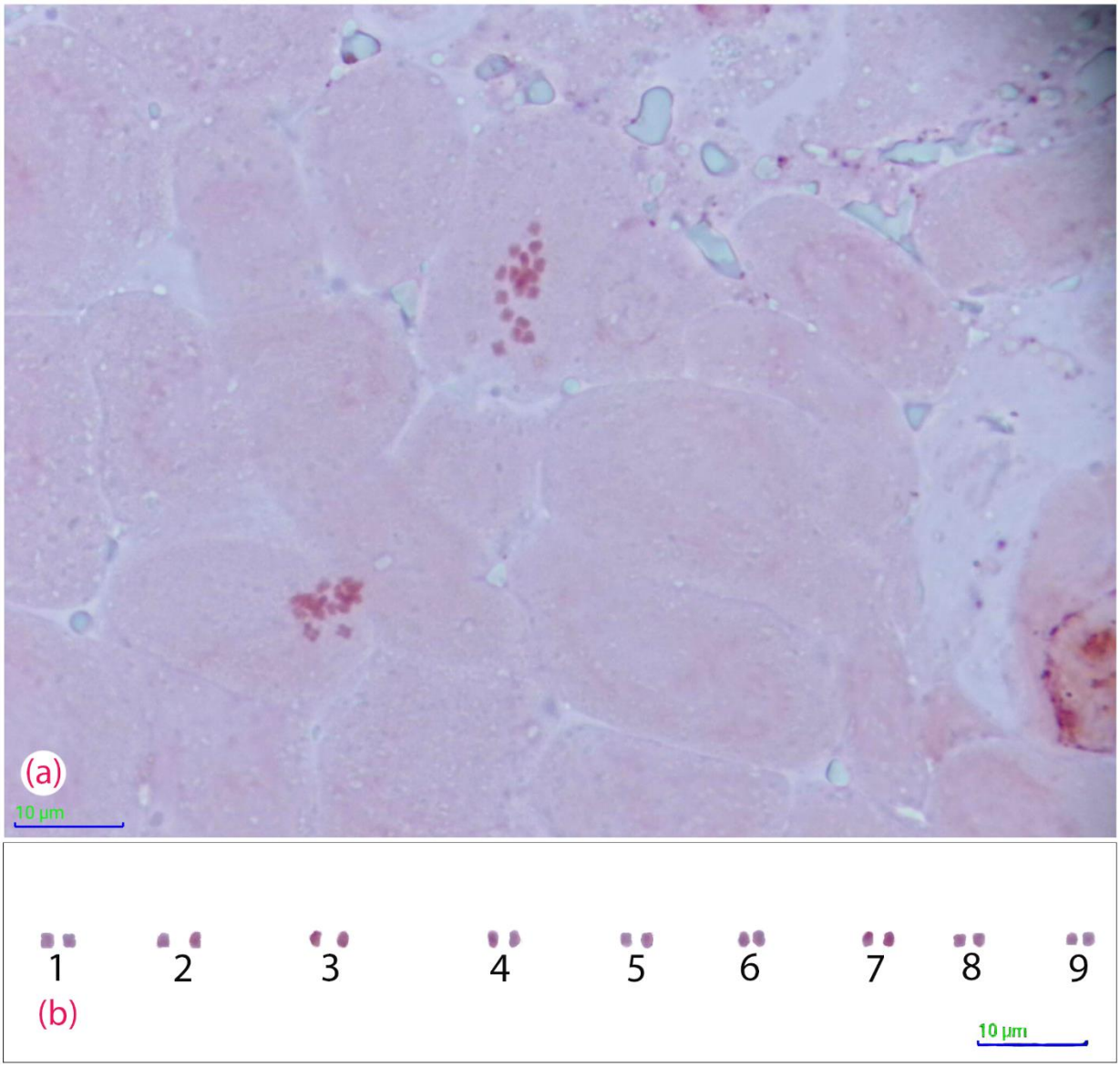

Figure 7. Somatic chromosomes and idiogram of the *Beta vulgaris* L. var. *saccharifera* Alef. variety Viktoriya (2n = 2x = 18). Microphotographs (a, b) represent somatic metaphase plates obtained from one of two analyzed samples of the variety. The idiogram was constructed based on measured chromosome parameters and graphically arranged using Adobe Photoshop. Scale bar = 10 µm.

Idiograms of seven Beta vulgaris L. varieties are presented: (a) Nimerchanskaya-030, (b) Oniks, (c) Novella, (d) Lara, (e) Diyor, (f) Drujba, and (g) Viktoriya. Each subfigure represents the idiogram of an individual variety. The idiograms were constructed based on measurements of somatic metaphase chromosomes using IdeoKar software and were graphically finalized in Adobe Photoshop. These idiograms visually demonstrate differences among the varieties in terms of chromosome length, centromere position, and arm ratio (AR). They provide essential cytogenetic information for variety identification and comparison of karyotype characteristics, which is valuable for breeding and genetic studies (Figure 8).

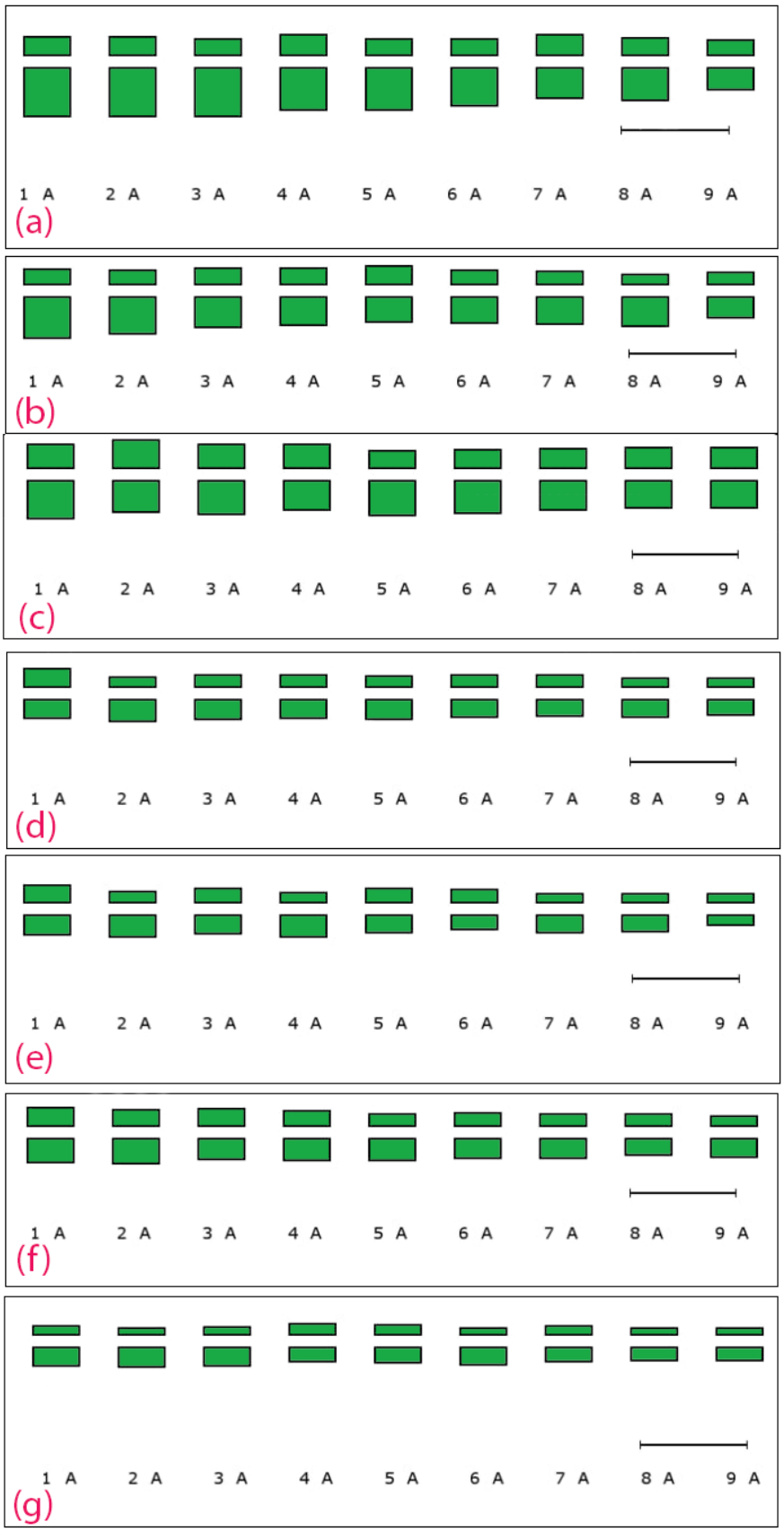

Figure 8. Idiograms of seven *Beta vulgaris* L. varieties: (a) Nimerchanskaya-030, (b) Oniks, (c) Novella, (d) Lara, (e) Diyor, (f) Drujba, and (g) Viktoriya. Each subfigure represents the idiogram of an individual variety. The idiograms were constructed based on measurements of somatic metaphase chromosomes using IdeoKar software and finalized graphically in Adobe Photoshop.

The karyotypic analysis of seven Beta vulgaris L. var. saccharifera Alef. varieties revealed distinct differences in chromosome morphology and asymmetry parameters (Table 1). The mean chromosome length (HCL) ranged from 11.86 µm in Viktoriya to 25.52 µm in Nimerchanskaya-030,

indicating notable variation in chromosome size among the varieties. The total form percentage (TF%) varied between 32.65% in Nimerchanskaya-030 and 41.7% in Drujba, reflecting differences in the proportion of short arms relative to the total chromosome length. Karyotype asymmetry indices (AsK%) ranged from 58.3% (Drujba) to 67.35% (Nimerchanskaya-030), whereas the proportion of symmetric chromosomes (S%) showed the highest value in Novella (79.51%) and the lowest in Diyor (55.13%). The mean relative length of the short arm (Xci) varied from 0.33 (Nimerchanskaya-030) to 0.42 (Diyor), while the asymmetry coefficient (A) ranged from 0.17 (Novella, Diyor, Drujba) to 0.33 (Nimerchanskaya-030). The mean relative length of the long arm (XcA) was lowest in Novella (16.94) and highest in Nimerchanskaya-030 (33.33). Coefficients of variation for chromosome length (CVcl) and centromeric index (CVci) showed that Novella had the most uniform chromosome sizes (CVcl = 8.91, CVci = 9.50), whereas Drujba and Diyor exhibited greater variation. The asymmetry index (AI) according to Romero-Zarco (1986) ranged from 69.61 (Viktoriya) to 178.81 (Drujba), demonstrating significant differences in karyotype asymmetry among the varieties. All varieties were classified as 1A according to Stebbins' (1971) system, indicating a relatively symmetrical karyotype. Intra-chromosomal (A1) and inter-chromosomal (A2) asymmetry indices also varied, with Nimerchanskaya-030 showing the highest A1 value (0.49) and Novella the lowest (0.28). Overall, these results indicate that while all seven sugar beet varieties share the same chromosome number (2n = 18), they exhibit considerable variability in chromosome size, symmetry, and karyotype structure, providing a cytogenetic basis for varietal differentiation and further breeding studies (table 1).

Table 1. Mean chromosomal and karyotypic characteristics of seven varieties.

Parametr	Nimerchanskaya-030	Oniksa	Novella	Lara	Diyor	Drujba	Viktoriya
HCL	25.52	20.15	24.41	14.55	14.15	16.59	11.86
TF	32.65	34.49	41.58	40.45	41.39	41.7	35.81
AsK%	67.35	65.51	58.42	59.55	58.61	58.3	64.19
S%	57.14	61.95	79.51	68.83	55.13	69.32	75.86
Xci	0.33	0.35	0.41	0.4	0.42	0.41	0.36
A	0.33	0.3	0.17	0.2	0.17	0.17	0.28
XcA	33.33	30.45	16.94	19.53	16.96	16.9	28.22
CVcl	16.48	14.25	8.91	10.36	16.32	13.47	9.68
CVci	16.75	15.01	9.5	11.58	15.52	7.54	13.91
AI	98.37	94.9	93.71	89.47	105.18	178.81	69.61
Stebbine C	1A	1A	1A	1A	1A	1A	1A
A1	0.49	0.46	0.28	0.32	0.27	0.28	0.43
A2	0.16	0.14	0.09	0.1	0.16	0.13	0.1

Note. This table summarizes the results of the analysis of 14 karyological parameters in seven varieties. For each species, two individuals were studied, and one metaphase plate was analyzed per individual. The analyzed parameters include ***HCL*** (mean chromosome length in micrometers), ***TF (%)*** (total form percentage representing the ratio of the sum of short arms to the total chromosome length), ***AsK (%)*** (karyotype asymmetry index by Corton calculated as the proportion of long arms), ***S (%)*** (proportion of symmetric chromosomes), ***Xci*** (mean relative length of the short arm), ***A*** (asymmetry coefficient according to Arano and Schmidt, 1964), ***XcA*** (mean relative length of the long arm), ***CVcl*** (coefficient of variation of chromosome length), ***CVci*** (coefficient of variation of the centromeric index), ***AI*** (asymmetry index according to Romero-Zarco, 1986), ***Stebbins C*** (karyotype category based on Stebbins' 1971 classification system), ***A1*** (intra-chromosomal asymmetry index), and ***A2*** (inter-chromosomal asymmetry index).

The cytogenetic analysis of haploid chromosomes in seven Beta vulgaris L. var. saccharifera Alef. varieties (Nimerchanskaya-030, Oniksa, Novella, Lara, Diyor, Drujba, and Viktoriya) revealed notable inter-varietal differences in chromosome morphology, despite all varieties having a consistent haploid chromosome number of n = 9. The mean chromosome lengths (L ± SE)

varied widely among chromosomes and varieties, ranging from 0.55 ± 0.00 µm (chromosome 9 in Diyor) to 2.34 ± 0.15 µm (chromosome 1 in Nimerchanskaya-030). Short arm lengths (S ± SE) similarly ranged from 0.40 ± 0.10 µm to 1.42 ± 0.00 µm, indicating considerable variation in chromosome arm proportions. Arm ratio (AR ± SE) values, calculated as the ratio of long arm to short arm, highlighted structural diversity, with values ranging from 1.00 ± 0.03 (chromosome 1 in Lara) to 2.76 ± 0.51 (chromosome 3 in Nimerchanskaya-030). Based on these AR values, chromosomes were classified as metacentric (m) or submetacentric (sm), with metacentric chromosomes generally exhibiting more symmetry, whereas submetacentric chromosomes displayed pronounced differences between long and short arms. Submetacentric chromosomes were particularly prevalent in Nimerchanskaya-030 and Viktoriya, whereas varieties like Novella and Lara contained a higher proportion of metacentric chromosomes. The centromeric index (CI ± SE) and relative length (RL% ± SE) further confirmed structural variability across varieties. The centromeric index, representing the ratio of short arm length to total chromosome length, ranged from 0.28 ± 0.03 to 0.49 ± 0.01, whereas relative chromosome length, expressed as a percentage of the total haploid set, varied between 7.41 ± 0.00% and 14.02 ± 0.37% (table 2). These data indicate that although the chromosome number is constant, the physical structure and relative size of individual chromosomes differ among varieties. Analysis of individual chromosomes revealed that certain chromosomes consistently showed the largest sizes across all varieties. For instance, chromosome 1 tended to have the highest mean length in Nimerchanskaya-030, Oniksa, and Novella, whereas chromosomes 8 and 9 were generally the smallest. Chromosomes exhibiting the largest differences in AR and CI, such as chromosomes 4 and 7, may represent regions of structural variation within the genome that could be associated with genetic differentiation among varieties. The classification of chromosomes into metacentric and submetacentric types provides an important cytogenetic framework for these varieties. Metacentric chromosomes (m) predominated in Novella, Lara, and Drujba, while submetacentric chromosomes (sm) were more abundant in Nimerchanskaya-030, Onix, Diyor, and Viktoriya. This variation reflects both inter-varietal and intra-chromosomal heterogeneity, highlighting the potential for selection of structural chromosome markers for breeding and genetic studies. Overall, this comprehensive haploid chromosome analysis demonstrates that, although the seven Beta vulgaris varieties share the same chromosome number, their chromosomal morphology, symmetry, and relative size differ substantially. These cytogenetic differences provide a valuable reference for karyotype characterization, identification of structural variation, and the development of breeding strategies and genetic linkage studies. The generated data serve as a foundation for future studies on chromosome mapping, genome organization, and comparative cytogenetics of sugar beet varieties.

Table 2. Karyotypic parameters of haploid chromosomes in seven varieties.

Nimerchanskaya-030									
Chr	*L ± SE*	*S ± SE*	*CL ± SE*	*AR ± SE*	*r-Value ± SE*	*RL% ± SE*	*F% ± SE*	*CI ± SE*	*Type*
1A	2.34±0.15	0.97±0.07	3.31±0.07	2.47±0.34	0.40±0.06	12.96±0.29	3.80±0.29	0.29±0.03	sm
2A	2.34±0.05	0.95±0.05	3.28±0.00	2.47±0.18	0.40±0.03	12.87±0.00	3.70±0.19	0.29±0.02	sm
3A	2.34±0.10	0.87±0.12	3.21±0.02	2.76±0.51	0.36±0.07	12.57±0.10	3.41±0.49	0.27±0.04	sm
4A	2.06±0.07	1.07±0.02	3.13±0.05	1.95±0.11	0.51±0.03	12.28±0.19	4.19±0.10	0.34±0.01	sm
5A	2.06±0.02	0.85±0.05	2.91±0.07	2.41±0.11	0.41±0.02	11.40±0.29	3.31±0.19	0.29±0.01	sm
6A	1.84±0.10	0.87±0.07	2.71±0.02	2.18±0.30	0.46±0.07	10.62±0.10	3.41±0.29	0.32±0.03	sm
7A	1.49±0.00	1.07±0.02	2.56±0.02	1.43±0.03	0.70±0.02	10.04±0.10	4.19±0.10	0.42±0.01	m
8A	1.62±0.22	0.90±0.00	2.51±0.22	1.78±0.25	0.56±0.08	9.84±0.88	3.51±0.00	0.36±0.03	sm
9A	1.09±0.10	0.80±0.10	1.89±0.00	1.38±0.30	0.73±0.16	7.41±0.00	3.12±0.39	0.42±0.05	m
Onix									
1A	2.00±0.00	0.83±0.08	2.83±0.08	2.50±0.22	0.40±0.04	14.02±0.37	4.09±0.37	0.29±0.02	sm
2A	1.83±0.08	0.75±0.10	2.58±0.18	2.40±0.23	0.42±0.04	12.78±0.87	3.72±0.50	0.29±0.02	sm
3A	1.43±0.03	0.85±0.00	2.28±0.03	1.65±0.03	0.61±0.01	11.29±0.12	4.22±0.00	0.37±0.00	m
4A	1.25±0.10	0.95±0.00	2.20±0.10	1.32±0.11	0.76±0.06	10.92±0.50	4.71±0.00	0.43±0.02	m
5A	1.50±0.00	0.85±0.05	2.35±0.05	1.76±0.10	0.57±0.03	11.66±0.25	4.22±0.25	0.36±0.01	sm
6A	1.30±0.05	0.78±0.08	2.08±0.03	1.73±0.23	0.58±0.08	10.30±0.12	3.85±0.37	0.37±0.03	sm
7A	1.38±0.03	0.73±0.03	2.10±0.00	1.93±0.10	0.52±0.03	10.42±0.00	3.60±0.12	0.35±0.01	sm
8A	1.45±0.10	0.55±0.05	2.00±0.05	2.64±0.43	0.38±0.06	9.93±0.25	2.73±0.25	0.28±0.03	sm
9A	1.08±0.08	0.68±0.08	1.75±0.15	1.62±0.07	0.62±0.03	8.69±0.74	3.35±0.37	0.38±0.01	m
Novella									

1A	1.88±0.10	1.22±0.10	3.10±0.00	1.54±0.21	0.65±0.09	12.68±0.00	4.99±0.42	0.39±0.03	m
2A	1.57±0.00	1.42±0.00	2.99±0.00	1.11±0.00	0.90±0.00	12.27±0.00	5.82±0.00	0.47±0.00	m
3A	1.50±0.08	1.22±0.10	2.72±0.03	1.21±0.17	0.83±0.11	11.12±0.10	4.99±0.42	0.45±0.03	m
4A	1.40±0.03	1.07±0.10	2.46±0.13	1.29±0.10	0.78±0.06	10.08±0.52	4.37±0.42	0.43±0.02	m
5A	1.70±0.13	1.24±0.13	2.94±0.00	1.38±0.24	0.73±0.13	12.06±0.00	5.09±0.52	0.42±0.04	m
6A	1.62±0.15	0.96±0.05	2.59±0.20	1.68±0.07	0.59±0.02	10.60±0.83	3.95±0.21	0.37±0.01	m
7A	1.73±0.05	0.91±0.15	2.64±0.10	1.89±0.38	0.53±0.10	10.81±0.42	3.74±0.62	0.34±0.04	sm
8A	1.47±0.10	1.04±0.03	2.51±0.08	1.45±0.13	0.69±0.07	10.29±0.31	4.26±0.10	0.41±0.02	m
9A	1.40±0.03	1.07±0.15	2.46±0.13	1.29±0.22	0.78±0.12	10.08±0.52	4.37±0.62	0.43±0.04	m
Lara									
1A	0.98±0.03	0.96±0.05	1.94±0.08	1.00±0.03	1.00±0.03	13.37±0.52	6.60±0.35	0.49±0.01	m
2A	1.11±0.05	0.56±0.00	1.67±0.05	2.00±0.09	0.50±0.02	11.46±0.35	3.82±0.00	0.33±0.01	sm
3A	0.91±0.05	0.68±0.03	1.59±0.03	1.38±0.12	0.72±0.07	10.94±0.17	4.69±0.17	0.43±0.02	m
4A	0.88±0.13	0.68±0.03	1.57±0.10	1.31±0.23	0.76±0.14	10.76±0.69	4.69±0.17	0.44±0.04	m
5A	1.04±0.03	0.68±0.03	1.72±0.05	1.54±0.02	0.65±0.01	11.81±0.35	4.69±0.17	0.40±0.00	m
6A	0.98±0.03	0.66±0.05	1.64±0.03	1.46±0.15	0.68±0.07	11.28±0.17	4.51±0.35	0.40±0.02	m
7A	1.01±0.00	0.61±0.00	1.62±0.00	1.67±0.00	0.60±0.00	11.11±0.00	4.17±0.00	0.38±0.00	m
8A	0.81±0.10	0.53±0.03	1.34±0.13	1.60±0.12	0.63±0.05	9.20±0.87	3.65±0.17	0.40±0.02	m
9A	0.93±0.03	0.53±0.03	1.46±0.05	1.80±0.04	0.56±0.01	10.07±0.35	3.65±0.17	0.36±0.00	sm
Diyor									
1A	1.03±0.08	0.93±0.03	1.96±0.10	1.11±0.05	0.90±0.04	13.85±0.71	6.57±0.18	0.48±0.01	m
2A	1.13±0.08	0.60±0.00	1.73±0.08	1.83±0.13	0.55±0.04	12.26±0.53	4.26±0.00	0.35±0.02	sm
3A	1.13±0.08	0.55±0.10	1.68±0.03	2.00±0.53	0.50±0.12	11.90±0.18	3.91±0.71	0.33±0.05	sm
4A	0.93±0.08	0.53±0.08	1.46±0.15	1.80±0.11	0.56±0.04	10.30±1.07	3.73±0.53	0.36±0.01	sm
5A	0.90±0.05	0.75±0.05	1.66±0.00	1.20±0.15	0.83±0.10	11.72±0.00	5.33±0.36	0.45±0.03	m
6A	0.98±0.13	0.75±0.05	1.73±0.08	1.27±0.25	0.79±0.15	12.26±0.53	5.33±0.36	0.44±0.05	m
7A	0.88±0.03	0.50±0.00	1.38±0.03	1.70±0.05	0.59±0.02	9.77±0.18	3.55±0.00	0.36±0.01	sm
8A	0.75±0.00	0.70±0.00	1.46±0.00	1.07±0.00	0.93±0.00	10.30±0.00	4.97±0.00	0.48±0.00	m
9A	0.55±0.00	0.53±0.03	1.08±0.03	1.10±0.05	0.91±0.05	7.64±0.18	3.73±0.18	0.49±0.01	m
Drujba									
1A	1.24±0.08	0.98±0.03	2.22±0.10	1.26±0.04	0.79±0.03	13.39±0.61	5.94±0.15	0.44±0.01	m
2A	1.09±0.03	0.93±0.08	2.02±0.10	1.17±0.07	0.86±0.05	12.18±0.61	5.63±0.46	0.46±0.01	m
3A	1.26±0.05	0.86±0.20	2.12±0.15	1.47±0.43	0.68±0.19	12.79±0.91	5.18±1.22	0.40±0.07	m
4A	1.11±0.10	0.83±0.03	1.94±0.13	1.38±0.08	0.73±0.05	11.72±0.76	5.02±0.15	0.43±0.01	m
5A	1.14±0.03	0.68±0.08	1.82±0.10	1.69±0.15	0.59±0.05	10.96±0.61	4.11±0.46	0.37±0.02	m
6A	1.01±0.00	0.71±0.05	1.72±0.05	1.43±0.10	0.70±0.05	10.35±0.30	4.26±0.30	0.41±0.02	m
7A	1.01±0.05	0.66±0.05	1.67±0.00	1.54±0.20	0.65±0.08	10.05±0.00	3.96±0.30	0.39±0.03	m
8A	0.86±0.05	0.68±0.08	1.54±0.03	1.31±0.22	0.76±0.14	9.28±0.15	4.11±0.46	0.44±0.04	m
9A	0.96±0.05	0.58±0.08	1.54±0.03	1.73±0.31	0.58±0.11	9.28±0.15	3.50±0.46	0.38±0.04	sm
Viktoriya									
1A	1.01±0.00	0.43±0.03	1.43±0.03	2.50±0.14	0.40±0.03	12.08±0.21	3.60±0.21	0.30±0.01	sm
2A	0.95±0.00	0.50±0.10	1.46±0.10	1.90±0.40	0.53±0.11	12.29±0.85	4.24±0.85	0.34±0.05	sm
3A	0.93±0.18	0.40±0.20	1.33±0.03	2.25±2.13	0.44±0.31	11.23±0.21	3.39±1.69	0.30±0.15	sm
4A	0.95±0.05	0.45±0.10	1.41±0.05	2.11±0.61	0.47±0.13	11.86±0.42	3.81±0.85	0.32±0.06	sm
5A	0.75±0.05	0.60±0.00	1.36±0.05	1.25±0.08	0.80±0.05	11.44±0.42	5.08±0.00	0.45±0.02	m
6A	0.83±0.08	0.55±0.10	1.38±0.18	1.45±0.14	0.69±0.06	11.65±1.48	4.66±0.85	0.40±0.02	m
7A	0.75±0.00	0.50±0.00	1.26±0.00	1.50±0.00	0.67±0.00	10.59±0.00	4.24±0.00	0.40±0.00	m
8A	0.73±0.08	0.40±0.10	1.13±0.03	1.75±0.68	0.57±0.20	9.53±0.21	3.39±0.85	0.35±0.08	sm
9A	0.70±0.05	0.40±0.10	1.11±0.15	1.75±0.33	0.57±0.10	9.32±1.27	3.39±0.85	0.36±0.04	sm

Note. This table presents the results of the analysis of seven chromosomal parameters for seven varieties (Nimerchanskaya-030, Oniks, Novella, Lara, Diyor, Drujba, and Viktoriya): ***Chr*** = Chromosome number***; L ± SE*** = Mean chromosome length ± Standard Error; ***S ± SE*** = Mean chromosome short arm length ± Standard Error; ***CL ± SE*** = Mean chromosome long arm length ± Standard Error; ***AR ± SE*** = Arm ratio (long arm/short arm) ± Standard Error; ***r-Value ± SE*** = Ratio of short arm to total chromosome length ± Standard Error; ***RL% ± SE*** = Relative length percentage of chromosome ± Standard Error; ***F% ± SE*** = Centromeric index percentage ±

Standard Error; ***CI* ± *SE*** = Centromeric index (short arm length / total chromosome length) ± Standard Error; Type = Chromosome type classification based on arm ratio. and **Chromosome type** — classified as metacentric (**m**), submetacentric (**sm**), based on centromere position.

DISCUSSION

The present study provides a detailed cytogenetic characterization of seven sugar beet (Beta vulgaris L. var. saccharifera) varieties, revealing notable differences in chromosome morphology, centromere position, and karyotype asymmetry. All seven varieties exhibited the diploid chromosome number of 2n = 18, consistent with previous reports for Beta vulgaris subspecies [1,3,4]. This confirms the stability of chromosome number across sugar beet varieties and underscores the conserved nature of their karyotype structure. The idiograms constructed for each variety revealed that metacentric and submetacentric chromosomes predominated, but the distribution of these chromosome types differed among varieties. For instance, Nimerchanskaya-030 and Oniks exhibited longer chromosomes with higher arm ratios and slightly more submetacentric chromosomes, whereas Novella and Lara showed higher karyotype symmetry with predominantly metacentric chromosomes. Drujba and Diyor displayed intermediate asymmetry, while Viktoriya presented more submetacentric chromosomes and higher structural variability. These variations reflect subtle cytogenetic diversity within sugar beet germplasm, which may correspond to phenotypic and agronomic differences such as plant height, leaf morphology, and sucrose content.

Comparing our results with Sun et al. (2019) on red leaf beet (Beta vulgaris var. cicla), several similarities and differences emerge. Both studies found a diploid chromosome number of 2n = 18, with metacentric and submetacentric chromosomes predominating. Leaf beet varieties studied by Sun et al. contained one pair of satellites per variety, similar to sugar beet varieties in our study, suggesting that the satellite-containing chromosomes may represent a conserved feature in Beta vulgaris subspecies. Moreover, both studies report low to moderate karyotype asymmetry indices, indicative of a relatively primitive karyotype and a stable evolutionary status. However, the sugar beet varieties in our study exhibited slightly higher inter-varietal diversity in terms of centromeric index, arm ratio, and total form percentage, likely reflecting the influence of different breeding histories, selection pressures, and adaptation to diverse environmental conditions.

Karyotype asymmetry analysis based on Stebbins' classification [10] indicates that most sugar beet varieties fall into the 1A–2A types, reflecting a predominance of symmetrical chromosomes, consistent with the primitive karyotype nature reported for red leaf beet. Nimerchanskaya-030, with the highest mean chromosome length and AsK% (67.35%), shows slightly greater asymmetry, suggesting minor chromosomal evolution within cultivated germplasm. Such variability in karyotype structure could be exploited in breeding programs for introducing desirable traits or monitoring genetic stability.

CONCLUSION

In conclusion, our cytogenetic analysis demonstrates that while sugar beet varieties maintain a conserved chromosome number and general karyotype type, they exhibit measurable variation in chromosomal morphology and asymmetry indices. This cytogenetic diversity parallels observations in red leaf beet, supporting the notion that Beta vulgaris subspecies maintain primitive karyotypes while allowing modest structural differentiation due to breeding and environmental adaptation. These findings provide a solid foundation for varietal identification, genetic improvement, and breeding programs aimed at enhancing agronomic traits in sugar beet.

REFERENCES

1. F.S. Zhang, Y.C. Sun, Simple analysis on the advancement of foliage beet researches, Sugar Crops of China. 2 (2000) 46-48.
2. T.C. Barickman, D.A. Kopsell, Nitrogen form and ratio impact Swiss chard (Beta vulgaris subsp. cicla) shoot tissue Carotenoid and chlorophyll concentrations, Scientia Horticulturae. 204 (2016) 99-105.
3. Paesold, S., Borchardt, D., Schmidt, T., & Dechyeva, D. (2012). A sugar beet (Beta vulgaris L.) reference FISH karyotype for chromosome and chromosome-arm identification, integration of genetic linkage groups and analysis of major repeat family distribution. The Plant Journal, 72(4), 600-611.
4. Sun, B., Tian, Y., Xia, X., Zhang, F., & Tang, H. (2019, April). Karyotype Analysis of Three Varieties of Red Leaf Beet. In IOP Conference Series: Earth and Environmental Science (Vol. 252, No. 2, p. 022017). IOP Publishing.
5. G.K.G. Campell, Sugar beet: Beta vulgaris (Chenopodiaceae) Evolution of Crop Plants. Longman Press, London, 1976.
6. Toshtemirov, J.G.; Dumacheva, E.V.; Yusupov, Z.O. Karyotype analysis of Tulipa undulatifolia var.

Micheliana (Hoog) and Tulipa lehmanniana Merckl. in Uzbekistan. Materials of the international scientific and practical conference «Conservation of Biological Diversity in Central Asia: Problems, solutions and prospects», 2024, 755, 12–16. The materials were published in Namangan city, at Namangan State University.

7. Barykina, R.P.; Veselova, T.D.; Devyatov, A.G.; Dzhalilova, Kh.; Ilyina, G.M., Chubatova, N.V. Handbook of botanical microtechnique: Fundamentals and methods [Spravochnik po botanicheskoy mikrotekhnike. Osnovy i metody]. 2004, Moscow: Moscow State University Publishing.
8. Mirzaghaderi, G.; Marzangi, K. IdeoKar: an ideogram constructing and karyotype analyzing software. Caryologia 2015, 68(1), 31–35. https://doi.org/10.1080/00087114.2014.998526.
9. Levan, A.; Fredga, K.; Sandberg, A.A. Nomenclature for centromeric position on chromosomes. Hereditas 1964, 52, 201–220.
10. Stebbins, G.L. "Chromosomal evolution in higher plants," Edward Arnold (Publishers) Ltd., 1971, London, UK.