https://doi.org/10.5281/zenodo.22845626
UDC 635.132:631.526.32

EFFECT OF DIFFERENT PLANTING SCHEMES ON CARROT GROWTH, ROOT YIELD AND MARKETABLE QUALITY

Orazymbetov Edilbek Kaypbekovich
Head of the Laboratory for Agrotechnics and Plant Protection of Vegetable, Melon, and Potato Crops, Karakalpakstan Scientific Experimental Station, Research Institute of Vegetables, Melons, and Potatoes
edilbekorazimbetov@gmail.com
https://orcid.org/0009-0006-4020-8684

Abstract. *Plant density strongly influences competition, individual root size, grade distribution and marketable carrot yield. This paper presents a factorial framework for determining the effects of 50 × 5, 50 × 10, 50 × 15 and 50 × 20 cm planting schemes on the growth, root yield and marketable quality of Ziynatli and Mshak 195 under Karakalpakstan conditions. The eight cultivar × spacing combinations are arranged in a randomized complete block design with four replications under uniform seed quality, nutrient supply, irrigation and crop protection. Soil electrical conductivity, pH, nutrient status and weather variables are recorded to support interpretation. Assessment integrates field emergence, phenology, leaf traits, root length, shoulder diameter, individual root weight, shape uniformity, cracking, forking, greening, total yield and marketable yield. Two-factor analysis of variance estimates cultivar, spacing and cultivar × spacing effects, while linear and quadratic contrasts describe responses to increasing within-row distance. The framework identifies the spacing that provides the most favourable balance between plant population, root size uniformity and marketable yield for each cultivar and supports cultivar-specific recommendations for the saline, arid environment of the Aral Sea region.*

Keywords: *Daucus carota L.; Ziynatli; Mshak 195; plant spacing; plant density; root quality; marketable yield; Karakalpakstan.*

Annotatsiya. *Maqolada Qoraqalpog‘iston sharoitida 50 × 5, 50 × 10, 50 × 15 va 50 × 20 sm ekish sxemalarining Ziynatli hamda Mshak 195 sabzi navlari o‘sishi, ildizmeva hosildorligi va tovarbop sifatiga ta’sirini aniqlashning ilmiy-uslubiy asoslari bayon etilgan. Ikki omilli tajribani tasodifiylashtirilgan bloklar usulida to‘rt takrorlanishda o‘tkazish, tuproqning elektr o‘tkazuvchanligi, pH ko‘rsatkichi, oziqa elementlari bilan ta’minlanganligi va meteorologik omillarni qayd etish nazarda tutilgan. Baholash tizimi dala unuvchanligi, fenologik rivojlanish, barg apparati, ildizmevaning uzunligi, yelka diametri va vazni, shakl bir xilligi, yorilish, shoxlanish va yashillanish, yalpi hamda tovarbop hosildorlikni qamrab oladi. Ikki omilli dispersiya tahlili yordamida nav, ekish sxemasi va ularning o‘zaro ta’siri aniqlanadi.*

Taklif etilgan yondashuv har bir nav uchun tovarbop hosildorlik va ildizmeva sifatining eng maqbul nisbatini ta'minlaydigan o'simlik qalinligini belgilash imkonini beradi.

Kalit so'zlar: *Daucus carota L.; Ziynatli; Mshak 195; ekish sxemasi; o'simlik qalinligi; ildizmeva; tovarbop hosildorlik; Qoraqalpog'iston.*

Аннотация. *В статье изложены научно-методические основы определения влияния схем посева 50 × 5, 50 × 10, 50 × 15 и 50 × 20 см на рост, урожайность и товарное качество корнеплодов сортов моркови Ziynatli и Mshak 195 в условиях Каракалпакстана. Двухфакторный опыт предусматривается проводить методом рандомизированных блоков в четырех повторениях с регистрацией электропроводности и pH почвы, обеспеченности элементами питания и метеорологических факторов. Система оценки включает полевую всхожесть, фенологическое развитие, листовой аппарат, длину, диаметр плечиков и массу корнеплода, однородность формы, растрескивание, разветвление и позеленение, общую и товарную урожайность. Двухфакторный дисперсионный анализ позволяет определить влияние сорта, схемы посева и их взаимодействия. Предлагаемый подход предназначен для установления оптимальной густоты растений, обеспечивающей наилучшее сочетание товарной урожайности и качества корнеплодов каждого сорта.*

Ключевые слова: *Daucus carota L.; Ziynatli; Mshak 195; схема посева; густота растений; корнеплод; товарная урожайность; Каракалпакстан.*

INTRODUCTION

Carrot (*Daucus carota* L.) is an economically important root vegetable valued for fresh consumption, processing and dietary quality. Its storage roots supply carbohydrates, fibre, minerals and bioactive compounds, especially carotenoids. Commercial value depends not only on total biomass but also on root size, colour, shape uniformity, surface smoothness and freedom from defects. Cultivar choice is therefore a central component of profitable and resource-efficient carrot production [1–3].

The lower Amu Darya region is characterized by a sharply continental arid climate, saline soils, hot winds, low relative humidity and variable irrigation-water availability. Carrot is particularly vulnerable during germination and early seedling growth because its small seed, slow initial development and shallow young root system can lead to uneven stands. Later exposure to water deficit, salinity or excessive temperature may restrict leaf area, shorten the root-filling period and increase forking, cracking, fibrous texture and non-uniformity [4–7].

Cultivar performance represents the expression of genotype within a specific environment and management system. Descriptions obtained under favourable or temperate conditions cannot be transferred directly to Karakalpakstan. Locally replicated trials are required to determine whether a cultivar establishes a uniform stand, maintains foliage under stress and converts assimilates into roots that satisfy market specifications. Simultaneous measurement of agronomic and quality traits is essential because a high total yield can coincide with a low proportion of marketable roots [8–10].

Ziynatli and Mshak 195 are relevant materials for the station's carrot breeding and seed-production programme. The objective of this paper is to determine how within-row plant spacing influences stand development, storage-root formation, yield structure and marketable quality in these cultivars under Karakalpakstan conditions. The factorial framework permits the main effects of cultivar and spacing, as well as their interaction, to be evaluated under salinity, high temperature and restricted water supply.

LITERATURE REVIEW

Carrot productivity is established through a sequence of connected processes: rapid and uniform emergence, formation of a functional leaf rosette, initiation and thickening of the storage root, and maintenance of root quality until harvest. Weak performance at any stage can reduce final marketable yield. Emergence percentage and stand density should therefore be considered explanatory variables rather than treated only as routine observations [3, 4].

Salinity imposes both osmotic and ionic stress. During germination it delays water uptake and can reduce the number and vigour of emerged seedlings. During vegetative growth, salt accumulation may restrict leaf expansion, photosynthesis and root enlargement. Genotypic differences in germination under saline conditions have been reported in diverse carrot germplasm, supporting the value of cultivar-specific screening at both establishment and harvest stages [4, 5].

Water deficit influences carrot yield through reduced canopy growth, premature senescence and limited assimilate supply to the storage root. Irregular water availability may also contribute to cracking and non-uniform root development. Irrigation records and soil-moisture observations are thus required to distinguish an inherent cultivar response from management-induced variation. An efficient cultivar should combine acceptable productivity with stable marketable quality rather than simply producing large vegetative biomass [6, 7].

Root morphology is strongly associated with commercial acceptance. Length and shoulder diameter describe root size, whereas taper, tip fill, straightness and surface smoothness characterize market type. Forking can arise from genetic tendency, soil compaction, undecomposed organic matter, nematode or insect injury, and damage to the primary root. Because several causal factors are possible, defect scoring must be accompanied by careful characterization of soil preparation and crop health [8, 9].

Nutritional and processing quality are commonly described using dry matter, soluble solids, sugars, carotenoids and nitrate concentration. Orange pigmentation is largely associated with carotenoid accumulation, but visual colour alone is not an analytical substitute. Sampling must be standardized by harvest stage, root position within the plot and laboratory method. Multi-environment or multi-year trials are also necessary because quality traits and yield components may respond differently to seasonal conditions [2, 3, 10].

RESEARCH METHODOLOGY

3.1 Study site and environmental characterization. Field experiments are designed for the experimental fields of the Research Institute of Vegetables, Melons and Potatoes, Karakalpakstan Scientific Experimental Station, Nukus, Uzbekistan,

during successive growing seasons. Before sowing, composite soil samples are collected from the 0–30 and 30–50 cm layers. Soil texture, bulk density, organic matter, pH, electrical conductivity, total nitrogen, available phosphorus, exchangeable potassium and water-soluble salts are determined by validated methods. Daily minimum and maximum temperature, precipitation, relative humidity and, where available, reference evapotranspiration are obtained from the nearest meteorological station. Irrigation dates and applied water are recorded throughout the crop cycle.

3.2 Plant material, spacing treatments and experimental design. The plant material consists of the carrot cultivars Ziynatli and Mshak 195. Four planting schemes are evaluated: 50 × 5 cm, 50 × 10 cm, 50 × 15 cm and 50 × 20 cm. These schemes correspond to target populations of approximately 400,000, 200,000, 133,333 and 100,000 plants ha−1, respectively. The experiment is arranged as a two-factor randomized complete block design with four replications, where factor A is cultivar and factor B is within-row spacing. The eight cultivar × spacing combinations are randomized independently within each block. Seed lots are tested for purity and laboratory germination before sowing, while sowing depth, plot size and row length remain uniform across all treatments.

Table 1. Experimental status and principal role of the two carrot cultivars

Cultivar	Experimental status	Purpose in the trial
Ziynatli	Test cultivar	Comparative assessment of adaptation, yield and root quality
Mshak 195	Test cultivar	Comparative assessment of adaptation, yield and root quality

Table 2. Plant-spacing treatments included in the factorial field experiment

Treatment	Planting scheme	Area per plant	Target population
S1	50 × 5 cm	0.0250 m²	400,000 plants ha−1
S2	50 × 10 cm	0.0500 m²	200,000 plants ha−1
S3	50 × 15 cm	0.0750 m²	133,333 plants ha−1
S4	50 × 20 cm	0.1000 m²	100,000 plants ha−1

3.3 Crop establishment and management. The seedbed is prepared to provide a fine, uniform and uncompacted tilth. Seeds are sown on the same date and at the same depth using calibrated equipment. After emergence, seedlings are thinned precisely to the assigned 5, 10, 15 or 20 cm within-row distance; missing plants are not replaced after the establishment period. Fertilizer is applied according to soil-test results, avoiding excessive nitrogen that could stimulate foliage at the expense of root quality or increase nitrate accumulation. Irrigation, inter-row cultivation, weed control and plant-protection measures are applied uniformly to all plots. Border rows and end plants are excluded from sampling. Any deviation in water distribution, pest pressure or soil condition is documented at plot level.

3.4 Phenology, stand establishment and canopy traits. Dates of first emergence, 50% emergence, 75% emergence and harvest maturity are recorded. Field emergence is calculated as the percentage of sown seeds producing established

seedlings within the defined observation area. Plant survival to harvest and final stand density are determined from fixed sections of each plot. At standardized growth stages, leaf-rosette height, number of leaves per plant, canopy uniformity, chlorosis, marginal necrosis and premature senescence are assessed on preselected non-border plants. Biotic damage is recorded separately from abiotic injury.

3.5 Root yield, morphology and marketability. Each net plot is harvested separately at a common physiological or market maturity. The number and fresh weight of roots are measured, and total yield is converted to tonnes per hectare as $Y = 10M/S$, where Y is yield (t ha−1), M is root mass from the net plot (kg), and S is net plot area (m^2). On a representative sample, individual root weight, root length, maximum shoulder diameter, core diameter and root length-to-diameter ratio are recorded. Shape uniformity, straightness, tip fill and surface smoothness are assessed using predefined descriptors. Forked, cracked, green-shouldered, diseased, mechanically damaged and undersized roots are counted and weighed separately. Marketability is calculated as $T = (Mm/Mt) \times 100$, where Mm is marketable root mass and Mt is total root mass.

3.6 Biochemical quality assessment. Quality samples are obtained from the inner rows of every plot and handled identically. Dry matter is determined gravimetrically; soluble solids are measured by calibrated refractometry; and total sugars, carotenoids and nitrates are quantified using validated laboratory protocols. Results are expressed on a clearly stated fresh- or dry-weight basis. Composite sampling should not replace replication: each block must provide an independent analytical sample so that cultivar differences can be tested statistically.

Table 3. Core indicators for evaluating cultivar and plant-spacing effects

Trait group	Indicator	Unit or scale	Assessment stage
Establishment	Field emergence; final stand	%; plants m−2	Emergence; pre-harvest
Phenology	Days to 50% emergence; days to harvest	days	During season
Canopy	Rosette height; leaf number; injury score	cm; number; ordinal scale	Defined growth stages
Root morphology	Length; shoulder diameter; individual weight	cm; mm; g	Harvest
Defects	Forking; cracking; greening; disease	% by number and mass	Harvest
Productivity	Total and marketable yield	t ha−1; % marketability	Harvest
Quality	Dry matter; soluble solids; sugars; carotenoids; nitrate	method-specific units	Harvest laboratory sample

3.7 Statistical analysis and cultivar-selection rule. Plot data are analysed using two-factor analysis of variance appropriate to a randomized complete block design. The model estimates the effects of cultivar, plant spacing and cultivar × spacing interaction. Treatment means are reported with standard errors, and differences are

evaluated at $p \leq 0.05$; Fisher's least significant difference is presented when the corresponding effect is significant and model assumptions are satisfied. Orthogonal polynomial contrasts may be used to test linear and quadratic responses to increasing within-row spacing. Residuals are examined for normality and homogeneity of variance; proportions and counts are transformed or analysed with generalized models when required. In combined analysis across years, year and its interactions with cultivar and spacing are included. Agronomic efficiency is assessed from marketable yield per hectare together with marketability, mean root weight and dimensional uniformity.

ANALYSIS AND RESULTS

The comparative framework identifies stand establishment as the first decisive component of adaptation. Uniform emergence creates an even canopy and reduces competition among neighbouring plants, whereas gaps and delayed seedlings increase variability in root diameter and maturity. For Ziynatli and Mshak 195, emergence percentage should be interpreted together with laboratory germination and soil electrical conductivity. This separates seed-lot limitations from cultivar response to the field environment.

Phenology provides a second line of interpretation. Earlier establishment and root filling may help a cultivar avoid late-season heat and water deficit, but rapid maturity is beneficial only when it is accompanied by adequate root size and marketable yield. A longer-duration cultivar may remain competitive if it preserves green leaf area, sustains root growth and produces a uniform harvest. Consequently, days to harvest must be assessed jointly with canopy condition and yield formation.

Leaf-rosette development describes the photosynthetic source supporting storage-root growth. Large foliage can improve radiation interception, yet excessive vegetative growth may delay assimilate partitioning to roots and complicate harvest. Rosette height and leaf number are therefore explanatory traits, not independent selection goals. Their agronomic value is determined by their relationship with individual root weight, total yield and marketability.

Root dimensions and shape reveal different aspects of cultivar performance. Root length indicates penetration and elongation, shoulder diameter reflects thickening, and the length-to-diameter ratio helps describe market type. A cultivar with a favourable mean size may still be commercially weak if variability is high. Distribution of roots among predefined grades and the coefficient of variation for key dimensions therefore provide more useful evidence than a mean value alone.

Defect analysis is essential because total yield can overestimate usable production. Forking, cracking, greening and disease directly reduce marketable output. Their causes must be interpreted carefully: forking may be associated with genotype, compacted soil or injury to the primary root, while cracking can reflect irregular growth following fluctuations in water supply. Uniform seedbed preparation and irrigation across all plots allow the cultivar component of these responses to be assessed more reliably.

Biochemical indicators complement visual and yield evaluation. Dry matter and soluble solids are associated with texture and processing behaviour, sugars influence

flavour, and carotenoids contribute to nutritional value and root colour. Nitrate concentration is important for food-quality assessment and can respond strongly to nitrogen supply, irrigation and harvest stage. Standardized sampling and replicated laboratory measurements are necessary before quality differences are attributed to cultivar.

Plant spacing changes the balance between productivity per plant and productivity per unit area. Narrow spacing increases the number of plants occupying one hectare but intensifies competition for light, water and nutrients; this commonly reduces individual root mass and shifts the harvest toward smaller diameter classes. Wider spacing increases the soil and canopy resources available to each plant and can promote larger roots, although the reduced plant population may limit yield per hectare. The agronomic optimum is therefore the spacing that maximizes marketable yield rather than either plant density or individual root size alone.

The cultivar × spacing interaction is central to interpretation. Ziynatli and Mshak 195 may differ in rosette architecture, root growth rate and capacity to exploit additional space. If the interaction is significant, a single planting recommendation for both cultivars would be inappropriate. Each cultivar should then be assigned the spacing that provides the most favourable combination of marketable yield, grade distribution, uniformity and low defect incidence.

`Repeated testing across seasons is required to establish consistency. A significant cultivar × year interaction would indicate that relative performance changes with environmental conditions. In that case, recommendation should emphasize stability and the conditions under which each cultivar performs best. This evidence-based approach supports decisions that are agronomically meaningful and statistically defensible for Karakalpakstan.

CONCLUSION AND RECOMMENDATIONS

1. Plant spacing should be treated as a cultivar-specific management factor because it directly controls competition, individual root size, grade distribution and marketable yield per hectare.
2. The factorial combination of Ziynatli and Mshak 195 with 50 × 5, 50 × 10, 50 × 15 and 50 × 20 cm schemes provides a defensible experimental range for identifying the agronomic optimum.
3. A randomized complete block design with four replications, uniform management and documented environmental conditions is required to separate cultivar, spacing and cultivar × spacing effects.
4. Marketable yield, root uniformity and defect incidence should be the principal criteria, supported by emergence, maturity, canopy traits and biochemical quality.
5. The final planting recommendation should be based on replicated multi-year evidence and may differ between Ziynatli and Mshak 195 when their density responses are not parallel.

REFERENCES

1. Food and Agriculture Organization of the United Nations. FAOSTAT: Crops and livestock products database. Rome: FAO; 2025. Available from: https://www.fao.org/faostat/

2. Que F, Hou XL, Wang GL, Xu ZS, Tan GF, Li T, et al. Advances in research on the carrot, an important root vegetable in the Apiaceae family. Horticulture Research. 2019;6:69. doi:10.1038/s41438-019-0150-6.

3. Simon PW, Freeman RE, Vieira JV, Boiteux LS, Briard M, Nothnagel T, Michalik B, Kwon YS. Carrot. In: Prohens J, Nuez F, editors. Vegetables II. New York: Springer; 2008. p. 327–357.

4. Bolton A, Kluepfel D, Dungan R, et al. Variation for salinity tolerance during seed germination in diverse carrot germplasm. HortScience. 2019;54.

5. Shannon MC, Grieve CM. Tolerance of vegetable crops to salinity. Scientia Horticulturae. 1999;78:5–38.

6. Elshamly AMS, et al. Stimulating growth, root quality, and yield of carrots under water stress conditions. Scientific Reports. 2023;13.

7. Geem KR, et al. The role of carrot storage roots in drought response and recovery. Plants. 2025.

8. Rubatzky VE, Quiros CF, Simon PW. Carrots and Related Vegetable Umbelliferae. Wallingford: CABI; 1999.

9. Department of Agriculture, Fisheries and Forestry, Queensland Government. Carrot production guide: crop establishment, nutrition, irrigation and quality management. Brisbane; 2022.

10. Farwan K, et al. GGE biplot analysis of yield performance and stability in carrot genotypes across environments. 2024.