RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (5) 1983-1993, 2025
http://doi.org/10.54910/sabrao2025.57.5.19
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

INTRODUCTION OF LEAFY CABBAGE KALE (*BRASSICA OLERACEA* VAR. *SABELLICA*) IN SOUTHEAST KAZAKHSTAN

A.S. JANTASSOVA, A.O. NUSUPOVA, J.A. TOKBERGENOVA, G.M. IBRAGIMOVA, E.U. TAYSHIBAEVA, and S.K. JANTASSOV*

Kazakh Research Institute of Fruit and Vegetable Growing LLP, Almaty, Kazakhstan
*Corresponding author's email: s_jantassov@mail.ru
Email addresses of co-authors: aigerim-jantasova@mail.ru, aigul.nusupova.65@mail.ru, zh.tokbergenova@mail.ru, gulnara.0868@mail.ru, elvira701@mail.ru

SUMMARY

This research aimed to study the most productive F1 hybrids of kale cabbage (*Brassica oleracea* var. *Sabellica*) through various cultivation methods under field and greenhouse conditions for the possible development of a green conveyor for year-round provision with fresh vitamins. Six selected hybrids of kale cabbage from the field during 2020–2021 sustained evaluation in the greenhouse using the nutrient film technique (NFT) technology and aquaponics. The recording of data included the growth and phenological parameters and yield. The three kale cabbage F1 hybrids stood out for productivity and quality indicators under field and greenhouse conditions. The kale F1 hybrids Dwarf Green Curled, Scarlet, and Nero di Toscana emerged with the highest yield indicators under field conditions. The hybrids Nero di Toscana, Scarlet, and Dwarf Green Curled had maximum yield increases of 195.3%, 461.58%, and 198.1%, respectively, with NFT technology compared with aquaponics. Overall, the kale F1 hybrid Dwarf Green Curled was remarkable, with the best results on productivity in long-term cultivation (from 1.5 to two months) under field and greenhouse conditions.

Keywords: kale cabbage (*Brassica oleracea* var. *Sabellica*), hybrids, growth and phenological traits, productivity, hydroponics, aquaponics

Key findings: The kale cabbage (*Brassica oleracea* var. *Sabellica*) hybrids showed better results both under field and greenhouse conditions. The three kale F1 hybrids, viz., Dwarf Green Curled, Scarlet, and Nero di Toscana, emerged as highly recommended for cultivation under field and greenhouse conditions using the NFT technology.

Communicating Editor: Dr. Anita Restu Puji Raharjeng

Manuscript received: October 15, 2024; Accepted: April 22, 2025.

Citation: Jantassova AS, Nusupova AO, Tokbergenova JA, Ibragimova GM, Tayshibaeva EU, Jantassov SK (2025). Introduction of leafy cabbage kale (*Brassica oleracea* var. *Sabellica*) in Southeast Kazakhstan. *SABRAO J. Breed. Genet.* 57(5): 1983-1993. http://doi.org/10.54910/sabrao2025.57.5.19.

INTRODUCTION

The introduction and exploration of new vegetables has played a major role in the history of plant cultivation. In the 1920s of the last century, researchers from various regions observed the greater role of introducing new plants in the development of world agriculture, and, as a result, numerous theories and methods of launching plants cropped up (Kirsanova, 2010; Belyuchenko and Mustafaev, 2013).

The movement and introduction of crop plants in the new area has always been one of the most central features in world agricultural progress. Scientists have identified seven geographical centers of origin of cultivated plants, where the most valuable world vegetable species amass. A significant number of plants originated in Europe and Asia (62.5%), Africa (7.8%), and the Americas (15.6%). The discovery of America succeeded in a massive exchange of new plant species, which gave a sharp jump in the development of agriculture in all continents (Startsev *et al.,* 2020; Zanozina, 2021). N.I. Vavilov substantiated the problem of the introduction of new crops into domestic crop production, with the need to introduce the world's plant resources into the culture. In this regard, it is necessary to introduce new, promising crop plants into the world crops. Global agriculture researchers have completely built this industry on the domestication of foreign plants (Dzyubenko and Vishnyakova, 2007).

The introduction of new vegetable species has always been relevant and crucial in different ecological and geographical zones of Kazakhstan that considerably allow expanding the range of vegetables and improving population nutrition, making it more diverse. Vegetable products are rich sources of biologically active substances, minerals, vitamins, carbohydrates, and amino acids. Most of these organic substances are antioxidants that react with free radicals and lead them to partial or complete inactivation (Sharafutdinova *et al*., 2011).

In the Brassicaceae family, the vegetables are the most widely consumed in the production of various foods worldwide (Nizhelskaya and Chizhikova, 2016). Among these vegetables, the kale leafy cabbage attracts the special attention of end users. Recently, kale has become widespread due to its unique biochemical composition. The biochemical composition of cabbage includes P, K, vitamins B1 and B2, nicotinic and ascorbic acids, inositol, folic acid, and biotin, as well as being rich in mineral elements (Ca, Fe, and Mg) (Almugrabi *et al*., 2018; Ortega-Hernandez *et al*., 2021; Anteh *et al*., 2021). The kale leaf cabbage also contains the highest concentration of flavonoids (quercetin and kaempferol) and carotenoids (Samec *et al.,* 2019; Jurkow *et al.,* 2019; Jantassova *et al.,* 2023). Thus, according to the observations of world scientists, kale is a very useful vegetable (Hollman and Arts, 2000; Kapusta-Duch *et al.,* 2012).

In vegetable production, one of the main objectives is to provide the population with a sufficient supply of green leafy crops during their common growing season and even in the off-season. One of the most productive methods to solve this problem is the cultivation of vegetables in protected conditions on hydroponics (Pivovarov, 2006). Hydroponics cultivation methods are superior to traditional technologies for growth rate, productivity, and product quality. Hydroponics has long been a most recognized, effective, and feasible method of increasing yield (Texier, 2020). Today, hydroponic technology is widespread worldwide; however, variations in hydroponic systems exist, ranging from small home installations to large industrial systems (www.agbz.ru). Aquaponics is one type of hydroponics that essentially is the skillful combination of hydroponics (growing plants without soil in water) and aquaculture (raising fish, shrimp, and other aquatic creatures). In the closed biological system, the waste from the fish serves as a source of food for crop plants, which, in turn, filter the water for fish culture. In these processes, another participant is the nitrifying bacteria, which convert ammonia from fish waste into nitrite and then nitrate. Aquaponics is a practical and beneficial one-time process (gidronom.ru).

Nowadays, a healthy lifestyle and proper nutrition are becoming increasingly important. However, in this case, the crucial role of green and spicy crops requires much attention because even a small amount of greens has a positive effect on the human diet. The green crops cultivation and use are also environmentally friendly, given their shorter vegetation periods that allow continuous cultivation of products at least 4–5 times during one season without using chemical preparations (Girenko and Zvereva, 2007). Salads are the leader among green vegetables in greenhouses, while cabbage crops come in second place (Muravyev*,* 2007). Rapid development of mini crop farms and the transition of populations to organic and vitamin products allowed incorporating new vegetable crops like kale in modern cultivation technologies—microgreens and baby greens.

Introduction and domestication of kale cabbage and evaluation of promising cultivars under different cultivation conditions (field and greenhouse) will contribute to the diversification and expansion of vegetable culture in Kazakhstan. Additionally, the population will have an opportunity to have a year-round source of vitamin supply. The state register of the breeding achievements has no registration of kale leaf cabbage cultivars and hybrids in Kazakhstan. Therefore, the introduction and further exploration of the kale leaf cabbage culture are relevant in Kazakhstan.

MATERIALS AND METHODS

The related research took place in 2020–2021 in field conditions. The six F1 hybrids of curly cabbage kale, i.e., Dwarf Green Curled, Nero di Toscana, Scarlet, Red Russian, Kapitan, and Kapral, were options for study and evaluation (Figure 1). Seedling planting continued at the age of 40 days with 4–5 true leaves in the field. The subplot size was 1.4 m × 10 m, and the total area was 14 m^2, comprising 30 plants in each experimental unit with four replications. Hybrids released under field conditions in the first few years of the study also sustained evaluation in the greenhouse. The data recorded comprised growth parameters (stem height, number of leaves, and leaf area), phenological traits, and the early and total yield. The three kale-cabbage hybrids stood out for productivity and quality indicators under field conditions (Figure 2).

In 2021–2022, the three hybrids of kale cabbage obtained assessment under greenhouse conditions with two different types of hydroponics, i.e., the new film technique (NFT) technology and aquaponics, with three replications. After laying out the experiments in the greenhouses, recording the data ensued on the growth and phenological traits and the yield. In the cultivation process of kale cabbage, the 2-fold cutting of leaves of kale plants succeeded. In the greenhouses, the installed tiered racking structures consisted of three levels and a system of recirculation of nutrient solutions (Figure 2).

The unit size comprised a width of 1.2 m, a length of 3.0 m, and three tiers. The kale cabbage plants' placement in the cells had the scheme of 30 cm × 30 cm. Growing the plants of three kale cabbage cultivars took 90 days under both the aquaponics and NFT technology to evaluate the suitability of the kale cabbage with these new growing systems. All three hybrids grew well in both systems. In the presented research on these kale-cabbage hybrids, an acceptable cultivation period was noteworthy without loss of palatability, where obtaining maximum leaf productivity was possible.

For the evaluation of these kale hybrids in 2021–2022 under greenhouse conditions, two different types of hydroponics used were NFT technology and aquaponics. The first measurement of biometric parameters occurred after one month of vegetation (December 19, 2021), while the second measurement proceeded one month after the first (January 19, 2022). The recording of the height of the main stem (cm), number of leaves, and leaf area also succeeded.

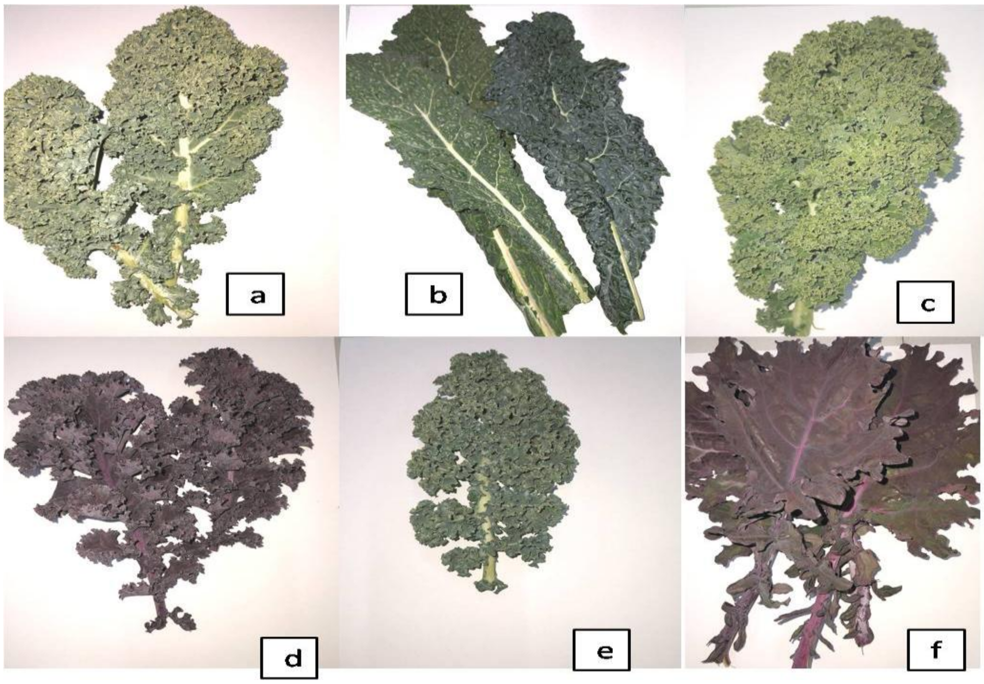

Figure 1. F1 hybrids of curly cabbage Kale: a) Dwarf Green Curled, b) Nero di Toscana, c) Kapitan, d) Scarlet, e) Kapral, and f) Red Russian.

Figure 2. Shelf plants for growing leafy greens: a) open field, b) growth rack, and c) fish tank.

Determining the leaf area of strongly dissected leaves had the following formula applied as per the methodology:

$$Y = a + b \times x$$

Where Y = leaf area, a and b = constants determined for each crop by the regression method, and x = the product of the leaf length by the leaf width.

N.F. Konyaev derived 18 formulas for determining the leaf area of the vegetables, and in this case, the study used the following formula (Litvinov, 2011):

$$Y = 16 + 0.624 \times x$$

Table 1. Chemical composition of water (nutrient medium) used for growing Kale cabbage on hydroponics.

No.	Indicators for determination, units of measurement	Test assessment reference	Results obtained	
			NFT technology	Aquaponics
1	PH, Hydrogen Index	ST RKISO 10523-2013	6.66	6.85
2	EC, mS/cm	WD 52.24.495-2005	3.24	0.99
3	Potassium K, mg/dm3	GOST 26449.1-85	448.7	87
4	Nitrogen ammon. (N-NH4) mg/dm3	GOST 33045-2014	0.11	0.00
5	Nitrate nitrogen (N-NO3) mg/dm3	ST RK 2730-2015	293.8	31.6
6	Calcium Ca, mg/dm3	GOST 31954-2012	313.2	69.9
7	Magnesium Mg, mg/dm3	GOST 31954-2012	138.4	32.1
8	Sodium Na, mg/dm3	GOST 26449.1-85	16.0	67.3
9	Hydrocarbonates, mg/dm3	ST RK 2726-2015	78.8	99.1

Plant growth monitoring was regular throughout the period of the experiment (Afolabi, 2020). The measuring of averages of leaf length, leaf width, the number of leaves per plant, and plant height continued every 10 days, from the beginning of the experiment until the last day.

During the research to evaluate the different hybrids of kale cabbage, applying the methodological recommendations for conducting experiments with vegetables in greenhouses and methods of field experiments in vegetable and melon growing transpired (Litvinov, 2011). According to phenological observations, the following recorded dates comprised sowing, single and mass sprouts, and harvesting. According to biometric observations, data recording ensued for the main stem height (cm), number of leaves, and leaf area. Harvesting progressed in the whole area, comprised of three repetitions. Biochemical analysis also occurred to assess the qualitative indicators in kale-cabbage hybrids. Statistical compilation of the obtained data used the methods of dispersion analysis (Dospekhov, 1985). During the kale cabbage cultivation, the study followed agro-techniques adopted in the given zone, considering the biological features of the crop. Cabbage leaf area calculation followed the regression model (Litvinov, 2011). In the testing laboratory of Kos Agro Kommerts LLP, carrying out the comparative analysis of irrigation water (used in both systems for growing kale cabbage on hydroponics) was successful (Table 1).

RESULTS AND DISCUSSION

The relevant results enunciated that the two kale cabbage F1 hybrids, Dwarf Green Curled and Scarlet, were visible with early sprouts obtained on day 5 (dated April 15). However, the late sprouting obtained for the kale cabbage F1 hybrid Red Russian was on day 7. Moreover, for the beginning of the maturation process, the different dates were evident with these kale cabbage F1 hybrids, i.e., Dwarf Green Curled and Scarlet (dated June 24 and June 26, respectively) and with the hybrid Red Russian (dated June 30). For the period from mass sprouting to the 1st harvest, the allocated days for the hybrid Dwarf Green Curled was 70 days, and in this phase, the late entry resulted in the hybrid Red Russian (74 days). The kale F1 hybrid Dwarf Green Curled showed distinction with the longest period of yielding (94 days), while the Red Russian F1 hybrid had the shortest period (88 days) (Table 2). Along with phenological observations, the conduct of biometric measurements also continued. A formation of primary collection of kale leaf cabbage carried out their study on a complex of economically valuable characteristics (Jantassova *et al.,* 2023). In Table 4, one can see that the biometric measurements happened three times (June, July, and August). The kale hybrid Nero di Toscana F1 gave the maximum values in all the parameters, like stem height and the number of leaves. The F1 hybrid Dwarf Green Curled was notable with the lowest values for the above traits among all the experimental plants (Table 3).

Table 2. Phenological observations of Kale cabbage under field conditions.

No.	Kale F1 hybrids	Data						Number of days from	
		Sowing	Sprouts		Planting	Final collection	Beginning of maturation	Mass. of sprouts up to the 1st harvest	Ripened to last harvest
			10%	75%					
1	Dwarf Green Curled	11.04	14.04	15.04	28.05	24.06	26.09	70	94
2	Nero di Toskana	11.04	14.04	16.04	28.05	28.06	26.09	73	90
3	Scarlet	11.04	14.04	15.04	28.05	26.06	26.09	72	92
4	Red Russian	11.04	16.04	17.04	28.05	30.06	26.09	74	88
5	Kapitan	11.04	15.04	16.04	28.05	28.06	26.09	73	90
6	Kapral	11.04	14.04	16.04	28.05	26.06	26.09	71	92

Table 3. Biometric parameters of Kale curly cabbage under field conditions.

Kale F1 hybrids	Date of measurement	Plant height (cm)	Number of leaves	Leaf length (cm)	Leaf width (cm)
Dwarf Green Curled	16.06.21	13.0	9	11.2	4.4
	15.07.21	19.6	25	25.1	11.05
	15.08.21	19.6	25	27.4	11.8
Nero di Toscana	16.06.21	15.1	11	11.3	4.6
	15.07.21	38.7	26	32.2	12.4
	15.08.21	38.8	28	34.1	12.6
Scarlet	16.06.21	14.9	13	8.7	4.5
	15.07.21	34.7	21	24.9	12.4
	15.08.21	37.7	25	24.9	20
Red Russian	16.06.21	11.1	9	11	5.1
	15.07.21	30.1	29	29.4	13.8
	15.08.21	30.5	32	29.4	13.9
Kapitan	16.06.21	12.0	8	7.7	4.5
	15.07.21	25.2	21	23.6	10.3
	15.08.21	26.4	21	26.4	11.9
Kapral	16.06.21	12.7	8	11.5	4.3
	15.07.21	25.0	27	22.2	11.7
	15.08.21	26.0	27	24.8	11.9

Table 4. Productivity indicators of Kale curly cabbage under field conditions.

No.	Kale F1 hybrids	Leaf productivity (kg)				Total leaves yield (kg)
		1 collect.	2 collect.	3 collect.	4 collect.	
1	Nero di Toscana	6.05	6.275	11.95	12.3	36.575
2	Scarlet	7.15	6.375	10.375	9.875	33.775
3	Kapitan	7.425	6.9	15.5	15.375	45.2
4	Kapral	6.625	5.675	11.5	12	35.8
5	Dwarf Green Curled	7.3	6.25	13.375	12.275	39.2
6	Red Russian	7.875	6.6	13.125	12.575	40.175
	Hsd 05 kg/plot					8.57
	CV %					22.28

Three hybrids of kale cabbage, grown by the researchers, ensued in the fields, greenhouses, and growth chambers (Ashenafi *et al.,* 2022). The collection of plants occurred in the three stages of development (seedlings, juveniles, and the mature plants), with their morphology, biomass, and pigment density measured. Scientists also conducted similar studies to identify the kale hybrids best adapted to the conditions of Kazakhstan. Furthermore, the biochemical analysis carried out helped determine the content of vitamins A and C, quercetin, dry matter, total nitrogen, potassium, calcium, phosphorus, and magnesium in kale leaves; however, data presentation is unavailable in this article. The maximum number of leaves appeared in hybrid Red Russian (32), while the minimum was in the hybrid Kapitan (21). According to the indicator of leaf length, the hybrid Nero di Toscana stood out (34.1 cm), with the minimum leaf length observed in the kale hybrid Kapral (24.8 cm).

Harvesting proceeded four times during the whole vegetation period, as the leaf mass increased. For the first and second harvests, a nonsignificant difference existed in leaf mass, ranging from 5.6 to 7.8 kg for kale hybrids. In the third and fourth harvests, the kale F1 hybrid Kapitan showed the maximum productivity (45.2 kg/plot), followed by the Red Russian (40.17 kg/plot) and the Dwarf Green Curled (39.2 kg/plot) (Table 4). On the dry matter content in kale cabbage leaves, F1 hybrid Scarlet stood out (11.4%), while the lowest value for the said trait resulted in the kale hybrid Kapitan (8.0%). The highest index of total sugar content was notable in the kale hybrid Dwarf Green Curled F1 (12.3%), while the lowest index was apparently in the hybrid Kapitan (7.6%). Vitamin C with the maximum index arose in the kale hybrid Scarlet (36.2 mg/100 g), followed by the hybrid Kapral (31.3 mg/100 g). However, the lowest index of vitamin C surfaced in the kale hybrid Kapitan (20.7 mg/100 g) (Table 5).

The primary collection of kale cabbage, consisting of six hybrids, had the study of the leaf cabbage collection carried out on the economically valuable traits. Summarizing the results, one can conclude an inverse relationship existed between the productivity and quality indicators (Table 6). The correlation coefficient's calculation used the formula (Dospekhov, 1985):

$$r = \frac{\sum x * y \; - \; \frac{\sum x * y}{n}}{\sqrt{(\sum x^2 - \frac{(\sum x)^2}{n}) * (\sum y^2 - \frac{(\sum y)^2}{n})}}$$

Where r = correlation coefficient, n = number of observations, and x and y = variables.

The resulting negative value of the Pearson correlation coefficient indicates the presence of a feedback between X and Y. The value of the correlation coefficient equal to -0.000212 shows the relationship between X and Y is weak.

In the related experiments, during the first month of development (the date of measurements was December 19, 2021), the plants of all three kale hybrids with both cultivation technologies were relatively at par for stem height and the number of leaves. However, a significant difference appeared only in the leaf area, and the increase resulting from NFT technology in the kale F1 hybrids was the following: Nero di Toscana (169.4%), Scarlet (161.2%), and Dwarf Green Curled (171.8%). After 30 days (dated January 19, 2022), the following significant differences in NFT technology in the kale F1 hybrids were in Nero di Toscana, Scarlet, and Dwarf Green Curled in stem height (136.4%, 163.5%, and 165.1%, respectively), in the number of leaves (123.3%, 144.9%, and 181.6%, respectively), and in the average leaf area (245.6%, 278.0%, and 278.3%, respectively) (Table 7). The indicators considerably affecting the productivity of green and leafy crop plants are the number of leaves and the average leaf area (Table 8). Total productivity (average number of leaves and their weight by kale hybrids and variants) took place two times—the first on January 19, 2022, and the second on February 26, 2022.

The harvest in the first month showed the NFT technology was two times more

Table 5. Biochemical composition of Kale cabbage under field conditions.

No.	Experience variants	Dry matter (%)	Total sugar (%)	Vitamin C (mg/100g)	Nitrates (mg/kg (MAC-)
1	Dwarf Green Curled	9.9	12.3	28.0	82
2	Nero di Toscana	8.9	9.3	24.4	63
3	Scarlet	11.4	10.4	36.2	70
4	Red Russian	9.1	11.0	27.1	57
5	Kapitan	8.0	7.6	20.7	51
6	Kapral	10.8	11.2	31.3	66

Table 6. Correlation coefficient (r) between total yield leaves and biochemical composition of Kale cabbage (open field).

No.	F1 Hybrids	Total leaf yield (kg) (x)	Total sugar % (y)	x*y	x^2	y^2
1	Nero di Toscana	36.58	12.30	449.87	1337.73	151.29
2	Scarlet	33.78	9.30	314.11	1140.75	86.49
3	Kapitan	45.20	10.40	470.08	2043.04	108.16
4	Kapral	35.80	11.00	393.80	1281.64	121.00
5	Dwarf Green Curled	39.20	7.60	297.92	1536.64	57.76
6	Red Russian	40.18	11.20	449.96	1614.03	125.44
	Amount	230.73	61.80	2375.74	8953.83	650.14

Table 7. Biometric indices of Kale hybrids under greenhouse conditions.

No.	Kale F1 hybrids	Date of measure-ment	Stem height (cm)	Number of leaves	Leaf length (cm)	Leaf width (cm)	Average leaf area (cm^2)
Aquaponics							
1	Nero di Toscana	19.12.21	11.37	5.27	5.33	2.63	24.75
		19.01.22	31.67	14.27	14.27	5.67	66.46
2	Scarlet	19.12.21	9.40	4.77	4.53	3.07	24.77
		19.01.22	25.57	10.07	9.20	5.03	44.88
3	Dwarf Green Curled	19.12.21	10.60	4.97	4.33	2.93	24.07
		19.01.22	26.53	11.60	13.27	5.50	61.50
NFT technology							
1	Nero di Toscana	19.12.21	11.80	7.07	8.87	4.67	41.92
		19.01.22	43.20	17.60	25.40	9.27	163.21
2	Scarlet	19.12.21	10.60	7.13	7.60	4.93	39.93
		19.01.22	41.83	14.60	16.87	10.33	124.78
3	Dwarf Green Curled	19.12.21	12.73	6.67	7.53	5.40	41.35
		19.01.22	43.80	21.07	21.03	11.80	171.13

productive than aquaponics in the two kale F1 hybrids, Nero di Toscana and Dwarf Green Curled. High responsiveness to fertilizers was visible in the kale hybrid Scarlet, wherein this indicator was at the level of 7.6 times. One should consider that the conduct of these experiments sought to identify and optimize the timing of harvesting kale leaves at maximum productivity without losing product quality. The kale cabbage sets leaves as the stem grows, and it is possible to harvest leaves over a longer period of time than other leafy and green crops. The harvesting of baby leaves can occur when the kale plants are more than 14 days old.

Table 8. Productivity of Kale hybrids with different cultivation technologies under greenhouse conditions.

Kale F1 hybrids	Productivity of cabbage leaves					
	January 19, 2022		February 26, 2022		Average	
	Total leaves weight (g)	Number of leaves	Total leaves weight (g)	Number of leaves	Total leaves weight (g)	Number of leaves
Aquaponics						
Nero di Toscana	670.00	96.00	766.67	100.33	1436.67	196.33
Scarlet	590.00	111.67	633.33	101.00	1223.33	212.67
Dwarf Green Curled	844.17	83.33	900.00	115.00	1744.17	198.33
CV	5.7					
Hsd_{05}	257.76					
NFT technology						
Nero di Toscana	1340.00	106.00	1466.67	128.33	2806.67	234.33
Scarlet	4513.33	92.67	1133.33	104.33	5646.66	197.00
Dwarf Green Curled	1688.33	108.67	1766.67	117.00	3455.00	225.67
CV	3.72					
Hsd_{05}	328.22					

Kale cabbage plants in the first 30 days of growth met these parameters, and the leaf length ranged from 4.33 to 5.33 cm for aquaponics and 7.53 to 8.87 cm for NFT technology. For longer cultivation periods, the study recommends that after the first month of vegetation, further harvesting of leaves should continue every 14 days. Past research showed the combined treatment using the AB Mix nutrition type and the growing medium type did not have a significant effect on the height of cabbage plants at the age of 14, 21, 28, 35, 42, and 49 days after planting (Nafiah *et al*., 2023). However, in the latest studies, we conducted counts 30 and 60 days after planting kale plants. Kale plants with NFT technology showed a significant difference in growth parameters.

Similar findings in kale cabbage populations in the Black Sea Region of Turkey have also come from Afolabi (2020). Data presented provided a comparison of the cultivation of kale cabbages in the open ground using the DWC aquaponic system in greenhouse conditions. In general, the results on aquaponics showed better outcomes than when growing cabbage in the open ground. When evaluating kale-cabbage hybrids in the open and protected ground, a similar pattern was evident in our studies. The results of the assessment in the open ground during 88–94 days of cultivation revealed the total weight of fresh leaves per plant was in the hybrids Nero di Toscana (201.7 g), Scarlet (212.3 g), Kapitan (230.0 g), Kapral (186.7 g), Dwarf Green Curled (243.3 g), and Red Russian (220.0 g). Afolabi (2020) also reported NFT technology growing in a greenhouse, where an excess of productivity per plant in hybrids emerged, i.e., Nero di Toscana (210.8 g), Scarlet (418.48 g), and Dwarf Green Curled (322.58 g), compared with the open ground by 4.5%, 97.11%, and 32.58%, respectively.

Overall, the number of leaves per plant remained unchanged under different cultivation technologies, with small deviations by the hybrids within acceptable norms. Nevertheless, a large increase in productivity appeared with NFT technology. The three kale F1 hybrids, Nero di Toscana, Scarlet, and Dwarf Green Curled, had the maximum yield increase of 195.3%, 461.58%, and 198.1%, respectively, with NFT technology versus aquaponics. Nafiah *et al*. (2023) reported the right combination of nutrients (AB Mix) and types of media to enhance the yield and growth of kale plants grown under hydroponic substrates. The presented research studied the effect of nutrients in two different hydroponic setups on the yield and growth of kale hybrid plants. As shown in Table 1, the content of N, P, Ca, Mg, and S was different in the irrigation solution.

However, one should consider that leaf production obtained through aquaponics was environmentally friendly and does not contain nitrates, and its production cost was much lower than in NFT technology with the use of mineral fertilizers. In irrigation water, the nitrate nitrogen content under NFT technology (293.8 mg/dm^3) was almost 10 times higher than in aquaponics (31.6 mg/dm^3). The weight and cost of fish used in aquaponics were unaccounted for, which can also affect the production cost under this technology.

CONCLUSIONS

Summarizing the results, an inverse relationship between the productivity and quality indicators of the kale cabbage occurred. The negative correlation indicates the presence of feedback between X and Y. The kale F1 hybrids Kapitan, Red Russian, and Dwarf Green Curled were leading for productivity. Meanwhile, for qualitative traits, the F1 hybrids Scarlet, Nero di Toscana, and Dwarf Green Curled excelled over other hybrids. The F1 hybrids Nero di Toscana, Scarlet, and Dwarf Green Curled had maximum yield increases of 195.3%, 461.58%, and 198.1%, respectively, compared with aquaponics. Overall, the kale F1 hybrid Dwarf Green Curled was notable with the best productivity in long-term cultivation under the field and greenhouse conditions.

ACKNOWLEDGMENTS

Authors are grateful to RAM Bio Science LLP, Republic of Kazakhstan, Almaty, for the free provision of seeds of kale-cabbage hybrids.

The data published in the article were results from the implementation of the project BR22885335, "Ensuring sustainable development of potato, vegetable, and melon growing in Kazakhstan on the basis of breeding, seed production, biotechnology, and innovative agro-technologies," with funds from the Competition for Program-Targeted Funding for scientific and technical programs for 2024–2026 of the Ministry of Agriculture of the Republic of Kazakhstan.

REFERENCES

Afolabi K (2020). Productivity of Kale (*Brassica oleracea var. acephala*) and Nile tilapia (*Oreochromis niloticus*) culture in aquaponic systems. *Mast. Thes. AUC Knowl. Fount.* https://fount.aucegypt.edu/etds/1449

Almugrabi E, Kalimullin MI, Timofeeva OA (2018). Phytochemical composition of *Brassica oleracea var. Sabellica* in different growing conditions. *J. News Ufa Sci. Cent.* 3(1): 16-21.

Anteh JD, Timofeeva OA, Mostyakova AA (2021). Assessment of mineral impact on metabolites accumulation in kale (*Brassica oleracea var. Sabellica*). *Siberian J. L. Sci. Agric.* 3(13): 208-224. doi: 10.12731/2658-6649-2021-13-3-208-224.

Ashenafi EL, Nyman MC, Holley JM, Mattson NS, Rangarajan A (2022). Phenotypic plasticity and nutritional quality of three kale cultivars (*Brassica oleracea* L. var. *acephala*) under field, greenhouse, and growth chamber environments. *J. Environ. Exp. Bot.* 199: 104895. https://doi.org/10.1016/j.envexpbot.2022.104895.

Belyuchenko IS, Mustafaev BA (2013). Plant introduction as a method of expanding the species composition of cultivated phytocenoses in the southern regions of the CIS. *Ecol. Bull. Nort. Caucasus*. 4(9): 73-89.

Dospekhov BA (1985). Methodology of Experimental Work. Agropromizdat, Russia.

Dzyubenko NI, Vishnyakova MA (2007). Vavilov and VIR. *J. Agric. News* 2: 42-43.

Girenko MM, Zvereva OA (2007). Green Vegetables. Manual for amateur gardeners. Niola 21 Century, Russia.

Hollman PCH, Arts ICW (2000). Flavonols, flavones and flavanols — Nature, occurrence and dietary burden. *J. Sci. Food Agric.* 7(80): 1081-1093. https://doi.org/10.1002/(SICI)1097-0010(20000515)80:7<1081::AID-JSFA566>3.0.CO;2-G.

Jantassova A, Aitbaev T, Nusupova A, Jantassov S (2023). Assessment of the productivity of kale leaf cabbage in the open ground conditions of the South-east of Kazakhstan. *J. Izdenister Natigeler* 1(97): 37-46. https://doi.org/10.37884/1-2023/05.

Jurkow R, Jurkov R, Kalis A, Sekara A, Cebula S (2019). Cold stress modifies bioactive compounds of kale cultivars during fall - winter harvest. *J. Acta Agrobot.* 1(72): 1-14. https://doi.org/10.5586/aa.1761.

Kapusta-Duch J, Kopec A, Kope A, Piatkowka E, Borczak B, Leszczynska T (2012). The beneficial effects of *Brassica* vegetables on human health. *Poland J. Ann. Nat. Inst. Hyg.* 63(4): 389-395. https://www.researchgate.net/publication/236598046.

Kirsanova VF (2010). Introduction of pumpkin crops at the agrobiological station of BSPU*. J. Stud. Loc. lore Amur Reg.* 4(13): 13-19.

Litvinov SS (2011). Methodology of Field Experiment in Vegetable Growing. Rossel khozakademia, Russia.

Muravyev AY (2007). Production of lettuce and green crops on salad and seedling complexes of the Russian Federation in 2007. *J. Greenh. Rus.* 3. pp. 23-26.

Nafiah OZ, Nugrahani P, Makhziah (2023). The effect of hydroponic nutrient sources and planting media types on the growth and production of Chinese kale (*Brassica oleraceae* L.). *Indonesia J. Tekn. Pert. Lamp.* 2(12): 443-457. http://dx.doi.org/10.23960/jtep-l.v12i2.443-457.

Nizhelskaya KV, Chizhikova OG (2016). Cabbages as an additional source of biologically active substances in meat-containing semi-finished products intended for gerodietic nutrition. *J. Act. Biotechnol*. 3(18): 153-156.

Ortega-Hernandez E, Antunes-Ricardo M, Jacjbj-Velaquez DA (2021). Improving the health-benefits of kales (*Brassica oleracea L. var. acephala DC*) through the application of controlled abiotic stresses. *J. Plants* 10(12): 2629. https://doi.org/10.3390/plants10122629.

Pivovarov VF (2006). Vegetables of Russia. RRISSGVC, Russia.

Samec D, Urlic B, Salopek-Sondi B (2019). Kale (*Brassica oleracea var. acephala*) as a superfood: Review of the scientific evidence behind the statement. *J. Food Sci. Nutri.* 15(59): 2411-2422. doi.org/10.1080/10408398.2018.1454400.

Sharafutdinova EN, Ivanov, AV, Matern AI, Brainina HZ (2011). Quality of food products and antioxidant activity*. J. Anal. Cont.* 3(15): 281-286.

Startsev VI, Golubkina NA, Temichev AV (2020). The role of introduction in improving the quality of varieties and hybrids of cabbage. *J. Agric. Biol.* 3: 113-118.

Texier W (2020). Hydroponics for everybody, all about home horticulture. Quick American Archives, USA.

Zanozina EV (2021). Centers of origin of cultivated plants as a basis for the formation of the most ancient agricultural civilizations. *Geograph. Sci. XIV Russ. Sci. Pract. Conf.* Astrakhan. pp. 77-80.