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Agronomic characteristics of tomato plant cultivar Santa Cruz Kada grafted on species of the genus *Solanum*

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ABSTRACT

In this study were evaluated gas exchanges, fruit production and fruit quality of tomato Santa Cruz Kada grafted onto different species of the genus *Solanum,* using two grafting methods. For the grafted tomato cultivation, the authors used a randomized complete block design, in a 8x2 factorial scheme, evaluating eight rootstocks: accessions of mini tomatos (0224-5, RVTC 57, RVTC 20 and 6889-50); wild tomato species *Solanum habrochaites* var. *hirsutum* (PI-127826); *Solanum pennellii* (LA716); *Solanum sessiliflorum* (cubiu); and tomato cultivar Santa Cruz Kada (self-grafting, control), and two grafting methods [cleft grafting (FC) and approach grafting (EC)]. The authors verified a significant interaction between rootstock x grafting method. The *S. pennellii* rootstock provided the best results for physico-chemical characteristics, when grafted using the cleft method. However, the same method, along with cubiu rootstock, presented lower fruit production. Considering the gas exchange and productive characteristics, *S. habrochaites* as rootstock for tomato Santa Cruz provided the best results for photosynthetic yield and water use efficiency, and for the commercial fruit production characteristic, both grafting methods, and for the average mass of commercial fruits when grafted using FC, with about 5.03 kg/plant and 163.5 g/fruit, respectively. In relation to the grafting methods, the cleft showed to be the most suitable.

Keywords: *Solanum lycompersicum*, *Solanum habrochaites,* grafting, cubiu.

RESUMO

Caracteristicas agronômicas de plantas de tomate cultivar Santa Cruz Kada enxertadas em espécies do gênero *Solanum*

No presente trabalho teve-se como objetivo avaliar trocas gasosas, a produção e qualidade de frutos do tomateiro Santa Cruz Kada enxertado em diferentes espécies do gênero *Solanum* e por dois métodos de enxertia. Para o cultivo de tomateiro enxertado, foi utilizado delineamento experimental de blocos ao acaso, em esquema fatorial 8x2, avaliando-se oito porta-enxertos: acessos de mini tomates (0224-5, RVTC 57, RVTC 20 e 6889-50); espécies silvestres de tomateiro *Solanum habrochaites* var. *hirsutum* (PI-127826); *Solanum pennellii* (LA716); *Solanum sessiliflorum* (cubiu); e tomateiro cultivar Santa Cruz Kada (autoenxertia, testemunha), e dois métodos de enxertia [fenda cheia (FC) e encostia (EC)]. Verificou-se que para todas as características avaliadas, houve interação significativa entre porta-enxerto x método de enxertia. O porta-enxerto *S. pennellii* proporcionou os melhores resultados para as características físico-químicas, quando enxertado por meio do método de fenda cheia. No entanto, o mesmo, juntamente com o porta-enxerto cubiu, apresentou menor produção de frutos. Considerando as características de trocas gasosas e produtivas, *S. habrochaites* como porta-enxerto para o tomateiro Santa Cruz Kada proporcionou os melhores resultados para rendimento fotossintético e eficiência do uso da água, e para a característica produção de frutos comerciais, para ambos os métodos de enxertia e para massa média de frutos comerciais, quando enxertados por FC, com respectivamente (aproximadamente 5,03 kg/planta; e 163,5 g/fruto). Quanto aos métodos de enxertia, o por fenda cheia mostrou-se o mais adequado.

Palavras-chave: *Solanum lycompersicum*, *Solanum habrochaites,* enxertia, cubiu.

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The use of appropriate rootstocks can provide resistance to grafted seedlings, allow cultivation in soils contaminated with pathogens or provide abilities in relation to certain environmental conditions, such as resistance to low temperature, drought, excess of moisture, salinity, increase of nutrient uptake and improvement of fruit quality (Colla *et al*., 2010; Flores *et al.*, 2010; Gama *et al.*, 2013).

Grafting is usually used with vegetables, just like watermelon, melon, cucumber, tomato, sweet pepper and eggplant, having the main role of giving tolerance and resistance to adverse environmental conditions, as well as to pathogens. This practice has also been adopted as a strategy in order to increase the production and quality of fruits (Flores *et al*., 2010; King *et al.*, 2010), considering that for some species characteristics related to fruit quality are quickly transferred, using the rootstock, to the canopy through the xylem (Lee, 1994).

However, evaluating rootstocks,

which promote resistance to adverse soil conditions and also enable the increase in photosynthetic potential and productivity and quality of tomato fruit, is necessary. In this context, studies on the potential of different *Solanaceas* (Farias *et al*., 2013; Petran & Hoover, 2014), wild species tomato (Venema *et al*., 2008; Lee *et al.*, 2010) and accessions of mini tomatoes can be an alternative.

In Brazil, studies on the potential of different species of *Solanaceas* as rootstock for tomato crop were carried out by Pinheiro *et al.* (2009), by Coutinho *et al.* (2010) and by Farias *et al.* (2013). The cultivated tomato has low genetic diversity (Tam *et al.*, 2005). Thus, the evaluation of the potential of wild species, or accessions to be used as rootstocks is also a possibility. So, the use of rootstocks permits direct exploitation of genetic characteristics which enable to improve qualitative properties of the fruits and promote tolerance/resistance to different factors (Venema *et al.*, 2008; Flores *et al*., 2010; Lee *et al.*, 2010), as well as to increase the yield per production area.

The success or failure of grafting is closely related to factors which can influence the healing of the graft union. Among these, the authors highlight the affinity between the rootstock / grafting, which comprises the morphological and physiological characteristics of the plants (Sirtoli *et al*., 2008).

Vascular connection between rootstock and grafting may interfere with water absorption and salt translocation, affecting several physiological characteristics. When evaluating setting and grafting compatibility, some studies concluded that grafting method influenced the success of grafting, in which the most appropriate method can vary according to rootstock / grafting combination (Lee, 1994; Mohamed *et al.,* 2014).

Considering that more information on grafting to improve tomato fruit quality is necessary, this study was performed to evaluate gas exchanges, production and the quality of tomato cultivar Santa Cruz Kada, grafted on different species of the genus *Solanum,* using two grafting methods.

MATERIAL AND METHODS

The experiment was carried out in Setor de Olericultura do Departamento de Agronomia da Universidade Estadual do Centro-Oeste in Guarapuava, Paraná State (25°38'S, 51°48'W, altitude 1100 m). The local climate is cfb type, according to Köppen classification (humid subtropical mesothermal), temperate, without defined dry season, with hot summer and moderate winter (Wrege *et al.*, 2011).

The authors used cultivar Santa Cruz Kada as rootstock. The experimental design was completely randomized, arranged in an 8x2 factorial scheme, four replications, and each plot of the experiment consisted of four plants. Eight rootstocks were evaluated: four accessions of mini tomato: 0224-53; RVTC 57; RVTC 20 and 6889-50; one wild species *S. habrochaites* var *hirsutum* access PI-127826; one wild species *Solanum pennellii* access 'LA716'; cubiu (*Solanum sessiliflorum*); and cultivar Santa Cruz Kada (self-grafting, control). The authors used two grafting methods: cleft grafting (FC) and approach grafting (EC).

In order to obtain plant-arrays, the authors carried out the sowing of rootstocks and graftings into polystyrene trays with 200 cells, containing commercial substrates (Mecplant®) and grown in floating hydroponic system. The cubiu rootstock was sown thirty days before the grafting sowing, whereas the *S. habrochaites* and *S. pennellii* rootstocks were sown ten days before the grafting sowing. The mini tomato rootstocks were sown together with the grafting and the control. Sowing was carried out in different dates due to the difference of emergence and growth of the rootstocks.

Graftings were carried out in the beginning of November, 2013, when the rootstocks showed 3-4 young and expanded leaves, using for grafting methods, carbon steel blades, and biodegradable tape for fixing and wooden shaft to support the plants in order to decrease the stress in seedlings caused by grafting.

The seedling transplanting was carried out when the plants showed 5-6 fully expanded leaves (21 days after grafting, after the healing process of the grafts), into 10 dm^3 capacity polyethylene pots of low density, containing sieved soil and cattle manure at a ratio of 3:1. In order to reduce weed infestation and to keep moisture, the authors covered the surface of the pots with 3 cm of decomposed wood. The compost containing sieved soil and cattle manure was corrected previously, through liming, applying 4.38 g of dolomitic limestone (PRNT 75%) per pot, according to the need pointed out by the soil chemical analysis in order to reach V= 80%. The plants were carried out in a greenhouse, keeping a main stem, tutored by a vertical rootstock.

During the cycle, the authors used micro drippers in order to carry out the irrigation. Fertirrigation was carried out in the morning, using the recommendations adapted by Trani & Carrijo (2004), according to the development stage of the crop. This does not apply to phosphorus (P), which was supplied only during transplanting, using the soil analysis results, 6.3 g of simple superphosphate per pot. For fertirrigation formula, the authors used in the first stage: 0.015 g of urea, 0.06 g of potassium chloride, 0.012 g of Nitrabor, 0.03 g of Krista SOP and 0.1 g of Krista SOP per pot; second stage: 0.11 g of potassium chloride, 0,05 g of Nitrabor, 0,1 g of Krista SOP and 0.4 of Krista Mag per pot; third stage: 0.17 g of potassium chloride, 0.24 g of Nitrabor, 0.4 g of Krista SOP and 0.87 g of Krista Mag per pot; fourth stage: 0.17 g of potassium chloride, 0.48 g of Nitrabor, 0.4 g of Krista SOP and 1.1 g of Krista Mag per pot; fifth stage: 0.2 g of potassium chloride, 0.48 g of Nitrabor, 0.4 g of Krista SOP and 1.1 g of Krista Mag per pot.

For phytosanitary control, the authors applied preventive sprayings, according to the manufacturer´s recommendations, using tiametoxam (Actara®), copper oxychloride + mancozeb (Cuprozeb®) and azoxystrobin + diphenoconazole (Amistar Top®).

Gas exchanges were evaluated using a portable photosynthesis system (IRGA, Infrared Gas Analyzer, Li-cor, LI6400XT), with 1,000 µmol

photons/m^2/s, 400 µmol/mol of CO_2 and ΔCO_2 + ΔH_20 less than 1%, determining photosynthetic yield or liquid assimilation (*A*, µmol CO_2/m^2/s) and transpiration rate (*E*, mmol H_2O/m^2/s). Evaluations were carried out using fully expanded leaves, located in the middle third, and obtaining the measurements close to noon. Three evaluations were carried out along the crop cycle fortnightly, after the beginning of flowering and the average of evaluations was carried out. The water use efficiency (*EUA*, mmol/H_2O) was estimated through ratio between CO_2 assimilation rate and transpiration rate (*A*/*E*).

Harvesting was carried out by collecting those fruits which presented light red maturation stage, which were evaluated considering the number of commercial fruits (NFC), determined by the number of fruits harvested in different dates on which the harvestings were carried out, in order to establish the total number of fruits classified according to commercial standards per plant; production of commercial fruits (PFC) (kg/plant), determined through weighing the accumulated production of fruits, in harvestings, in order to establish total production of fruits which were classified according to commercial standards per plant; and average mass of commercial fruits (MMFC) (g/fruit), determined according to the ratio among (PFC) and (NFC), (MMFC): PFC/NFC) at different harvesting dates.

In order to determine the physico-chemical analyses of the fruits, at fourth and fifth harvestings, six commercial fruits per replication were sampled. These were separated, packed in expanded polystyrene trays and kept on a bench until they reached full ripening. Then, the analyses were carried out: firmness (N) determined using a digital penetrometer (Instrutherm DD-200) with a 8 mm diameter tip, exerting compression on two points of the central region of the whole fruits, with results expressed in Newton (N); soluble solid (SS) through homogenized and filtered pulp, which was analyzed with the aid of a portable digital refractometer (model PAL%1), with values expressed in °Brix; and, titratable acidity (AT) determined according to the technique standardized by the Adolf Lutz Institute (2005), by titration of 10 g of crushed pulp added + 100 mL of distilled H_2O with standard solution of 0.1 M NaOH at 0.1 M. The authors obtained the turning point, when the solution reached pH 8.2 (turning point), with results expressed in grams of citric acid per 100 g of pulp.

The obtained data were tested for normality and homogeneity and subsequently submitted to analysis of variance, by F test and, when these data were significant, the authors compared them using the Scott & Knott test at 5% probability. The data were analyzed using computer program ASSISTAT version7.7, 2014 (Silva, 2014).

RESULTS AND DISCUSSION

For gas exchanges, photosynthetic yield (*A*, µmol CO_2/m^2/s), transpiration rate (*E*, mmol H_2O/m^2/s) and water use efficiency (*EUA*, mmol/H_2O), the authors noticed significant interaction among sources of variation (rootstock x grafting method) (Table 1).

S. habrochaites, comparing to the other rootstocks, showed highest results for *A* and *EUA* and lowest results for *E* (Table 1). The highest EUA, for this rootstock for both grafting methods was due to an increase of *A*, as well as the reduction of *E*. It is extremely desirable to obtain plants with higher photosynthetic yield, and high water use efficiency (Jaimez *et al.*, 2005; Taiz & Zeiger, 2013).

When the authors used the cleft grafting (FC), in comparison with the approach grafting method, the rootstocks 0224-53, RVTC 57, *S. habrochaites* and cubiu stood out for photosynthetic yield; 0224-53, RVTC 57, RVTC 20 and *S. pennellii* for transpiration rate; and *S. habrochaites* and control for water use efficiency. On the other hand, the approach grafting method allowed better results for 6889-50 and *S. pennellii*; *6889-50* and cubiu*;* and 0224-53, RVTC 57, RVTC 20 and *S. pennellii,* respectively for *A, E* and EUA (Table 1).

For all rootstocks, harvesting started at 62 days and finished at 90 days

Table 1. Photosynthetic yield (*A*), transpiration rate (*E*) and water use efficiency (*EUA*), of tomato grafted on different species of the genus *Solanum,* using different grafting methods. Guarapuava, UNICENTRO, 2013/2014.

Rootstocks	*A* (µmol CO_2/m^2/s)		*E* (mmol H_2O/m^2/s)		*EUA* (mmol H_2O/m^2/s)	
	FC[1]	EC[2]	FC	EC	FC	EC
0224-53	19.97 Ac*	18.52 Bb	3.70 Ab	2.82 Bb	5.38 Bd	6.55 Ab
RVTC 57	21.28 Ab	18.86 Bb	4.16 Aa	3.17 Ba	5.11 Bd	5.93 Ac
RVTC 20	20.26 Ac	20.40 Aa	3.18 Ac	2.93 Bb	6.41 Bc	6.96 Ab
6889-50	15.91 Be	18.11 Ac	2.58 Bd	3.20 Aa	6.14 Ac	5.63 Ac
S. habrochaites	22.25 Aa	20.68 Ba	2.63 Ad	2.69 Ab	8.49 Aa	7.67 Ba
S. pennellii	17.73 Bd	18.71 Ab	3.63 Ab	3.38 Ba	4.88 Bd	5.53 Ac
Cubiu	19.51 Ac	17.56 Bc	2.73 Bd	3.38 Aa	7.16 Ab	7.36 Aa
Control	18.03 Ad	17.62 Ac	3.12 Ac	3.25 Aa	5.77 Ac	5.36 Bc
CV (%)	5.41		6.72		5.53	

Averages followed by different uppercase letters in lines and different lowercase letters in columns differ significantly by using the Scott & Knott test, 5%; [1]Cleft grafting method; [2]Approach grafting method.

Table 2. Number of commercial fruits (NFC), production of commercial fruits (PFC) average mass of commercial fruits (MMFC), firmness (N), soluble solids (SS) and titratable acidity (AT) of grafted tomato on different solanaceous species and using different grafting methods. Guarapuava, UNICENTRO, 2013/2014.

Rootstocks	NFC/plant		PFC (kg/plant)		MMFC (g/fruit)	
	FC[1]	EC[2]	FC	EC	FC	EC
0224-53	40.1 Aa	35.0 Aa	3.75 Ab	3.43 Ab	92.9 Ab	98.0 Aa
RVTC 57	41.6 Aa	30.9 Bb	4.41 Aa	3.48 Bb	104.2 Ab	114.8 Aa
RVTC 20	23.7 Bc	31.5 Ab	2.37 Bc	3.39 Ab	99.8 Ab	108.0 Aa
6889-50	26.2 Ac	31.0 Ab	2.58 Ac	3.01 Ab	107.9 Ab	98.7 Aa
S. habrochaites	30.1 Bb	39.0 Aa	4.91 Aa	5.15 Aa	163.5 Aa	133.3 Bb
S. pennellii	11.1 Bd	17.1 Ad	1.29 Ad	1.29 Ad	114.1 Ab	76.6 Bb
Cubiu	16.4 Ad	13.0 Ad	2.52 Ac	0.78 Bd	153.4 Aa	60.5 Bb
Control	32.5 Ab	21.9 Bc	2.51 Ac	2.42 Ac	79.8 Bb	113.3 Aa
CV (%)	14.11		16.04		17.07	
	N		SS (°Brix)		AT	
0224-53	37.3 Ab	26.0 Bc	5.0 Ab	4.8 Aa	0.35 Ab	0.37 Ab
RVTC 57	39.1 Ab	32.0 Ba	4.7 Ab	5.0 Aa	0.42 Aa	0.44 Aa
RVTC 20	35.6 Ab	29.4 Bb	3.8 Bc	4.8 Aa	0.44 Aa	0.37 Bb
6889-50	30.8 Bc	34.9 Aa	4.8 Ab	4.5 Aa	0.38 Ab	0.36 Ab
S. habrochaites	33.0 Ac	26.8 Bc	4.5 Ab	4.8 Aa	0.35 Bb	0.42 Aa
S. pennellii	43.0 Aa	33.0 Ba	6.3 Aa	5.3 Ba	0.44 Aa	0.38 Bb
Cubiu	23.0 Ad	22.2 Ad	6.6 Aa	5.1 Ba	0.36 Ab	0.38 Ab
Control	30.1 Ac	26.5 Bc	4.6 Ab	4.0 Ab	0.39 Aa	0.40 Aa
CV (%)	7.06		9.36		5.47	

Averages followed by different uppercase letters in lines and different lowercase letters in columns differ significantly by using the Scott & Knott test, 5%; [1]Cleft grafting method; [2]Approach grafting method.

after transplanting, regardless of the grafting method used, except for cubiu rootstock, in which harvesting started at 75 days and finished at 111 days after transplanting.

Number of commercial fruits (NFC), production of commercial fruits (PFC), average mass of commercial fruits (PMFC) and physico-chemical analyses [firmness (N), soluble solid (SS) and titratable acidity (AT)], were also influenced by rootstock / grafting combination (Table 2).

Observing the productive characteristics, which can be considered as those of major importance, the cleft grafting method showed superior results when comparing with the approach grafting method for rootstocks RVTC 57 and self-grafting for NFC; RVTC 57 and cubiu for PFC; and *S. habrochaites, S. pennellii* and cubiu for PMFC. On the other hand, the approach grafting method provided better results for rootstocks of RVTC 20, *S. habrochaites* and *S. pennellii*; RVTC 20; and self-grafting, respectively for NFC, PFC and PMFC (Table 2).

The *S. habrochaites* rootstock, besides providing better results for *A* and *EUA*, also showed results which stood out for PFC, for both grafting methods and for MMFC, when grafted by FC, with approximately 5.03 kg/plant; and 163.5 g/fruit, respectively (Table 2).

Unlike the *S. habrochaites* rootstock, *S. pennellii,* besides providing the worst results for NFC and PFC, also showed inferior result for MMFC, which is related to fruit size, in both grafting methods. However, for firmness, SS and AT, the *S. pennellii* rootstock grafted by FC, showed superior results without differing from the other treatments (Table 2).

For SS (°Brix), when compared with other grafting methods, the RVTC 20 rootstock grafted by the approach method showed result superior than the one grafted by the cleft grafting method. On the other hand, when the cleft grafting method was used, the *S. pennellii* and cubiu rootstocks showed results superior than the approach method, presenting the highest °Brix values between interactions, 6.3 and 6.6°Brix, respectively. In relation to AT, the cleft grafting method allowed superior results for the RVTC 20 and *S. pennellii* rootstocks; on the other hand, the approach method allowed superior results for *S. habrochaites* (Table 2).

For physico-chemical characteristics, cubiu rootstock also stood out. Despite showing lower values for NFC and PFC, just like *S. pennellii*, cubiu rootstock, when grafted by FC, presented significant values for SS (Table 2).

Comparing the rootstocks with the control (self-grafting) in relation to physiological traits and fruit production, the authors could verify that 0224-53, RVTC 57, RVTC 20, 6889-50 and *S. habrochaites* showed results superior than the self-grafting for *A,* NFC, PFC and MMFC. These results show that the mentioned rootstocks showed the ability to stimulate photosynthetic

processes, which provide energy to increase the development and growth of reproductive organs. The authors can consider that higher fruit production for treatment *S. habrochaites* is related to the fact that the rootstock had provided higher *A* and *EUA* too.

Satisfactory results for rootstock of wild species *S. habrochaites*, for gas exchanges and fruit production, show that this species present good chemical, morphological and physiological affinities to tomato cultivar Santa Cruz Kada. According to Venema *et al.* (2008), *S. habrochaites*, which has high vegetative vigor, is adapted to the wide range of latitudinal distribution, showing characteristics which may promote the development of grafted tomato, even when the conditions during the day, or during the cycle, are not favorable for the development of non-grafted tomato, showing that this rootstock is a good option as a rootstock for increasing fruit production.

According to Higashide *et al*. (2013), one tomato rootstock, which promotes good grafting compatibility, can corroborate the increasing of photosynthesis, water use efficiency and fruit production, since it shows higher vegetative vigor and abundance of root system. These same authors, as verified in the present study, also concluded that depending on the evaluated rootstock, the increasing of water use efficiency and fruit production may vary.

The *S. pennellii* rootstock, when grafted through the cleft grafting method, improved fruit physico-chemical characteristics. Since it promotes better firmness, which is one of the most important quality characteristics, both for tomatoes dedicated for fresh and for industrial consumption (Bernardi *et al.*, 2007), this rootstock enables harvesting in advanced stage of fruit ripening, without damaging the quality.

The use of wild tomatoes, through breeding strategies, is commonly applied to improve organoleptic, functional and nutritional characteristics of fruits (Baxter *et al.*, 2005). Short-term grafting is able to promote an increase of SS contents (Flores *et al*., 2010), as the authors noticed in the present study when using *S. pennellii* as rootstock. However, in addition to being a slow process, success is not always guaranteed.

The increasing in °Brix level, promoted by *S. pennelli*, may be related to the fact that the species has as a natural habitat the region belonging to the east of the Peruvian Andes to the west on the Pacific Coast, characterized by hot, saline and dry weather (Holtan & Hake, 2003). *S. pennellii* shows tolerance to soil salinity and water deficit, also allowing an improvement of fruit quality.

The contribution to the increase of soluble solids, promoted by cubiu and *S. pennellii* rootstocks, in the cleft grafting (FC) is desirable, considering that this is a quality criterion of great importance in order to improve the taste of the fruits, the quality of the paste, when dedicated to processing (Flores *et al.*, 2010). However, the low fruit production provided by both rootstocks, makes it unfeasible for commercial cultivation, taking into account that the grafting method leads to an increase in the need for labor and production cost. Thus, the use of grafting is relevant when increasing the productivity and improving fruit chemical characteristics is a possibility (Flores *et al.*, 2010).

According to Flores *et al.* (2010), depending on the rootstock / grafting combination, a decreasing or increasing of fruit quality can be noticed. Being of extreme difficulty a simultaneous increase of fruit production and analytical characteristics, considering that, for SS, an inverse relationship between fruit production and the characteristic improvement of the predominant characteristic prevails (Bai & Lindhout, 2007).

Superior results for the cleft grafting method, for gas exchanges and fruit physico-chemical characteristics, according to Lee *et al.* (2010), may be due to the fact that the cleft grafting method provides better vascular connection between rootstock and grafting and healing of rootstock and graft unions. On the other hand, the approach method does not always allow a safe recomposition of the connection of the rootstock with the grafting. Cañizares & Goto (2002), comparing three grafting methods in cucumber seedling production, also verified that the cleft grafting provides better conditions for plant development after grafting.

Based on the conditions in which this research was done, the authors could consider the use of species *Solanum habrochaites* var *hirsutum* access 'PI-127826', as rootstock of tomato Santa Cruz Kada, as an important alternative for an increasing of photosynthetic yield, water use efficiency and fruit production. The authors recommend for grafting in tomato Santa Cruz Kada the use of cleft grafting method (FC).

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