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Article

Characteristics and challenges of the nopal vegetable cultivation system in Cuautlacingo, Otumba

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Abstract

The State of Mexico is the third producer of nopal vegetable nationwide, Otumba concentrates 57% of state production. In the decade 2010-2020 the area increased by 27%, with a 44% increase in production. However, it faces a number of socioeconomic and technical constraints. The objective of the research was to diagnose the nopal vegetable cultivation systems in Cuautlacingo, Otumba and propose strategies to improve their functioning. Work was carried out with 47 cooperating producers to whom a questionnaire structured in the following three axes was applied: 1) socioeconomic characteristics of the production units; 2) characteristics of the nopal vegetable cultivation system; and 3) technical schedule of the nopal vegetable cultivation system. Through a cluster analysis, two groups of producers were identified, the problems they face are incidence of pests and diseases, low technification, poor organization and marketing channels, need for training and technical accompaniment and lack of government impulse. It is recommended to join efforts to plan actions, attend and develop the production niches of the region and seek alternatives to increase the competitiveness of nopal vegetable.

Keywords: characterization, family production units, group of producers, technical schedule.

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Introduction

Nopal (*Opuntia ficus indica* L.), in addition to its nutritional and socioeconomic value, has a historical and cultural symbolism in Mexican society. The consumption of nopal vegetable at the national level is 6.4 kg per inhabitant (FND, 2020), it has become popular for its multiple attributes and uses (González, 2010). National production in 2020 was 864 243.5 t and it was grown in 12 618 ha distributed in 27 states (SIAP, 2021). The State of Mexico is the third producer nationwide, in 2020 nopal occupied 1 088 ha and 84 809 t were produced. The municipality of Otumba concentrates 57% of the state production. In the period 2010-2020 the state area increased by 27%, which implied an increase of 44% in production (SIAP, 2021). Nopal production systems are heterogeneous depending on the edaphoclimatic conditions, their available resources, technology used, technical schedule and production destination (Maky *et al*., 2015).

Nopal producers face limitations associated with poor agronomic and input management, lack of technical assistance, scarce marketing channels, among other elements that have been documented, mainly for the production of nopal fruit (SINACATRI, 2013; Vaquero, 2013). To solve these limitations, it is necessary to have a systemic vision to understand the functioning of the production units and their determinants. The present study aimed to diagnose, characterize and identify the problems of the nopal vegetable cultivation systems in the ejido of Cuautlacingo and propose intervention and/or management strategies to improve their functioning.

Materials and methods

The research was carried out during 2017 in the locality of Cuautlacingo, Otumba (19º 42’ 55” north latitude and 98º 49’ 00” west longitude), it has an area of 143.42 km^2 and an average height of 2 630 masl (INEGI, 2015). In 71% of the municipality the climate that predominates is the temperate subhumid climate with rains in summer of lower humidity, and in the remaining 29%, temperate subhumid with rains in summer of medium humidity (COPLADEM, 2016). The average annual temperature is 14 ºC and an average annual rainfall of 274 mm (INEGI, 2015). The dominant soil type is lithosol (INEGI, 2015).

Fifty-nine percent of the economically active population is engaged in agriculture. The agricultural area is 854 165 ha, mainly on rainfed land. The most important crops are corn, beans, barley, wheat, fodder oats, maguey, nopal fruit, nopal vegetable and xoconostle (COPLADEM, 2016).

The research had a mixed connotation, non-experimental cross-sectional design. The systemic approach was applied for the qualitative and quantitative diagnosis of family production units (FPUs) and the characterization of the nopal vegetable cultivation system (NVCS). In the locality of Cuautlacingo there are small property (SP) and seven irrigation units (IUs). Interviews were conducted with SEDAGRO authorities, delegates from the locality of Cuautlacingo and ejido commissariat. Through this approach, work was carried out with 47 producers of nopal vegetable, who agreed to work voluntarily in the research.

A questionnaire structured in the three following fundamental axes was applied: 1) socioeconomic characteristics of the FPU: age, schooling, members per family, economic activities, monthly income, land tenure, average area; 2) socioeconomic characteristics of the NVCS: area of nopal

vegetable and other crops, predominant labor, income from nopal, government support, credit, training, organization, self-consumption-sale, commercialization, establishment costs and maintenance costs, among others; and 3) technical schedule of the NVCS: age of the plantations, varieties, population density, yield, type of cut, production records, fertilization, pests and diseases and their control, pruning, problems, topics of interest for training, etc. A hierarchical cluster analysis was performed with the IBM SPSS Statictis 21® software, Ward's method was used to identify groups of producers based on their similarity between variables.

Results and discussion

Socioeconomic characteristics of family production units

Twenty-eight percent of the interviewees belonged to the Hueyapan IU, 23% to the Carril IU and 49% are distributed among the other 5 IUs and the SP. Through the cluster analysis, two groups of producers were identified: G1 and G2. G1 was made up of 25 producers and G2 was made up of 22 (Figure 1).

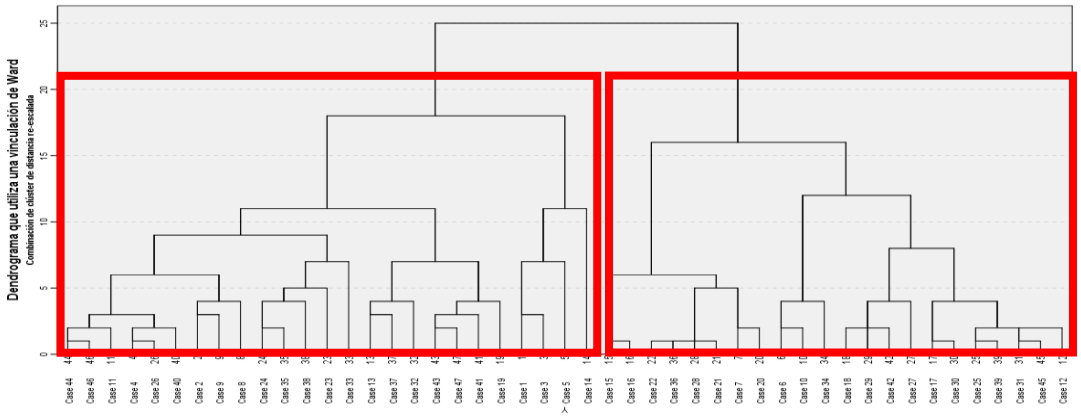

Figure 1. Clusters of similarity that group 47 producers of nopal vegetable from the locality of Cuautlacingo, State of Mexico.

G1 is made up of producers with an average age of 50 years and with junior high school education (40%). The families are made up of 5.2 members, with 3.4 children and 2.5 economic dependents. Throughout the year, the monthly income is $10 628.00, with agriculture being the main activity (88%). Fifty-two percent of producers are engaged in an economic activity (agriculture, livestock farming or trade); 40% in two activities (agriculture-livestock farming, agriculture-trade, livestock farming-agriculture, agriculture-services and agriculture-masonry). The remaining 8% in three economic activities (trade-service-agriculture and agriculture-services-trade). They have 3 ha, of these 1.5 ha are owned by them, and 1.6 ha rented. Land tenure is mainly ejido (40%), in addition to other modalities: private (12%), rented (4%), ejido-private (28%), ejido-rented (4%), rented ejido-private (12%).

In G2 the average age of producers is 41 years and 50% the maximum educational level is junior high school. The families have four members, with two children and 2.5 economic dependents. The average monthly income is $9 909.00, agriculture is the main activity (82%). Sixty-eight percent carry out an economic activity (agriculture, services, day laborer, teaching,

plasterer/decorator); 23% have two activities (agriculture-livestock farming, agriculture-services, day laborer-agriculture and teaching-agriculture), the remaining 9%, three activities (plasterer/ decorator-services-agriculture and services-masonry-agriculture). The producers own on average 0.85 ha, of these, 0.82 ha are owned by them, 0.03 ha rented. The main land tenure is ejido (77%), there is also private property (18%) and rented ejido-private property (5%).

Socioeconomic characteristics of the nopal vegetable cultivation system

Producers of G1 have grown nopal vegetable for 16 to 20 years. Forty-eight percent are engaged only in this crop and have an average of 1.95 ha. Fifty-two percent grow nopal fruit, xoconostle, nopal fruit-maguey combinations, corn, beans, vegetables and oats. The average area of these crops is 1.17 ha.

The producers present two variants of labor: 1) family labor (36%), the producers do the work in the nopal orchards, without considering a salary for them, but pay a fixed salary to their relatives, fixed salary; and 2) salaried labor (36%), local workers are hired permanently. The annual income from nopal vegetable is $ 8 077.28, it represented 76% of the total income. Twenty-eight percent of producers received government support from the Secretariat of Agricultural Development of the State of Mexico (SEDAGRO, for its acronym in Spanish) during 2016. In the period from 2015 to 2017, 12% had access to credit through a National Banking and Financial Institution, 20% received training from SEDAGRO and 12% of producers are organized into family groups.

Ninety-eight percent of nopal production is sold through intermediaries. The main market is the central de abasto (supply center) of Ecatepec (45%). In a low proportion (4%) there is international commercialization, the main destination are markets located in Texas (McAllen, Dallas, Houston), Oregon (Merlin) and Georgia (Atlanta) of the United States of America. The average cost to establish one hectare of nopal vegetable is $118 000.00 and the average annual maintenance cost is around $49 000.00 pesos.

Producers of G2 have been growing nopal vegetable for an average of 25 years. Sixty-four percent cultivate only this species, on an average area of 0.75 ha. Thirty-six percent grow nopal fruit, xoconostle, corn, vegetables and the alfalfa-barley combination, in an average area of 0.10 ha. Xoconostle is the second most important crop, practiced by 14% of producers. The main labor is salaried (36%). The production of nopal vegetable of G2 is sold in the regional market, mainly in the central de abasto of Ecatepec. The cost to establish one hectare is $111 000.00 and the average annual maintenance cost is $49 000.00. The income from the nopal vegetable oscillates around eight thousand pesos, which represents 84% of the total income from the economic activities of the producers.

Overall, producers did not receive government support in 2016. During the period 2015-2017, only 5% had access to credit through family loans, 18% received training from the technical staff of agrochemical houses. The classification of the two groups allowed the identification of differences in aspects such as time spent on the production of nopal vegetable, complementary economic activities, available area, labor and destination of production. Among the producers there is no type of organization, in other producing regions such as Tlalnepantla, Morelos, the producer organization has generated conditions that benefit the production and commercialization of this crop.

The production of nopal vegetable has been built through government actions, which has favored its commercialization locally and in Mexico City (Aguilar-Sánchez and Sánchez-Salazar, 2022). Producers have implemented income diversification strategies. These strategies are common in nopal-producing regions such as Zacatecas, Milpa Alta (García-Herrera *et al*., 2004; Bonilla, 2009). This gives continuity to the family production unit, and they are linked to urban sectors (Torres, 1997), given the seasonality of nopal production. In both groups, diversification is carried out with vegetables and xoconostle; the latter has gained importance lately. Diversification, in addition to coping with edaphoclimatic variations, is a means of food security and income in the face of fluctuations in product prices.

Technical schedule of nopal vegetable cultivation

The technical schedule is the set of most frequent practices implemented by producers (Figure 2). Overall, in both groups the same practices are carried out; however, there were variations in the timing of implementation, number of interventions and type of inputs used.

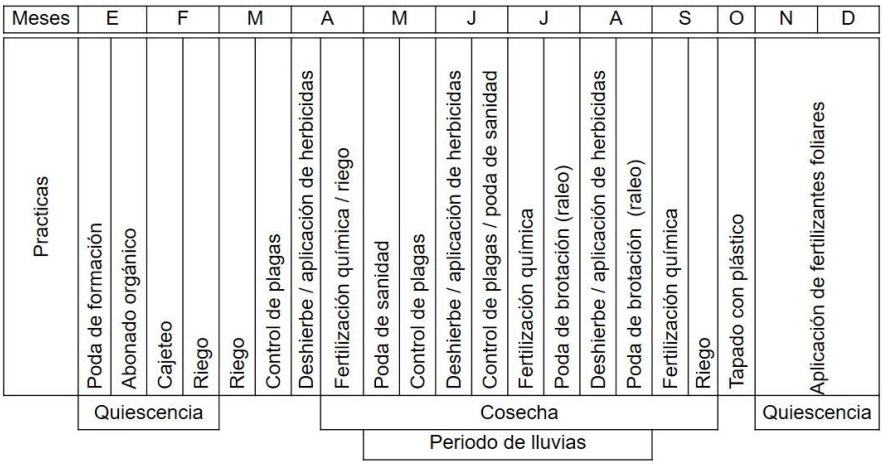

Figure 2. Technical schedule of the cultivation of nopal vegetable in the locality of Cuautlacingo, Otumba, State of Mexico.

The agronomic practices implemented are pruning, hole digging, irrigation, control of insects, diseases and weeds, fertilization and covering. The harvest takes place over six months (April-September). There are two periods of quiescence or rest period, in which maintenance practices such as pruning, irrigation and nutrition are carried out. In both groups the orchards have been in production for between six and ten years. In this category are 48% of the producers of G1 and 58% of G2.

The average population density of orchards in G1 is 34 212 plants ha^{-1}. The predominant variety is Atlixco (40%), with a yield of 50 t ha^{-1}. In G2, the population density is 29 809 plants ha^{-1}, the main variety is Criolla (32%) (Local variety) with a yield of 38.5 t ha^{-1}.

G1 has a population density 13% higher than G2, which implied a 23% higher yield. However, the population density in both cases is 20% lower than the technical recommendations (40 000 plants ha^{-1}) that allow achieving greater productivity (Callejas *et al*., 2009; Financiera Rural, 2011). The population density that producers manage has been the result of their experience and they consider that having a lower population density makes the management of the crop easier.

Four types of pruning were identified: 1) formative, it is done to give a certain type of canopy to the plants and facilitate management; 2) health, pads (adult cladodes) that present malformations or damage by pests and diseases are removed; 3) shooting, it is known as 'thinning', pads that are not suitable for commercialization are eliminated. Thinning is also done when plants have many shoots, in order to have larger nopalitos (fresh cladodes). There can be between 8 and 15 nopalitos per pad; and 4) rejuvenation or removing of pads, it is done when the plantation is between 15 and 20 years old. Old pads are removed, pruning is executed at least five times throughout the year.

Variations in the types of pruning were observed among the producers. In G1, 52% of producers carry out shooting pruning and only 16% carry out formative pruning. Most producers (68%) remove pads after three years. Seventy percent carry out the renewal of the orchards (establishment of new plants) after 10 years. This consists of the establishment of new plants. In G2, 59% of producers carry out shooting pruning and only 18% do health pruning. Sixty-three percent remove pads at three years and 66% renew the orchards at 12 years.

Irrigation is carried out for four months. In G1, a quarter of the producers have technified irrigation, by micro-sprinkler, and the remaining 75% irrigates by furrow/flooding by channels. In G2, 12% of irrigation is technified by micro-sprinkler and 86% irrigates by furrows/flooding by channels. Furrow irrigation has water losses during the process of conduction to the plots. Producers express the need and interest to modernize their irrigation systems; through pressurized irrigation either by drip or micro-sprinkler that allows a more efficient use of water (Rodríguez *et al*., 2014). Nevertheless, a major limitation to its implementation is the lack of economic solvency and the lack of government support for this sector.

The incidence of insect pests occurs between March and June. The main pest in both groups is the wild cochineal (*Dactylopius coccus* Costa), followed by the red spider mite (*Tetranychus urticae* Koch.), which is present in 38% of the orchards of both groups, in addition the presence of gray bug (*Chelinidea tabulata* Burm), snail (*Helix aspersa* O. F. Müller), among others, is reported. For their control, insecticides such as Foley (chlorpyrifos), Lorsban (chlorpyrifos ethyl), Malathion (malathion) and Lannate (methomyl) are used; the application doses vary from 2 to 10 L ha^{-1}.

With regard to diseases, in G1 the main problem reported by 52% of producers is the black spot caused by *Pseudocercospora* sp., in addition, there are four other diseases: dry rot (*Alternaria* sp.), nopal pinto or mottling (virus), white rot and cow's eye (in both cases the causative agent is unknown). For disease control, Cupravit (copper oxychloride) and Captan (captan) are used, in doses ranging from 3 to 6 kg ha^{-1}. In the case of G2, the main disease reported by 36% of producers is the thickening of cladodes (viruses or mycoplasmas), however, six other diseases are reported:

soft rot (*Erwinia carotovora* subsp. carotovora), dry rot (*Alternaria* sp.), nopal pinto or mottling (virus), yellow spots, nopal gold (*Alternaria* sp., *Ascochyta* sp. or *Hansfordia* sp.) and black spot (*Pseudocercospora* sp.).

Despite these phytosanitary problems, only 9% use fungicides to control them. In both groups about 80% of producers use herbicides for weed control. The main ones are Faena (glyphosate), Gesaprim (atrazine), Machete (glyphosate), Lafam (glyphosate), in doses ranging from 4 to 8 L ha^{-1}, in general three applications are made throughout the year. The remaining 20% of producers carry out manual weeding.

The intensification through monoculture and the change of land use since the 90s in Otumba affected the diversity of agroecosystems and increased phytosanitary problems (Reyes *et al*., 2005), which reduces the quantity and quality of the harvest and the productive duration of the plant (Mena, 2004). Pesticides used in pest and disease control are classified as moderately to extremely toxic (WHO, 2020). Producers do not know alternatives to chemical control (Mendoza, 2016).

The practice of health pruning is widespread among the producers, at the end of this activity the pads are left in the orchards, which can be a factor for the persistence of phytosanitary problems. This requires short-term changes in cultural practices, such as removing pruned pads from the orchard or from their sides to prevent the spread of phytosanitary problems.

Several studies carried out in the area (Martínez *et al*., 2012; Ángeles-Núñez *et al*., 2014) report the presence of pesticide residues in nopales. The main problem is the lack of pesticides authorized for the management of phytosanitary problems of nopal crops. Producers resort to the use of pesticides recommended for other crops (COFEPRIS, 2004; SENASICA, 2012; Comité Estatal de Sanidad Vegetal, 2022). However, there are initiatives by research and education centers for the validation of biological and botanical pesticides (Comité Estatal de Sanidad Vegetal, 2022).

The standard of (Codex, 1993) establishes the provisions on the quality of agricultural products, it does not include permissible concentrations of pesticide residues in nopal (Codex, 1993). This scenario has implications both for the environment (pollution) and for the health of producers and consumers (Mena, 2004). Current safety trends and the emergence of alternative markets demand the management of phytosanitary problems through an agroecological approach.

During 2015, the campaign of nopal phytosanitary management was established in the state of Mexico, where phytosanitary monitoring and different methods of pest and disease control were established (SAGARPA-SENASICA-Gobierno del Estado de México-Comité Estatal de Sanidad Vegetal del Estado de México, 2015). Nonetheless, the scope of the program in Otumba was very small of the total number of producers benefited in Otumba, only 7% (15 producers) had access to this campaign.

Nopal fertilization is carried out through the use of organic fertilizers and mineral fertilizers. Organic fertilizers (cattle and sheep manure) are applied at the beginning of the year. In G1, 92% of producers apply manure, in doses ranging from 1 to 200 t ha^{-1} (137 t ha^{-1}, on average). Forty-

five percent of these producers apply fresh manure, without a drying treatment prior to application. In G2, 86% apply mainly cattle manure, in doses of 1 to 500 t ha^{-1} (187 t ha^{-1}, on average). Twenty-nine percent apply fresh manure. Organo-mineral fertilization is a common practice among producers, it promotes positive effects on nopal yield and soil properties (INIFAP, 2001).

The doses of manure applied by producers (137 and 187 t ha^{-1}) are within the range reported for intensive systems, which varies from 100 to 200 t ha^{-1} (Luna, 2011). However, manure application doses were not related to yield due to the diversity of forms, doses and dates of application. There are elements that must be considered in the use of manure, such as the frequency and quantities applied.

Most producers apply fresh manure, which makes it susceptible to loss of nutrients, pollution of water tables, phytosanitary risks increase as it is a source of grass seeds and microorganisms that are a health hazard for consumers (Márquez *et al*., 2009). Several studies have detected the presence of *E. coli* in nopal vegetable, which has been associated with the handling of cladodes during harvest, the type of irrigation water used, application of fresh manure and immature composts (Núñez *et al*., 2014).

This scenario implies the need to implement corrective measures in the management of manure that include composting, frequency and form of application, hygiene of the personnel who harvest the cladodes. In nopal vegetable production systems under the scheme of good agricultural practices, there has been a contribution to the reduction of these phytosanitary risks (Núñez *et al*., 2014).

The doses of mineral fertilization applied by the producers are relatively similar, in G1 the average dose of N-P-K (kg ha^{-1}) is 355-65-50, while in G2 the dose is 347-50-55, in both cases the application is divided into three parts. The doses of mineral fertilization applied are different from the technical recommendations: 120-100-00, 150-100-50 (García and Grajeda, 1991; Vázquez-Alvarado *et al*., 2006; Orona *et al*., 2006).

The amount of nitrogen applied by producers is 100% higher than these references. The excessive use of nitrogen accumulates nitrates in cladodes with possible effects on the health of consumers (Valdez *et al*., 2010). In the case of phosphorus, the doses are 50% lower than the technical references, while potassium is within the recommendations of the cited authors. Thirty-two percent use foliar products, the amounts applied vary between 1 and 2.5 L ha^{-1}. The total amount of nutrients applied to nopal crops is excessive, which can lead to nutrient losses and implications for production costs. Research on local fertilization doses based on expected yield and the amount of nutrients available in the soil is needed to promote efficient fertilization use.

The harvest is carried out in several periods. In both groups the cut is manual, in 70% of cases the nopal is removed by hand, making a twisting effort, the rest makes the cut with the help of a knife. The commercialization is in the period from April to September. The main form of sale is fresh (per hundred and with thorns). There is a marked seasonality in the commercialization, associated with environmental variations (Rodríguez *et al*., 2014), it is carried out in three seasons: 1) March to July. This season concentrates 60% of the volume. In April the price per hundred is between $15.00 and $20.00, there is an oversupply and the price decreases, the sale is not entirely lucrative

(INIFAP, 2011). In July the price varies from $30.00 to $50.00 per hundred; 2) August to October. In this period the production decreases due to a decrease in temperature. This time is considered as regular for commercialization; and 3) November to February. In this period, prices of $100.00 to $150.00 per hundred are reached, although there is a decrease in production due to low temperatures and incidence of frost.

Despite the seasonality in production, no alternatives have been sought or experience to give added value to the nopal is limited. In the Teotihuacán Valley, alternatives for the preparation of nopal derivatives are an opportunity to further boost the territorial economy (Sandoval-Trujillo *et al*., 2018).

The main problems and needs faced by G1 are the presence of pests and diseases (48%), technical advice for pest and disease control (46%) and access to financing (21%). In G2, the main problems are commercialization (36%), the need for training on pest and disease management (45%) and organization (18%).

Although the producers are grouped around the ejido and in the irrigation units. No organization was found around the cultivation of nopal either for the purchase of inputs or commercialization. Producers mention bad experiences in their attempts to organize to find commercialization channels and the lack of trust between them was detected.

The organizational processes are a limitation among the producers who belong to the ejido of Cuautlalcingo because it currently faces a complex process, the 'full domain' that threatens the disappearance of this and disconnects the actors from the territory, with the presence of fractional interests. Given this scenario and in accordance with current trends, organizational processes must be promoted from a perspective of sustainable rural development under a territorial approach to have a greater impact on the different links of production.

Producers do not have sufficient support from the government sector to obtain of financing and technical advice and/or training. The support has been of the welfare-type, which sometimes responds to clientelist logics. In the Teotihuacán Valley, there are incentives for the production of nopal, but they are not used by producers, due to ignorance of their existence (Sandoval-Trujillo *et al*., 2018).

Conclusions

Two groups of producers were identified, whose main differences are time spent on the production of nopal vegetable, available area, labor, destination of production, number of assets they have, population density of plantations, varieties of nopal and yield. There are limitations in the technical schedules of nopal cultivation, phytosanitary problems, inefficiencies in the management of crop fertilization are faced, which implies the need for training and accompanying programs.

Seasonal production and ignorance of the added value of nopal have led to the main commercialization route being concentrated in the regional market. Given the problems currently faced, efforts must be joined by the various actors involved: producers, local and state authorities,

academia, consumers, to plan actions that lead to territorial cohesion, public policy to attend and develop the production niches of the state and in the search for alternatives to increase competitiveness in the territory.

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