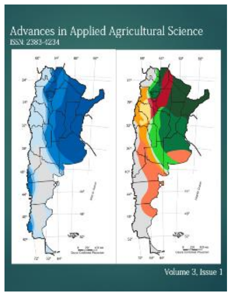
Advances in Applied Agricultural Science

Volume 03 (2015), Issue 01, 23-39

Journal homepage: www.aaasjournal.com

ISSN: 2383-4234



Research Article

Modeling an agroclimatic zoning methodology to determine the potential growing areas for *Cyamopsis tetragonoloba* (cluster bean) in Argentina

S.L. Falasca [1*], C. Miranda [2] and S. Pitta-Alvarez [3]

[1] *CONICET Researcher. Climate and Water Institute. INTA. Las Cabañas y Los Reseros S/N, Castelar, Buenos Aires province. Argentina.*

[1] *CONICET Scholarship. School of Humanities. CINEA. University of the Center of Province of Buenos Aires, Pinto 399, Tandil, Buenos Aires. Argentina.*

[1] *CONICET Researcher. Algae and Plant Biotechnology Laboratory. UADE, Lima 717, Buenos Aires, Argentina.*

ARTICLE INFO

Article history:

Received: August 01, 2014
Revised: September 22, 2014
Accepted: October 05, 2014
Available online January 23, 2015

Keywords:

Cluster bean
Bioclimatic requirements
Agroclimatic zoning
Argentina
Geographic Information System

* Corresponding Author;
E. Mail: sfalasca@conicet.gov.ar; slfalasca@gmail.com
Tel: +54 11 4621 0125

ABSTRACT

In the last few years, world demand for guar gum (*Cyamopsis tetragonoloba* L) has grown considerably and its price has increased consequently. Guar bean is a grain legume with potential as a summer crop in Argentina under subhumid, semiarid and arid climate. In Argentina, the cultivation of guar has not been established, and this research was conducted to explore this possibility. The authors developed an agro-climatic zoning methodology for guar bean in Argentina, based on the bioclimatic requirements of the crop. Using as reference the climatic data from regions where cluster bean is grown in the world, the authors analyzed the average climate data provided by the National Meteorology Service to identify the potential area suited to cluster bean production in Argentina. This model may be applied in any part of the world, using the agroclimatic limits presented in this work. To obtain the maps, a series of previously interpolated bioclimatic variables were used. Afterwards, these were processed with the Geographic Information System tool of the Arc-GIS 9.3 program. The agroclimatic zoning was obtained by superimposing the following three maps: frost-free days, annual rainfall and average temperature during growing period. As a result, ten classes of agroclimatic suitability were classified: optimal, very suitable, very suitable with complementary irrigation, suitable with complementary irrigation, suitable under humid and subhumid regime, suitable with constrains under tropical and temperate climate, marginal and non-suitable. The suitable areas are distributed from the North of Argentina to 40ºLatitude.

In the last few years, world demand for guar gum (*Cyamopsis tetragonoloba* L) has grown considerably and, as a result, its price has increased. These prices have suffered major fluctuations due to many factors, e.g. drought periods. For instance, there was a staggering 900% rise in prices in the period between May 2011 and May 2012. Afterwards, prices decreased 85% between May 2012 to May 2013 (RANTEC, 2013; NRAA, 2014).

The plant is native to India and Pakistan, and it is found throughout both countries. The monsoon usually produces delays in the guar growing belt. In 2104, the area cultivated within India diminished, since most of cluster bean is grown in rainfed conditions. A large part of the first sowing was already destroyed due to drought in rainfed guar growing belt. This deficit can further increase guar seed rates. In normal conditions, the expected prices are approximately INR 7000-8000/100 kg, but there is a possibility that they will reach INR 10,000/100 kg in 2014 (Prajapat, 2014; Agriculture Information.com, 2014).

One of the main reasons for the rising demand for guar gum is that petroleum industries are using it as part of the fracking fluids employed in hydraulic fracturing. Guar gum acts as a viscosifier when it is mixed with sand and water. This mixture produces a gelling agent that expels gas when it is bombed underground. Immediately after the fracking drilling process is over, the liquid containing guar is injected. Due to its rheological properties, its use increases the yield of horizontal wells. The consequent rise in production is of such magnitude that many unproductive exploitation sites are being recovered. These fracking technologies have revolutionized the natural gas industry because they have enabled the extraction of previously un-retrievable hydrocarbons from shale formations. As a result, the U.S. and global natural gas projected production has increased considerably, and so has the importance and price of guar gum.

According to Raveta & Soriano (1998) some native Argentinean leguminous species hold potential as gum producers. An interesting productive alternative for arid and semiarid zones in Argentina could be the cultivation of cluster bean, together with the extraction of gum with high commercial value from native species. However, to exploit and cultivate these native species, there is a need for strong evidence on the production and quality of the accumulated gums. Furthermore, the behavior of these species under diverse environmental conditions must be studied. The current information on these native species in general and for each particular genotype is poor, and must be generated in order to obtain gum in Argentina.

In recent years, cultivation of cluster bean has been explored in some provinces of Argentina (Wielinga 2010), but there are no official published data.

At the present time, there are no domestically produced guar products sold in Argentina. However, in the period 2013-2104, Argentina imported from India 2,328.24 MT of powdered guar gum (Prajapat, 2014), mainly for use as a food ingredient, but also for the mining (nickel sulphide flotation), oil and gas (fracturing and drill muds), personal care product (bath and shower gels) and agrochemical industries.

Argentina owns the world’s second-biggest shale-gas reserves, most of them in Vaca Muerta. These deposits were nationalized in 2012 and now belong to the national petroleum company, YPF (Yacimientos Petrolíferos Fiscales). A study done by the US Energy Information Administration (EIA) indicated that the field holds 16.2 billion barrels of shale oil and 308 trillion cubic feet of shale gas, accounting for more shale oil than Mexico and more shale gas than Brazil. These amounts are sufficient to satisfy Argentina’s current energy demand for over 150 years, and could make the country an exporter once again. Another Argentine basin is the Chaco-Paraná one.

Argentina is currently facing an energy crisis. The country´s oil and natural gas production has declined rapidly in the last 15 years, while the demand for natural gas has grown at an annual rate of 5 – 6%. Despite Argentina´s abundant reserves, the country has become a net importer of natural gas. Thus, the exploitation of shale oil and gas is urgent and imperative. As a result, the demand for guar gum will increase not only because of Vaca Muerta but also with the discovery of new unconventional petroleum and shale oil deposits.

Characteristics of cluster bean, uses and productivity

Cyamopsis tetragonoloba L. belongs to the Leguminosae family, and it has different common names: guar bean, cluster bean, guar, guaerdou, cottaveraykai, kothaverai, etc. The plant is a moderately sized annual herb found throughout India, and it is native to India and Pakistan (Patel & Mc Ginnis, 1985). The crop cycles fluctuate from 60-90 days, in determinant varieties, to 120-150 days in indeterminate varieties (NRAA, 2014). It has been observed that in the southern areas of the Limpopo province (South Africa), sowing time should be no later than mid-December. Because of its latitudinal similarity, this should also be the appropriate sowing period if it is cultivated in Argentina. Flowering begins about 30 days after planting and pod development after 40 days, continuing through to maturity in 90 to 120 days after planting. The growth characteristics of *C. tetragonoloba* make it beneficial for arid production areas.

Cluster bean is exported mainly as a seed crop for livestock feed, but its young tender pods are also used as vegetable and for traditional medicines (Sharma et al., 2011). The plant is also grown as green manure or used as fodder. Seed flour is used to improve the strength of paper and stamps or in textile sizing (FAO-Ecocrop, 2007).

The seeds of the cluster bean are commercially valuable as a source of a natural polysaccharide (galactomannan), commercially known as guar gum. The gum is obtained from the endosperm of the seed and it is employed as a thickener and stabilizer in a large variety of food products, such as salad dressings, ice cream and yoghurt. The gum and the water-soluble resin extracted from the seeds are also used in other industries, including paper manufacturing, cosmetics, mining and oil drilling (Wong & Parma, 1997).As previously mentioned, the demand for guar gum is rapidly rising because the petroleum industries are using it as part of the fracking fluids employed in the fracking technologies that have revolutionized the field.

Current international situation

As previously stated, *C. tetragonoloba* may have originated in India and Pakistan. Together, these two countries account for more than 95% of cluster bean seed production in the world. Although guar, both as a grain and gum, is a simple commodity, it has an established and very competitive market, dominated by India. During the last 10 years, cluster bean has been cultivated in this country on approximately 3 million ha. The average production is around 1.2 million ton, but it varies since there are years with pronounced droughts and others with high market demands (NRAA, 2014). The pattern of cluster bean production in India is erratic since it is cultivated on marginal land in rainfed areas. Only 10% of Indian production remains in the country and 90% of the exports are employed in the gas and shale oil industries. Consequently, many old cotton and wheat plantations have been converted into guar fields, due both to lower production costs and the high speculative prices of 2011 (NRAA, 2014). In Pakistan, before the 90´s, about 80% of guar was grown under irrigated conditions and the yields per hectare were higher than the present ones.

Until 2004, the world demand for guar gum grew at a rate of 2% annually. According to Bryceson & Cover (2004), the current production levels are estimated at 190,000 ton processed gum, 90% of which are produced by India. Other important world suppliers are Pakistan and the United States, with smaller acreages in Australia and Africa (Undersander *et al*., 1991). Cultivation has also been successful in Brazil, Zaire and Sudan (NRAA, 2014).

The world market for guar gum is estimated to be around 150,000 ton/year (Gon *et al*., 2011). The main markets are the United States, China, Germany, France, Mexico, Argentina, Japan and Indonesia. The increase in the area sown with guar bean in different countries and the search for substitutes to guar gum indicate that India and Pakistan will lose their monopoly of this commodity in the future.

Ecological requirements of the cluster bean

Different climate zones are appropriate for guar cultivation: tropical wet and dry (Aw), tropical wet (Ar), steppe or semiarid (Bs), subtropical humid (Cf), subtropical dry summer (Cs), subtropical dry winter (Cw), temperate oceanic (Do), temperate continental (Dc), temperate with humid winters (Df), temperate with dry winters (Dw). In the tropics, it can be grown successfully from sea level to 1000 m in elevation (FAO-Ecocrop, 2007). This species tolerates high temperatures and dry conditions, and is adapted to arid and semiarid climates. At planting time, soil temperatures should be above 21ºC for rapid establishment. The optimum temperature for root development is 24-30ºC (Daisy, 1979), but it can tolerate temperatures ranging from 10 to 45ºC. Seedling emergence occurs at a base temperature of 14.6ºC (Angus *et al*., 1981). Temperatures should fluctuate between 21-30ºC at planting time (Tyagi *et al*., 1982; Chapman & Pratt, 1961); and they should never be below 15ºC during the growing season. Towards the end of the season, the weather must be dry and the sunshine abundant. The plant is tolerant to shade, but susceptible to frosts and, to reach maturity, a minimum of 110 to 130 days of frost-free days is required (FAO-Ecocrop, 2007).Cluster bean is a drought-tolerant summer legume that requires only 400-500 mm annual rainfall (Yousif, 1984). The drought tolerance of this species is well known. Although the optimum rainfall for cluster bean fluctuates between 500 to 800 mm, it tolerates values ranging from 400 a 2700 mm (Yousif, 1984). It grows without irrigation even in areas with as little as 250 mm of annual rainfall (Undersander *et al*., 1991).In Nigeria, it grows in areas with 300-500 mm annual rainfalls (Mukhtar, 1981) but also performs well in areas with 400-900 mm of annual rainfall (Anon, 1975). In India, cultivation has been successful, with 300 mm of annual rainfall and the addition of one or two complementary irrigation periods. Although guar bean responds well to irrigation during dry periods, it is highly susceptible to waterlogging (Duke, 1981), which causes nodulation loss, nitrogen stress and severe root breakdown.

Abbas *et al*. (2008) conducted research at Wad Medani, Sudan, and concluded that the crop water requirement was about 682 mm with mean seed yield of about 1000 kg ha^{-1}. The plant is susceptible to pests under humid conditions, but it is fairly resistant to both pests and diseases when grown in a drier climate (FAO-Ecocrop, 2007).

Seed quality is lower when there is an excess in moisture during the early phase of growth and after maturation (Whistler & Hymowitz, 1979). However, frequent drought periods can lead to delayed maturation

(Undersander *et al*., 1997)

The plant remains the vegetative stage if day´s length is too long during the growing season. However, when the days are shorter, the plant flowers and its pods mature. There are short day (<12 hours) and neutral day (12-14 hours) biotypes (Daisy, 1979; FAO-Ecocrop, 2007).

According to Pathak & Roy (2013) climate variables impact significantly on seed yield, yield attributing traits and gum content of cluster bean. The authors observed that seed yields and gum content increased with high temperatures (36.1°C), low relative humidity (78 %), and longer sunshine periods (11 h). They also reported a significant positive association between endosperm and gum content. The authors concluded that the characters that improved seed yield were plant height, number of branches, seeds/pod and pods/plant, while higher seed weight resulted in higher endosperm and indirectly higher gum content. Cluster bean performs best on fertile, medium-textured and sandy loam alluvial soils, but it does not tolerate heavy black soils (FAO-Ecocrop, 2007). According to FAO-Ecocrop (2007) this species tolerates medium levels of salinity (4-10 dS m^{-1}). Moreover, it is used in reacquiring saline and alkaline soils (Bhan & Parsad, 1967; FAO-Ecocrop, 2007).

Elsayed (1994) reported that soil salinity significantly decreased nodulation, pod formation and yield of guar bean. Francois *et al*. (1990) found that soil salinity up to 8.8 dS m^{-1} did not affect guar bean, but that each unit increase above 8.8 dS m^{-1} reduced yield by 17%, which placed it in the moderately tolerant crops category. The optimum soil pH fluctuates between 7.5 and 8 but it is capable of tolerating a range of 5.5 to 8.5.

The agroclimatic zoning

Climate plays a pivotal role in crop production. The growing periods of crops, and their water and irrigation requirements, depend directly on weather conditions. Climate and water availability are the two variables that determine the type of agricultural land area. Therefore, it is of the utmost importance to develop scientific methods to determine agro-climatic zones.

Each plant possesses a particular sensibility to weather conditions. To satisfy plant´s physiological needs, there are minimum and maximum climate conditions that should be met for each particular species. Ometto (1981) has defined an “ideal temperature”, which is the range between these two values and it represents the energetic level that plants need for their physiological complex to work efficiently. Beyond such limits, they are negatively affected.

The “length of growing period” refers to the number of days within the period of temperatures above base temperature when moisture conditions are considered adequate (FAO, 1996).

In order to introduce a new crop such as cluster bean in Argentina, feasibility studies must be carried out. Furthermore, before cultivating large acreages of non-traditional crops, these have to be tested in small experimental pilot areas. Agro-climatology is a valuable tool to recognize agro-climates with favorable conditions for the introduction of new crops.

Agroclimatic zoning consists in the division of an area of land into climatic resource units. These units have a unique combination of climatic characteristics, which in turn specify the potentials and constraints for land use. Agroclimatic zoning can be understood as the division of an area according to the favorability for agriculture.

Agro-climatic classification systems are useful to identify yield variability and constraints for crop grow (Caldiz *et al*); to regionalize optimal crop management recommendations (Seppelt, 2000), compare yields trends (Gallup and Sachs, 2000) and to determine suitable location for new crops production (Falasca *et al*, 2010; Falasca & Ulberich, 2011; Falasca *et al*, 2012a; Falasca *et al*, 2012b; Falasca *et al*, 2013a; Falasca *et al*, 2013b; Falasca *et al*, 2014a; Falasca *et al*, 2013b; Falasca *et al*, 2013c; Falasca *et al*, 2013d).

Climate, represented by thermal and moisture regimes, forms a mosaic of small specialized areas. These small geographic areas are capable of supporting various land use systems (Troll, 1965). This approach allows the categorization of agro-climatically uniform geographical areas, and this in turn is useful for agricultural developmental planning and other interventions.

In Argentina, the cultivation of cluster bean has not yet been established. This research was conducted to explore the possibility of guar cultivation in Argentina. The aim of this work consisted in defining the potential growing areas in Argentina for *C. tetragonoloba* under dry-subhumid and semiarid climate conditions.

Materials and Methods

Study area

The area studied was the Argentine Republic. The country borders to the North with Bolivia and Paraguay; to the South with Chile and the Atlantic Ocean; to the East with Brazil, Uruguay and the Atlantic Ocean and to the West with Chile.

Argentina's total area is 1,072,067 square miles and it presents an exceptional climatic diversity, due to its vast territory. Different geographic factors influence the climatic characteristics of the different regions. One of these is latitude, since the Argentine Republic is characterized by its great latitudinal development: 21º46' in the North to 55º58' S in Cabo de Hornos, in the South. The extreme eastern limit of the country is located at 53 ° 38'W, in the town of Bernardo de Irigoyen.

Humid lowlands can be found in eastern Argentina, especially along the rivers of the Rio de la Plata system. The Argentine Mesopotamia, comprised by the provinces between the Uruguay and Parana Rivers, is made up of floodplains and gently rolling grassy hills. The greatest precipitation is registered in the extreme north of Misiones Province, where it amounts to about 2000 mm yearly. It then decreases towards the West, from 2000 to 1100 mm.

The alluvial plain of the Chaco-Pampean in the north has a subtropical climate with dry winters and humid summers. It is the most extensive level grassland in South America and it covers approximately one-quarter of the nation. Rainfall decreases from 1100 mm in the East to 500 mm in the West, and annual temperatures fluctuate from 14ºC in the south to 22ºC in the north. In this region, winters seem colder and summers hotter because of the high humidity. There are abrupt changes in temperature throughout the year, and these bring relief from the hot summers and the cold winters. The Chaco-Pampean is widely cultivated with wheat, soybean and corn.

Westward, the humid pampa (plain) turns into rangeland and finally to desert, interrupted only by irrigated oases. The rainfall decreases from East to West, from 1600 mm to 100 mm. Moisture derives from the South Atlantic

Anticyclone.

The Andes are the barrier mountain system that marks the western end of the plains. The Andean region expands from the dry north to the ice covered Patagonia mountains. In its path, it comes across the dry mountains and desert west of Cordoba and south of Tucuman and envelops the irrigated valleys on the eastern slopes and foothills of the Andes. Patagonia covers approximately 300,000 square miles and the region is characterized by arid, windswept plateaus. The pastureland is poor and dispersed, except for some irrigated valleys. To the south, the weather is permanently cold and stormy; the summers are practically non-existent and the winters are harsh. Annual temperature is lower 15ºC. Annual precipitation ranges from 100 to 300 mm in the arid regions and 500 to 2000 mm in Andean Patagonian Forest, whose moisture advection originates in the South Pacific Anticyclone.

Use of Geographic Information System

Recently, geo-information system advancement has dispelled the former restrictions to data integration. Geo-spatial databases have reproducibility and flexibility, and this enables handling and managing data in one single system from various sources, layers and scales. Modeling within a Geographic Information System (GIS) offers a mechanism to integrate the many scales of data developed in and for agricultural development.

To obtain the maps, a series of previously interpolated bioclimatic variables were used. Afterwards, these were processed with the GIS tool of the Arc-GIS 9.3 program. The bioclimatic variables were obtained from their interpolation from 125 meteorological stations, which cover all the Argentine Republic. Climatic interpolations were made using the “Interpolate to Raster” tool, within the “3D Analyst” extension of the same program, following the Ordinary Kriging interpolation method. Agroclimatic suitability mapped variables were obtained from multivariable integration geo-processing, using the “Raster Calculator” tool of the “Spatial Analyst” extension of the same program described above.

The Agroclimatic suitability delimitation

The identification of the optimal bio-climatic requirements of cluster bean must be accurate so that the cultivation of this crop can be undertaken in an appropriate region. First, to determine the requirements, limits and bio-meteorological tolerance and conditions for this species, the climatological characteristics of native areas and the regions of successful cultivation around the world were analyzed. The resulting bio-climatological indicators were extrapolated to the Argentine territory. Growth aspects, such as development and death chances by excess or deficiency, were specifically considered. To define the agroclimatic fitness for *C. tetragonoloba* in Argentina, the weather data used was the one collected in all the meteorological stations around the country in the period spanning from 1981 to 2010.

In parallel, an agro-climatological inventory was performed based on available climatological statistics. When all the information was gathered, the data were evaluated.

The first condition considered was the frost-free days. At least 130 frost free days are required to produce satisfactory yields (FAO-Ecocrop, 2007), thus ensuring the length of the growing period for guar. In Argentina, the dates of the first and the last frost are widely dispersed in relation to the mean dates (approximately 30 days). This means that the first frost or last frost may

Table 1. *Agroclimatic suitability classes for cluster bean.*

Agroclimatic Suitability	*Frost-free days (days)*	*Annual rainfall (mm)*	*Mean temperature growing cycle (ºC)*
Optimal area	> 150	500-800	24-30.
Very suitable area	> 150	400-500	24-30.
Suitable area with constraints (excessive humidity) under tropical climate	> 150	> 800	20-24
Suitable areas with constraints (excessive Humidity) under temperate climate	> 150	> 800	20-24.
Suitable areas under humid-subhumid regime	> 150	500-800	20-24
Suitable areas under dry-subhumid regime	> 150	400-500	20-24
Very suitable areas with complementary irrigation	> 150	250-400	20-24
Marginal areas	> 150	< 250	> 15
Non suitable areas	< 150	< 250	< 15

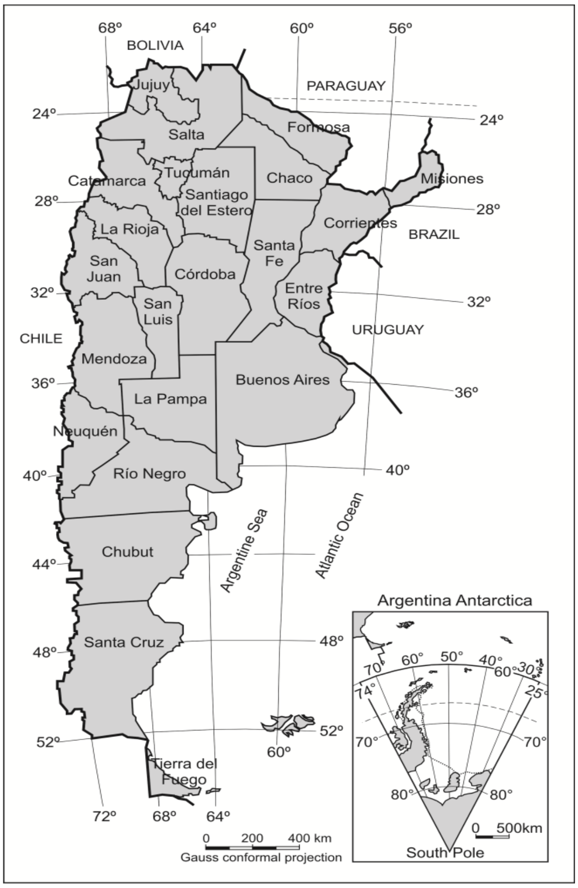


Fig. 1. Argentina´s political map

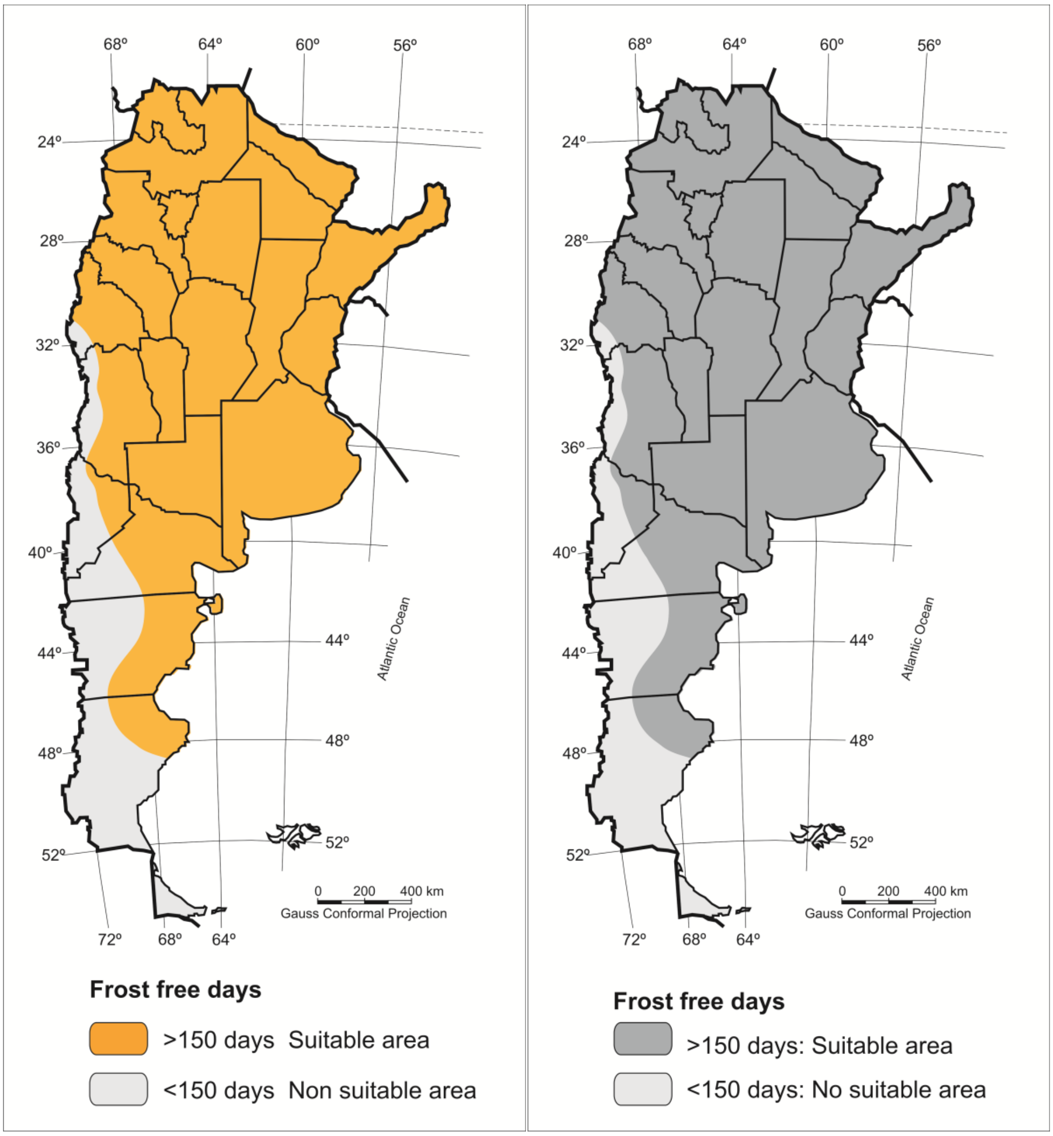


Fig. 2. Frost-free days

occur 30 days before or 30 days after the average date. This great dispersion is the result of two factors that act in combination: the great asynchronous variability of temperature and the scarce thermal tension in the time in which frosts occur. The easy entrance of polar air masses in the South-North direction and the small annual thermal amplitude (because Argentina is under maritime influence) are responsible for the resulting dispersion. For this reason, the isoline chosen was the one corresponding to 150 frost-free days.

The second condition was the thermal regime, which is to the amount of heat available for plant growth and development during the growing period. Therefore, the temperatures considered were the ones during the cultivation cycle, which extends from December to April. Since the base temperature is 14.6ºC (Angus *et al*., 1981), areas with temperatures below 15ºC were considered non suitable. In the range of 15 to 20ºC, the area qualified as marginal, 20 to 24ºC deemed it suitable (Tyagi *et al*., 1982; Chapman & Pratt, 1961), optimal areas were in the 24 to 30ºC range (Daisy, 1979) and if

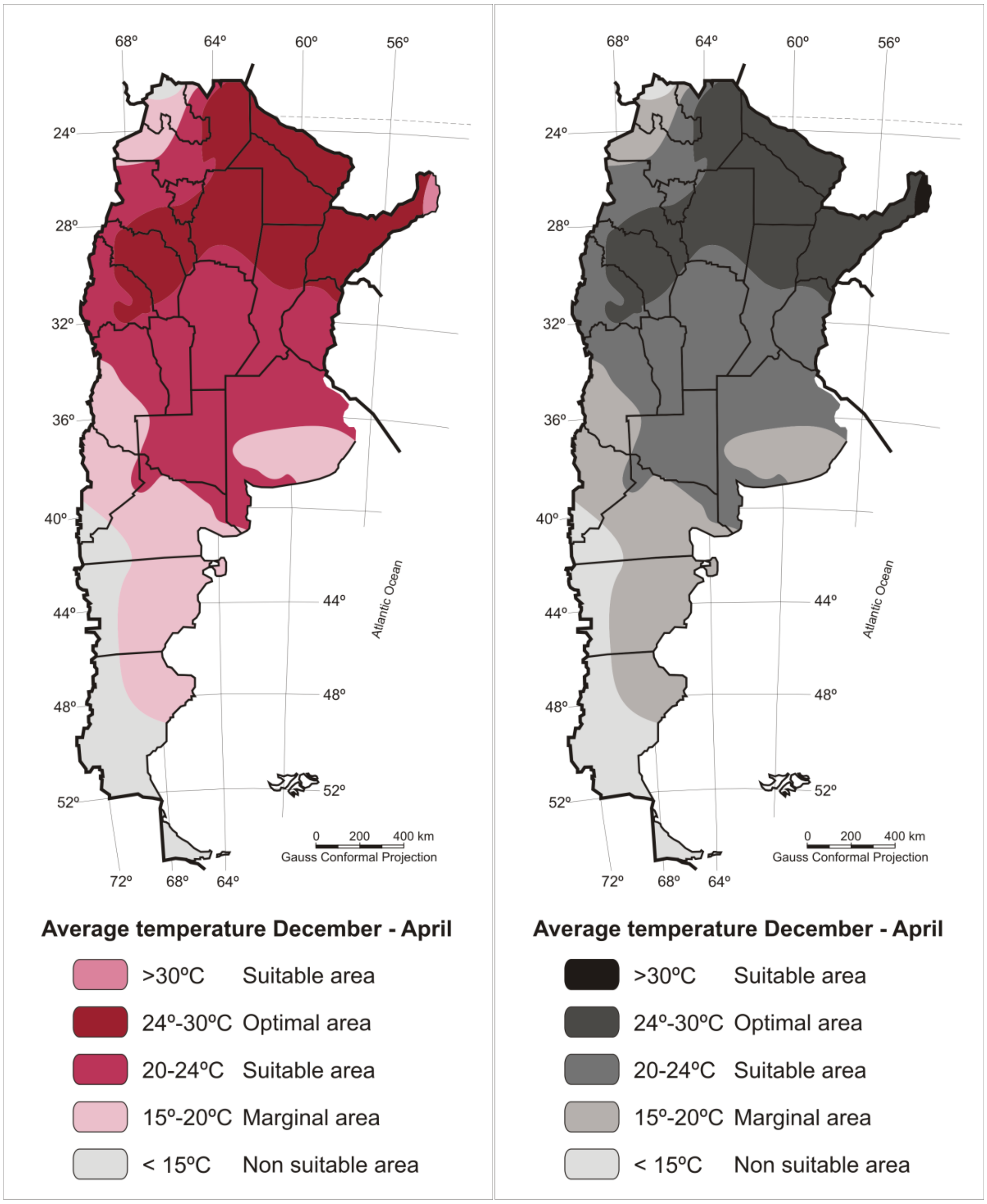


Fig. 3. Average temperature during growing period (December – April).

the temperatures were above 30ºC, the areas were classified as suitable.

To analyze the third condition, the moisture regime, the annual rainfall was examined. If it was above 800 mm, the area was classified as suitable, in the 500 to 800 mm range it was optimal (Yousif, 1984), and suitable from 400 to 500 mm (Anon, 1975). The areas deemed suitable with irrigation are the ones that receive from 250 to 400 mm of rainfall and the non-suitable ones receive less than 250 mm.

With the available database, the geographical limits for the different variables were used to define and map aptitude classes. The three maps described above (frost-free days, average temperature during growing period and annual rainfall) were superimposed to determine the agroclimatic zoning. As a result, ten classes of agroclimatic suitability areas were classified as optimal, very suitable, very suitable with complementary irrigation, suitable with complementary irrigation, suitable under humid and subhumid regime, suitable with constraints under tropical and temperate climate, marginal and non-suitable.

The agroclimatic suitability classes and the limits for each class are presented in Table 1.

In order to delineate the classified areas with different grades of agro-climatic fitness, Argentina´s political map, with the names of the provinces, is shown in Figure 1.

Results

Fig. 2 shows the areas with 150 frost-free days. These include a large part of the national territory, and it is during this period that agricultural activities can be accomplished. In this case, it also represents the duration of the cluster bean growing period.

Fig. 3 shows the average temperature during the growing period (December – April). It can be readily observed that the North and the center of Argentina present suitable and optimal conditions from the thermal point of view, and good conditions extend to the south of Buenos Aires province.

Fig. 4 shows that the optimal area extends through the center of the country, from the North to the South of Buenos Aires province. This area receives from 500 to 800 mm of rainfall annually. Two suitable areas can be identified on both margins. One of them receives more than 800 mm, and comprises the entire Northeast Region of Argentina (NEA), including a large part of the Chaco-Pampean Plain and part of the Northwest Region of Argentina (NOA). The remaining suitable area, receives from 400 to 500 mm of annual rainfall, and it is constituted by a narrow strip of land located to the West of the optimal zone.

From a hydric perspective, there is another optimal zone and a suitable one in the West and towards the South of the country, next to the Andean-Patagonian Forest region. However, both are negligible because they do not comply with the thermal requirements for this species.

The agroclimatic zoning was obtained by superimposing the maps pertaining to frost- free days, annual rainfall and average temperature during growing period. Thereby, ten different agro-climatic zones were delineated.

The optimal area comprises west of Formosa and Chaco, east of Salta, north, center and east of Santiago del Estero, south of Tucuman, SE of Catamarca and the east of La Rioja. This area receives an annual rainfall of 500 to 800 mm.

Very suitable areas occupy part of the provinces of La Rioja and Catamarca.

The suitable area under humid-subhumid regime covers part of the provinces of Cordoba, almost all of San Luis, the center and east of La Pampa and the west and the southwest of Buenos Aires, south of Santiago del Estero, part of Salta, Jujuy and Catamarca.

Towards the west of this area, a suitable area under dry-subhumid regime was distinguished. It covers South of Buenos Aires, the center of La Pampa, part of Rio Negro, the east of Mendoza, the northwest of San Luis, the south of La Rioja and the east of Catamarca.

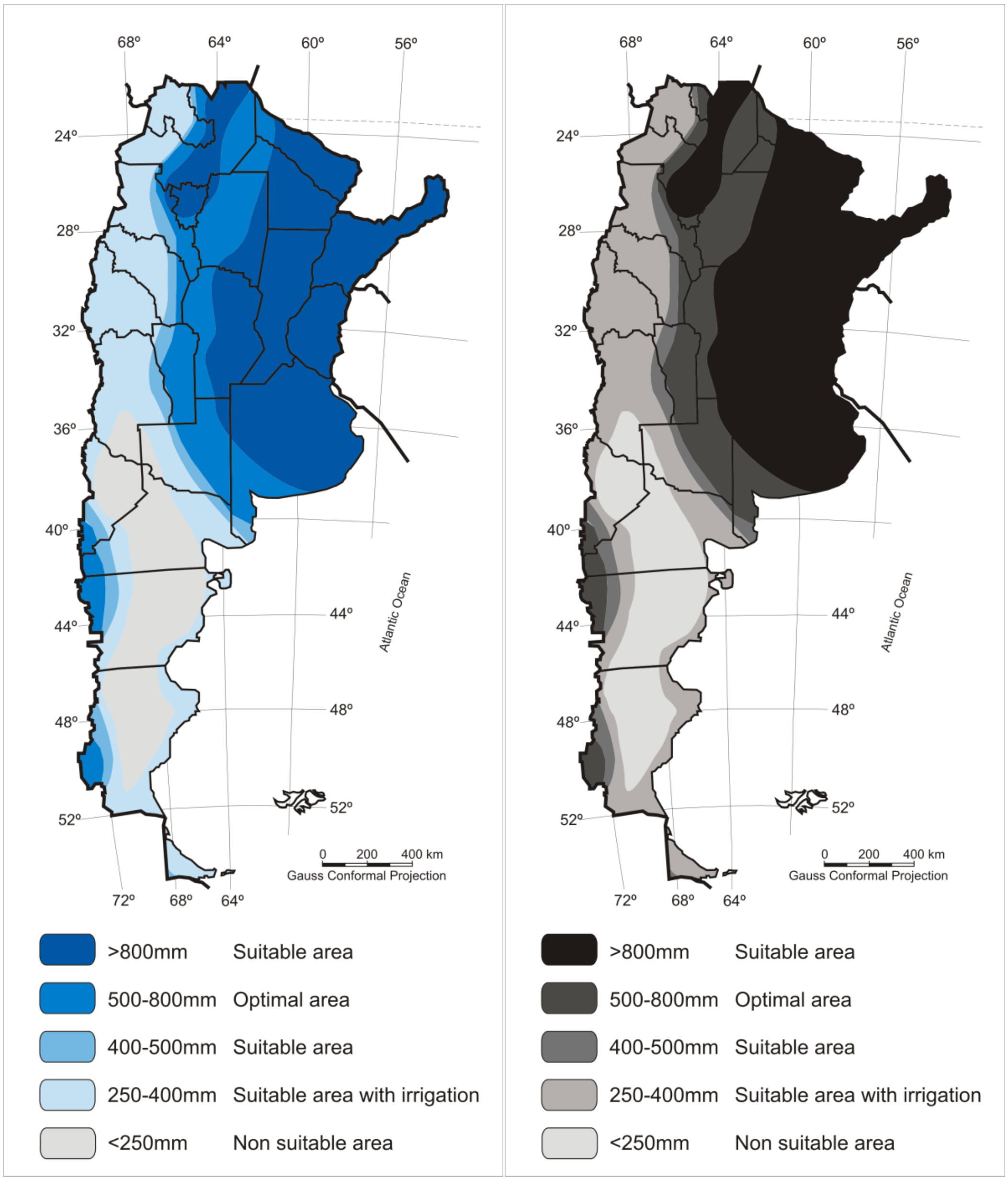


Fig. 4. Annual rainfall.

More to the west, two distinct areas were delineated: a very suitable area with complementary irrigation (it only covers part of the provinces of San Juan, La Rioja and Catamarca) and suitable areas with complementary irrigation (comprises areas in the provinces of La Pampa, Rio Negro, Mendoza, San Juan, San Luis, La Rioja and Catamarca). If the production of cluster bean is to be destined for food, complementary irrigation would be justified. However, if it is to be employed in fracking procedures, a cost analysis must be executed to compare it with the commercialization price.

There are two very extensive areas to the east of the 800 mm isohyets, both classified as suitable areas with constraints by excessive humidity. The zone delineated to the North presents tropical climate conditions, while the remaining one, more to the South, has temperate climate. For this reason, cultivation in these two areas is

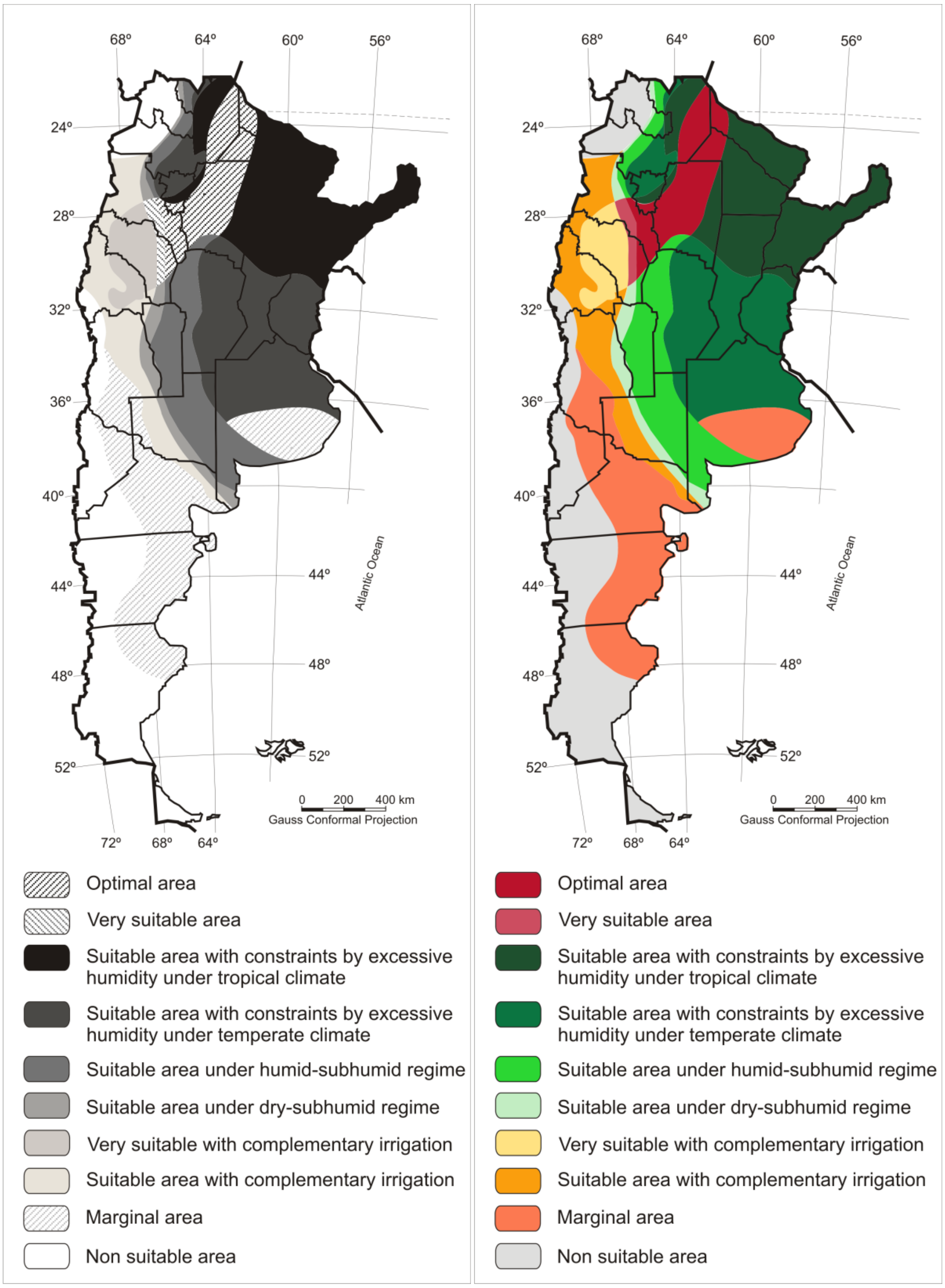


Fig. 5. Agroclimatic suitability for cluster bean.

not recommendable. This climate is hot and humid during the long summers and cool and humid during the short winter season. The excessive humidity produces darkening of the pod, diminishing its commercial value. Dry weather is essential once the pods are formed.

Marginal areas cover the center and the southeast of Buenos Aires and the entire region located to the south and west of the suitable area with complementary irrigation. Marginal and non-suitable areas present arid climate.

Discussion

The agroclimatic zoning shows that the potential growing areas for cluster bean extend from 40ºC latitude to the north. At first, this legume apparently could not be cultivated in the southernmost regions of Argentina. However, Discover life (undated) cites the cultivation of this species in median latitudes, in locations in Texas (34º07´N and 99º27´W), Saint Louis (38º36¨N and 90º15´W) and Washington (47º28´N and 121º49´W) in the North Hemisphere. There is also a reference from the Southern Hemisphere that corresponds to South Africa (29ºS and 24´E).

The Köppen Climate Classification System (1918) is the most widely used system for classifying the world's climates. Using the Köppen system, the suitable areas with constraints by excessive humidity correspond to areas classified as Cf (subtropical humid), while the optimal, very suitable and suitable areas present Cw (humid moderate climate with dry winter) or BS (steppe climate or semiarid) climate. These areas, among others, have been described FAO-Ecocrop (2007) as the climate where this species inhabits.

The authors of this work recommend the cultivation of cluster bean in the areas classified as Optimal (humid-subhumid climate), Very suitable (dry-subhumid), Suitable (under dry-subhumid and humid-subhumid) and Very suitable and Suitable areas, both with complementary irrigation (arid climate). In other words, cultivation is recommended in subhumid to arid climate. Each region should ideally have rains corresponding to its category, the temperature should never be below 15ºC during the growing season and it must be dry towards the end of the season, with plenty of sunshine.

At present, cluster bean cultivation has not yet been developed in Argentina, probably because the farmers know little about the species and also because agronomic information for this crop is poor and not readily available in our country. Research will be initiated to study the adaptability of a large collection of guar genotypes originating from various parts of the world, with emphasis on seed productivity and guar gum content in different regions of Argentina.

The description of different suitability classes for cultivating this species will be helpful in advocating its cultivation, thus achieving higher levels of land use and promoting the economic growth of our farmers. This, in turn, will impact our national income.

Conclusion

The authors developed an agro-climatic zoning methodology for cluster bean in Argentina, based on the bioclimatic requirements of the species. This model may be applied in any part of the world, using the agroclimatic limits presented in this paper.

This work was able to demonstrate the existence of a great extension of Argentina with agro-climatic suitability for cluster bean under subhumid, semiarid and arid climate. The suitable areas are distributed from the North of Argentina to 40ºLatitude.

Acknowledgements

This work was fully funded by the National Council of Scientific and Technical Research of Argentina.

References

1. Abbas IMI., Adam H. & Adeeb AM. (2008). Measuring crop coefficient of guar (Cyamopsis tetragonoloba (L.) Taub) under Gezira, Sudan conditions. (Abstr.). http://www.tropentag.de/2008/proceedings/node398.html
2. Agriculture Information.com. (2014). Guar Seed (Guar Gum). Cultivation details and other information. http://www.agricultureinformation.com/forums/consultancy-services/119615-guar-seed-guar-gum-cultivation-details-other-information-4.html.
3. Angus JF., Cunningham RBM., Moncur W. & Mackenzie DH. (1981). Phasic development in field crops -thermal response in the seedling phase. Field Crop Research 3: 365-378.
4. Anon. (1975). Kinman and Esser new guar varieties. In: Whistler RL. & Hymowitz T, editors. Guar: Agronomy, Production, Industrial Use, and Nutrition. Purdue University Press. USA. p 125.
5. Bhan S. & Prasad R. (1967). Guar has many uses. Indian Farming 17:17-19.
6. Bryceson KP. & Cover M. (2004). Value Chain & Market Analysis for the Australian Guar Industry. Rural Industries Research and Development Corporation. RIRDC Publication No 04/165.
7. Caldiz DO., Haverkort AJ. & Struik PC. (2002). Analysis of a complex crop production system in interdependent agro-ecological zones: a methodological approach for potatoes in Argentina. Agricultural Systems 73: 297–311.
8. Chapman HD. & Pratt PF. (1961). Method of analysis for soil, plant and water. University of California. USA.
9. Daisy EK. (1979). Food legumes. Tropical Products Institute. (TPI) London.
10. Discover life. Cyamopsis tetragonoloba (L). Taubert. http://www.discoverlife.org/20/q?search=Cyamopsis+tetragonoloba
11. Duke JA. (1981). (Cyamoposis tetragonoloba L.) Taubert- Handbook of legumes of World Economic Importance. Plenum Press. New York, p70-73.
12. Elsayed ME. (1994). The influence of locality and genotype on quality aspects of faba bean (Vicia faba L.) cultivars. M.Sc. (Agric.) Thesis, University of Khartoum, Sudan.
13. Falasca S, Flores N, Lamas M, Carballo S. & Anschau A. (2010). Crambe abyssinica: an almost unknown crop with a promissory future to produce biodiesel. International Journal of Hydrogen Energy 35: 5808-5812.
14. Falasca S, Miranda C & Ulberich, A. (2012a). Possibilities for growing queen palm (Syagrus romanzoffiana) in Argentina as a biodiesel producer under semi-arid climate conditions. International Journal of Hydrogen Energy 37:14843-14848.
15. Falasca S., Miranda C. & Waldman C. (2014a). Developing an Agro-climatic zoning model to determine potential growing areas for Camelina sativa in Argentina. Q Sciences Connect. Bloomsbury Qatar Foundation Journals. (BQFJ). 1-11. http://www.qscience.com/doi/pdfplus/10.5339/connect.2014.4
16. Falasca S., Miranda C. & Waldman C. (2014b). Halophytes: feedstocks for bioenergy in Argentina. In: Acosta M. editor. Advances en Energy Reserch. Book 17. Nova Science Publishers. NY. p 159-192.
17. Falasca S. & Ulberich A. (2011). Argentina's semiarid lands aptitude to cultivate nontraditional species for biodiesel production. In: Marchetti M. and Fang Z. Biodiesel: Blends, Properties and Applications. Nova Science Publishers. N.Y. p 123-150.
18. Falasca S., Ulberich A. & Acevedo A. (2014c). Identification of Argentinean saline drylands suitable for growing Salicornia bigelovii for bioenergy. International Journal of Hydrogen Energy. 39(16) 8682-8689.
19. Falasca S; Ulberich A & Miranda C. (2013a). Feedstocks for lignocellulosic biofuels: research for the energy future in Argentina. In: Acosta M., editor. Advances en Energy Reserch. Book 14. Nova Science Publishers N.Y. p 203-240.
20. Falasca S, Ulberich A. & Pitta S. (2014d). Possibilities for growing kenaf (Hibiscus cannabinus L) in Argentina as biomass feedstock under dry-subhumid and semiarid

climate conditions. Biomass & Bioenergy 64: 70-80.

21. Falasca S., Ulberich A & Ulberich E. (2012b). Developing an Agro-climatic zoning model to determine potential production areas for castor bean (Ricinus communis L). Industrial Crops and Products. 40: 185-191.
22. Falasca S.; Ulberich A. & Waldman C. (2013b). Possibilities of Argentina to produce biokerosene for aviation under dry subhumid to arid areas. In: Méndez-Vilas A, editor. Materials and processes for energy: communicating current research and technological developments. Formatex Research Center. Spain. p 327-334
23. F.A.O. (1996). Agro-Ecological Zoning Guidelines. Soil Resources, Management and Conservation Service. FAO Soils Bulletin 76. Rome.
24. F.A.O. - Food and Agriculture Organization of the UN. Ecocrop. (2007). The crop environmental requirements database. Roma. http://ecocrop.fao.org/ecocrop/srv/en/cropView?id=830
25. Francois LF.; Donovan TJ. & Maas EV. (1990). Salinity effects on emergence, vegetative growth and seed yield in guar. Agronomy Journal 82(3): 587-582.
26. Gallup JL. & Sachs JD. (2000). Agriculture, climate, and technology: why are the tropics falling behind? American Journal of Agricultural Economics 82:731-737.
27. Gong H., Liu M., Zhang B., Cui D., Gao C. & Ni B. (2011). Synthesis of oxidized guar gum by dry method and its application in reactive dye printing. International Journal of Biological Macromolecules 49(5): 1083–1091.
28. Köppen W. (1918). "Klassifikation der Klimate nach Temperatur, Nie-derschlag und Jahreslauf," Petermanns Mitteilungen 64: 193-203.
29. Mukhtar HA. (1981). Report on guar production and economics. F.A.O range management expert. Borno project. Maidnguri, Nigeria, p 1-6.
30. NRAA. (2014). Potential of Rainfed Guar (Cluster beans) Cultivation, Processing and Export in India. Policy Paper Nº3 National Rainfed Area Authority, NASC Complex. DPS Marg, New Delhi, India.
31. Ometto JC. (1981). Bioclimatology plant. São Paulo. Agronomic Editorial. Agronomic CERES.
32. Pathak R. & Roy MM. (2013). Climatic responses, environmental indices and interrelationships between qualitative and quantitative traits in clusterbean Cyamopsis tetragonoloba (L) Taub. under arid conditions. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences. doi 10.1007/s40011-013-0269-4
33. Patel MB. & Mc Ginnis J. (1985).The effect of autoclaving and enzyme supplementation of guar meal on the performance of chicks and laying hens. Poultry Science 64:1148-1156.
34. Prajapat G. (2014). Guar cultivation in India: current guar & guar gum rate / price. http://guarcultivationinindia.blogspot.com.ar/p/gaur-seed-and-guar-gum-rates.html.
35. RANTEC. (2013). Guar Pricing and History. http://www.ranteccorp.com/guar-pricing-and-history/
36. Ravetta, DA. & Soriano, A. (1998). Alternatives for the development of new industrial crops for Patagonia. Ecologia Austral 8:297-307.
37. Sharma P.; Dubey G. & Kaushik S. (2011). Chemical and medico-biological profile of Cyamopsis tetragonoloba (L) Taub: an overview. Journal of Applied Pharmaceutical Science 1: 32-37.
38. Seppelt R. (2000). Regionalised optimum control problems for agroecosystem management. Ecological Modelling 131: 121-132.
39. Troll C. (1965). Seasonal Climates of the earth. World maps of Climatology. Rodenwaltand E. & Jusatz H, editors. Berlin: Springer – Verlag, p. 28.
40. Tyagi CS., Paroda RS. & lodhi GP. (1982). Seed production technology for guar. Farming 32: 7-10.
41. Undersander DJ, Putnam DH, Kaminski AR, Kelling KA, Doll JD, Oplinger ES. & Gunsolus JL. (1991). Guar. In: University of Wisconsin Cooperative Extension Service, University of Minnesota Extension Service, Center for Alternative Plant and Animal Products. Alternative Field Crop Manual. http://www.hort.purdue.edu/newcrop/afcm/guar.html
42. Undersander DJ, Putnam DH, Kaminski AR, Kelling KA,

Doll JD, Oplinger ES, Wong LJ. & Parmar C. (1997). Cyamopsis tetragonoloba (L.) Taubert. Faridah Hanum, I & van der Maesen, LJG, editors. Record from Proseabase. PROSEA (Plant Resources of South-East Asia) Foundation, Bogor, Indonesia.

43. Whistler RL. & Hymowitz T. (1979). Guar: agronomy, production, industrial use and nutrition. Purdue University Press, West Lafayette.
44. Wielinga W. (2010). Seed Gums. In: Imeson A, editor. Food Stabilisers, Thickeners and Gelling Agents. FMC BioPolymer, UKA John Wiley & Sons, Ltd. 275-292.
45. Wong LJ. & Parmar C. (1997). Cyamopsis tetragonoloba (L.) Taubert. Record from Proseabase. Faridah Hanum, I & van der Maesen, LJG, editors. Plant Resources of South-East AsiaFoundation. Indonesia. http://proseanet.org/prosea/e-prosea_detail.php?frt=&id=3002
46. Yousif YH. (1984). Guar Agronomy. Shambat Research Station. Annual report. Soba Research Unit. p 3-4.